Tampere University

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Periodic Health Examinations in Young Athletes

The Finnish Health Promoting Sports Club (FHPSC) Study

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The Finnish Health Promoting Sports Club (FHPSC) Study

ACADEMIC DISSERTATION
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ACADEMIC DISSERTATION
Tampere University, Faculty of Medicine and Health Technology
UKK Institute of Health Promotion Research
Tampere Research Centre of Sports Medicine
Finland

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PunaMusta Oy – Yliopistopaino
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To my family

ABSTRACT

The purpose of this dissertation was to assess the physical activity and health of adolescents aged 14–17 participating in sports clubs and to evaluate the operability of a periodic health examination. The sports clubs participating in the study were from different regions of Finland, and the ten most popular sports were included. Both summer and winter sports and team and individual sports were incorporated. Adolescents of the same age not participating in sports clubs formed the control group.

Physical activity was measured with an accelerometer for one week. A comprehensive health examination was carried out at one of the Centers of Excellence in Sports Medicine by a physician on 399 sports club participants and 177 non-participants. The examination included a medical history questionnaire, general clinical examination, musculoskeletal examination, electrocardiogram, spirometry, blood pressure measurement and blood tests. Acute and overuse injuries within the past year were surveyed from 1,077 adolescents participating in sports clubs and 812 non-participants. The data was collected during 2013–2014.

In this study, the current World Health Organization and Finnish physical activity guidelines of an average of 60 minutes of moderate to vigorous physical activity daily, was reached by 85% of sports club participants and 45% of non-participants. While daily physical activity is recognized as being beneficial for health and developing basic endurance, athletes are recommended at least one day per week without programmed training to allow for sufficient recovery.

The downside of sports participation is the increased risk of injury. At least one acute injury within the past year was reported by 44% and at least one overuse injury by 35% of sports club participants. The corresponding percentages for non-participants were 20% and 17%, respectively. A higher training volume and greater number of competitions were associated with a higher acute injury risk in sports club participants. Injury prevention can be effective and deserves more attention, as injuries cause significant time loss from sports.

In the musculoskeletal examination, we found that sports club participation was associated with better shoulder and ankle mobility, better knee control in the vertical drop jump test, and better core muscle control in the plank test. However, both

groups had postural asymmetries and shortcomings in mobility and movement control, which may be associated with prolonged sedentary behavior and/or monotonous training. The interrater repeatability varied between different parts of the musculoskeletal examination, as a whole we found that it was adequate between two physicians.

The significance of iron deficiency and untreated asthma is underlined in endurance sports and the risk of asthma is increased especially among cross-country skiers. In this dissertation, iron deficiency was found in 23–60% of females and 5–30% of males, depending on the threshold value of ferritin used (15–30 μg/l). Less than 4% of adolescent males and females reported taking supplementary iron. A result diagnostic for asthma in the lung function test was found in 7% of sports club participants who were not using asthma medication.

The goal of the cardiovascular examination is to detect underlying cardiac disease that may endanger the health of the athlete. It is important to differentiate between physiological adaptations associated with training and pathologic changes which may be a sign of cardiac disease. We found that young athletes exhibit similar physiological adaptations to regular physical exertion as adults as adults, such as sinus bradycardia, higher QRS amplitude, and lower diastolic blood pressure, regardless of the type of sport. Systolic blood pressure was more frequently elevated in adolescents participating in non-endurance sports than in endurance sport participants and non-participants.

This dissertation showed that sports club participation is associated with health benefits, such as a greater amount of physical activity and better musculoskeletal control. Due to the factors found in the study that may compromise the health of the athlete and reduce the amount of healthy training days, we recommend carrying out periodic health examinations for adolescents participating in competitive sports. Daily physical activity, as well as frequent vigorous physical activity, is recommended for all adolescents. Therefore, more effort should be made to encourage sufficient amounts of physical activity, to prevent injuries, and systematically assess symptoms associated with physical activity in all adolescents in their regular medical checkups.

TIIVISTELMÄ

Tämän väitöskirjan tarkoituksena oli tutkia liikuntaseuroihin osallistuvien 14–17-vuotiaiden nuorten fyysistä aktiivisuutta ja terveydentilaa urheilijan terveystarkastuksella. Tutkimuksessa mukana olleet seurat olivat eri puolilta Suomea ja mukana oli kymmenen suosituinta lajia, mukana oli sekä kesä- että talvilajeja ja joukkue- sekä yksilölajeja. Vertailuryhmän muodostivat yhdeksäsluokkalaiset nuoret.

Fyysistä aktiivisuutta mitattiin viikon ajan kiihtyvyysmittarilla ja kattava urheilijan terveystarkastus tehtiin 399 seuratoimintaan osallistuvalle ja 177:lle seuratoimintaan osallistumattomalle nuorelle. Tarkastuksen suoritti lääkäri ja tarkastus sisälsi esitietojen läpikäymisen keskustellen, kliinisen yleistutkimuksen, perusteellisen tuki- ja liikuntaelimistön tutkimuksen, sydänfilmin, spirometria tutkimuksen, verenpaineen mittauksen sekä verikokeita. Tiedot äkillisistä- ja rasitusvammoista viimeisen vuoden ajalta 1077 seuratoimintaan osallistuvalta ja 812 seuratoimintaan osallistumattomalta nuorelta. Aineisto kerättiin vuosina 2013–2014.

Liikunnan positiiviset terveysvaikutukset ovat kiistattomat. Seuratoimintaan osallistuvista nuorista 85 % ja 45 % seuratoimintaan osallistumattomista nuorista liikkui suomalaisen ja maailman terveysjärjestön (WHO) suosituksen mukaisesti eli vähintään kohtuukuormitteisesti keskimäärin tunnin ajan joka päivä. Urheileville nuorille suositellaan palautumisen kannalta vähintään yhtä lepopäivää ohjelmoidusta harjoittelusta viikossa, toisaalta riittävä arkiaktiivisuus auttaa ylläpitämään hyvää peruskuntoa, joka on tärkeä ominaisuus kaikille nuorille.

Liikunnan harrastamisen varjopuolena on kohonnut vammariski. Väitöskirjatutkimuksessa viimeisen vuoden aikana seuratoimintaan osallistuvista nuorista 44 % raportoi vähintään yhden äkillisen vamman ja 35 % vähintään yhden rasitusvamman, seuratoimintaan osallistumattomista nuorista 20 % raportoi vähintään yhden äkillisen vamman ja 17 % vähintään yhden rasitusvamman. Seuratoimintaan osallistuvilla runsaampi harjoittelun ja kilpailujen määrä oli yhteydessä suurempaan vammariskiin. Vammat aiheuttavat paljon poissaoloja urheilusta, vammojen ehkäisy on kuitenkin mahdollista ja tähän tulisi jatkossa kiinnittää enemmän huomiota.

Tuki- ja liikuntaelimistön tutkimuksessa todettiin, että seuratoimintaan osallistuminen oli yhteydessä parempaan hartiaseudun ja nilkkojen liikkuvuuteen,

parempaan polven hallintaan pudotushyppytestissä sekä parempaan keskivartalonhallintaan lankkutestissä. Molemmilla ryhmillä esiintyi puolieroja ryhdissä sekä puutteita liikkuvuudessa ja liikehallinnassa, nämä voivat liittyä runsaaseen paikallaoloon ja/tai yksipuoliseen harjoitteluun. Toistettavuus vaihteli eri osatestien välillä, mutta yleisesti toistettavuus oli riittävä kahden lääkärin välillä.

Raudanpuutteen ja hoitamattoman astman merkitys etenkin kestävyyslajeissa on korostunut ja lajeista etenkin maastohiihtoon liittyy kohonnut astmariski. Raudanpuute todettiin käytetystä ferritiinin raja-arvosta riippuen 23–60 %:lla tytöistä ja 5–30 %:lla pojista ja rautalisä oli käytössä alle 4 %:lla tutkittavista. Astmaan sopiva tulos keuhkojen toimintakokeessa todettiin 7 %:lla seuratoimintaan osallistuvista nuorista. Ryhmien välillä ei ollut tilastollisesti merkitseviä eroja anemian, raudanpuutteen tai astmaan viittaavien löydösten suhteen.

Sydämen ja verenkiertoelimistön toiminnan tutkimisen tarkoituksena on löytää mahdollinen piilevä sydänsairaus, joka voi vaarantaa urheilijan terveyden. Sydänsairauteen viittaavat löydökset on tärkeä erottaa normaaleista harjoittelun aikaansaamista muutoksista. Toistuvan fyysisen rasituksen vaikutukset sydän- ja verenkiertoelimistöön, kuten matalampi syke, korkeampi QRS kompleksin amplitudi ja matalampi diastolinen verenpaine, ovat nähtävissä jo nuorilla urheilijoilla. Systolinen verenpaine oli useammin koholla ei-kestävyyslajeihin osallistuvilla nuorilla kuin kestävyyslajien urheilijoilla ja urheiluun osallistumattomilla.

Tämä väitöskirjatyö tuo esille, että liikuntaseurantatoimintaan osallistumiseen liittyy terveyden kannalta edullisia tekijöitä, kuten runsaampi fyysinen aktiivisuus ja parempi kehonhallinta. Urheilijan terveystarkastuksessa voidaan todeta piilevä sairaus tai muu poikkeavuus, joka heikentää suorituskykyä tai pahimmillaan vaarantaa urheilijan terveyden. Yhdistämällä tarkastuksen eri osa-alueista saatava tieto saadaan hyvä käsitys urheilijan terveydentilasta. Terveystarkastukset suositellaan otettavan osaksi tavoitteellisesti urheilevien nuorten valmennuksen tukitoimia. Liikuntaa suositellaan kaikille nuorille, joten riittävään liikunnan määrään ja laatuun, liikuntavammojen ehkäisyyn ja liikuntaan liittyviin oireisiin tulee jatkossa kiinnittää enemmän huomiota myös koko ikäluokalle tehtävissä terveystarkastuksissa.

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Tampere, September 2nd, 2021

Kerttu Toivo

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ABBREVIATIONS

ACL	anterior cruciate ligament
BP	blood pressure
CI	confidence interval
ECG	electrocardiogram
EVH test	eucapnic voluntary hyperventilation test
FHPSC-study	Finnish Health Promoting Sports Club–study
FMS	Functional Movement Screen
HR	heart rate
IOC	International Olympic Committee
LVH	left ventricular hypertrophy
MAD	mean amplitude deviation
MCH	mean cell hemoglobin
MCV	mean cellular volume
MET	metabolic equivalent
MVPA	moderate to vigorous physical activity
NMT	neuromuscular training
NP	an adolescent not participating in a sports club
OR	odds ratio
PHE	periodic health examination/evaluation
SC	sports club
SCP	sports club participant
VDJ	vertical drop jump
VPA	vigorous physical activity
vVPA	very vigorous physical activity
Sa_{O2}	arterial oxygen saturation
SD	standard deviation
$V'O_{2max}$	maximal oxygen uptake
WHO	World Health Organization

LIST OF ORIGINAL PUBLICATIONS

I Toivo K, Vähä-Ypyä H, Kannus P, Tokola K, Alanko L, Heinonen OJ, Korpelainen R, Parkkari J, Savonen K, Selänne H, Kannas L, Kokko S, Kujala UM, Villberg J, Vasankari T. Physical activity measured by accelerometry among adolescents participating in sports clubs and non-participating peers. European Journal of Sport Science, submitted

II Ristolainen L, Toivo K, Parkkari J, Kokko S, Alanko L, Heinonen OJ, Korpelainen R, Savonen K, Selänne H, Vasankari T, Kannas L, Villberg J, Kujala UM. Acute and overuse injuries among sports club members and non-members: the Finnish Health Promoting Sports Club (FHPSC) study. BMC Musculoskeletal Disorders. 2019 Jan 19;20(1):32

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IV Toivo K, Kannus P, Kokko S, Alanko L, Heinonen OJ, Korpelainen R, Savonen K, Selänne H, Vasankari T, Kannas L, Kujala UM, Villberg J, Parkkari J. Hemoglobin, iron status and lung function of adolescents participating in organized sports in the Finnish Health Promoting Sports Club (FHPSC) Study. BMJ Open Sport Exercise Medicine. 2020 Sep 3;6(1)

V Pentikäinen H, Toivo K, Kokko S, Alanko L, Heinonen OJ, Korpelainen R, Selänne H, Vasankari T, Kujala UM, Villberg J, Parkkari J, Savonen K. Resting electrocardiogram and blood pressure in young endurance and non-endurance athletes and non-athletes. Journal of Athletic Training, 2021 May 1;56(5):484-490.

AUTHORS CONTRIBUTIONS

The author contributed to the study conception and design in studies I-V. The literature search was carried out by the author in studies I, III, IV. In studies II and V, the literature search was carried out with L. Ristolainen and H. Pentikäinen. The statistical analyses were carried out by the author in studies III and IV, and together with H. Vähä-Ypyä and K. Tokola in study I. The author wrote the first draft of the paper in studies I, III, and IV and contributed to the writing of studies II and V. The author has carried out health examinations in the follow-up of the FHPSC-study.

1 INTRODUCTION

The definition of health, according to the World Health Organization (WHO), is "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO 1948). Recently, the definition of an athlete's health problem was expanded to any condition that reduces the athlete's normal full health, whether it has consequences on sports participation or performance or requires seeking medical attention (Clarsen et al., 2020). The benefits of physical activity (PA) on all aspects of health are well known for children and adolescents (Bangsbo et al., 2016; Janssen & Leblanc, 2010). However, injuries are the downside of sports participation and also cause a burden to public health (Maffulli & Bruns, 2000; Mattila et al., 2009). Young athletes are also susceptible to overtraining, burnout, and overuse injuries (Carter & Micheli, 2011).

Sports clubs (SCs) are a common way for adolescents to participate in sports in Nordic countries. Although over half of Finnish adolescents participate in SC activities, PA decreases in adolescence, including the total amount of PA, frequency of strenuous exercise, and participation in SCs (Aira et al., 2013; Husu et al., 2016). For this reason, a model of a Health Promoting SC (HPSC) was established in Finland in 2004 (Kokko et al., 2006). The Finnish Health Promoting SC study uses a setting-based approach, which has been used in health promotion in many environments, such as schools and workplaces, but less in environments relating to leisure time (Kokko et al., 2014). The relationship between sports participation and socioeconomic status has been found to be complex, although those with a higher socioeconomic status are more likely than those with a lower socioeconomic status to participate in PA and sports (Eime et al. 2015).

In 2015, the International Olympic Committee (IOC) gave recommendations for all stakeholders in youth sports for developing healthy, resilient, and capable youth athletes (Bergeron et al., 2015). Youth sports are highly selective, and sports performance progressively improves with growth and maturation, the rate of which varies between individuals (Bergeron et al., 2015; Lloyd et al., 2014). Furthermore, growth related changes in movement mechanics may predispose a young athlete to overuse injuries (Hawkins & Metheny, 2001).

Many organizations around the world require that athletes undergo a preparticipation medical evaluation to be able to participate in sports. There are many templates available for performing an athlete's periodic health evaluation (PHE), which, in a narrow sense, serves as a screen for conditions that may place the athlete at risk for unsafe participation. The different templates are designed for different target groups, and no universal model suits all situations.

Early detection aims at discovering and curing conditions that have already produced pathological changes but that have not reached a stage at which medical aid is sought spontaneously. The main principles of screening are that the condition screened for must be an important health problem; there has to be a detectable early stage at which treatment is more beneficial than at a later state, and a suitable test for detecting the disease in the early stage needs to be available. The importance of the health problem does not depend only on how serious it is but also on how common it is. (Wilson & Jungner, 1968.) When it comes to elite-level athletes in particular, anything that negatively affects performance or leads to time loss in training may be seen as important.

Injury and illness prevention is a priority in sports medicine (Engebretsen & Steffen, 2015). Clearly, injuries are an important health problem in many sports, but the other principles of screening need adaptation when being applied to sports injury prevention (Bahr, 2016). Injury risk assessment through a musculoskeletal examination has been a long-standing goal for sports medicine practitioners.

Organizations that require health evaluations to be performed rarely provide guidance on the content of the evaluation. Additionally, the effectiveness of PHE in athletes remains controversial. In 2009, the Olympic Committee assembled an expert group to discuss the state of health evaluations for athletes. The aim was to provide recommendations for a practical PHE for the elite athlete and outline the need for further research. (Ljungqvist et al., 2009.)

This dissertation is based on the FHPSC study, the goal of which was to investigate the health promotion activities of SCs and coaches, as well as the health and health behaviors of adolescents participating in SCs. This dissertation focused on the health and objectively measured PA of sports club participants (SCPs) using accelerometry measurements, an injury questionnaire, a personal and family medical history, a physical examination, and selected laboratory tests. (Kokko et al., 2015.) The aim was to investigate the yield of a health examination for young SCPs.

2 REVIEW OF THE LITERATURE

2.1 Adolescents and physical activity

While participation in organized sports is becoming increasingly popular, the physical fitness levels among youth have declined within the previous decades (Carter & Micheli, 2011). Insufficient amounts of total PA for athletic development and overall health, even in adolescents participating in organized sports, have been reported in the Nordic countries. To increase total PA time, it is suggested to encourage active transport, independent training, and other school- and leisure-time PA. (Eithsdóttir et al., 2008; Hakkarainen et al., 2008; S. Kokko et al., 2011.) Additionally, the polarization of PA has increased, and initiatives to increase PA among the least active adolescents should be of high importance from a public health perspective (Eithsdóttir et al., 2008).

2.1.1 Health benefits of physical activity in adolescents

Extracurricular sports participation during growth helps to maintain physical fitness, protect against fat accumulation, and increase lean body and bone mass (Ara et al., 2006). Exercise also has beneficial effects on cardiovascular risk factors, such as dyslipidemia, impaired glucose tolerance, and hypertension (Ekelund et al., 2012). Participation in sports is also associated with numerous positive health behaviors (Pate et al., 2000). Furthermore, positive effects on cognitive functioning, engagement, motivation, psychological well-being, and social inclusion have been found (Bangsbo et al., 2016).

2.1.2 Physical activity recommendations

The WHO PA guidelines, updated in 2020, state that children and adolescents should do at least an average of 60 minutes per day of moderate to vigorous intensity PA (MVPA) across the week and that vigorous-intensity aerobic activities, as well as those that strengthen muscle and bone, should be incorporated at least 3 days a week (Bull et al., 2020). The Canadian 24-hour movement guidelines released in 2016 also state that, on average, 60 minutes per day of PA is recommended. This allows for some normal day-to-day variability, and the daily average is used predominantly in studies upon which the guidelines are based. (Tremblay et al., 2016.) Similarly, the recently updated Finnish recommendation for physical activity for children and adolescents aged 7-17 years states that at least an average of 60 minutes of MVPA should be accumulated each day of the week, most of this should be endurance activity. Vigorous endurance-type activity and physical activity that increases muscle strength and bone health should be performed at least three days a week. (Ministry of Education and Culture, 2021.)

In contrast, the WHO PA guidelines from 2010 stated that 60 minutes of MVPA should be incorporated each day of the week (WHO, 2010). The influence of the fractionalization of MVPA throughout the week has been studied. Better cardiometabolic health in children and youth seems to be associated with meeting the 60-minute PA target on at least five out of seven days (Janssen et al., 2013).

2.1.3 Measuring physical activity

Questionnaires are the simplest way to assess individuals' PA, but they are subject to recall bias. Methods for measuring PA that are based on self-reporting usually overestimate the intensity and duration of different types of sports, the reliability usually being low-moderate compared to objective measures (Ekelund et al., 2011; Prince et al., 2008; Sprengeler et al., 2017). In many sports, such as soccer, PA is intermittent. Someone who plays soccer may report vigorous PA for one hour but may only be vigorously active for a limited time while playing the sport (Ekelund et al., 2011).

Accelerometry offers an objective way to measure PA. There is also considerable variability between studies in how PA recommendations are met, even when using device-based/accelerometry measurements, due to the different intensity thresholds used across studies (Ekelund et al., 2011). To address this problem, the mean amplitude deviation (MAD) of the raw acceleration signal can be used to produce comparable results across different studies (Aittasalo et al., 2015b). To reach the minimum PA recommendation of 60 minutes of accelerometer-measured MVPA, 11,500–14,000 accelerometer-measured steps are needed in adolescents (Adams et al., 2013).

2.2 Sports injuries in adolescents

Adolescent injuries are a common health problem most commonly associated with sports and recreation (Räisänen, Kokko, et al., 2018). In a cross-sectional study of students in 35 countries, medically treated injuries were reported by 33–64% of males and 23–51% of females annually (Pickett et al., 2005). Categorization into acute or overuse injuries is based on the injury mechanism and rapidity of symptom onset. Sporting injuries occur during either competition or training and can affect any type of musculoskeletal connective tissue, such as muscle, bone, tendons, cartilage, or ligaments. Injuries are inevitably a part of sports, but there is growing interest in the prevention of sports injuries (Hawkins & Metheny, 2001; Leppänen et al., 2014).

2.2.1 Acute injuries

An acute injury occurs during a single, identifiable traumatic event caused by a force that stresses the tissue more than the tissue can withstand, resulting in macroscopic damage. This force can come from either outside or inside the body; these are referred to as either extrinsic or intrinsic causes for acute injuries, respectively. Fast-paced team sports, such as basketball and floorball, that require running, pivoting, jumping, and landing carry a high risk of acute injuries, especially to the lower extremities. (Pasanen et al., 2017; Pasanen et al., 2018.) The general risk for a cruciate ligament injury of the knee is relatively low among adolescents and young adults, but participation in organized sports increases the risk significantly. This risk is especially high in active young women in various team sports. (Haapasalo et al., 2007; Parkkari et al., 2008.)

2.2.2 Overuse injuries

Microtrauma occurs in anatomic structures that are subjected to repetitive loading; when this loading exceeds the remodeling capacity of the tissue under stress, overuse injuries develop (DiFiori, 2010). Overuse injuries include tendinopathy, bone stress reactions, stress fractures, and juvenile osteochondritis dissecans (Aicale et al., 2018). Highly organized sports participation with year-round repetitive training and sports specialization have led to an increase in overuse musculoskeletal injuries (Bell et al., 2018; Hawkins & Metheny, 2001). The location of an overuse injury depends on the characteristics of the sport (Ristolainen et al., 2010). Overuse injuries are common, especially in endurance and technical sports (Hart et al., 2018; Jacobsson et al., 2013; Ristolainen et al., 2010). Overuse injuries of the back and upper extremity, common especially in young gymnasts, include spondylolysis and spondylolisthesis, osteochondritis dissecans of the radiocapitellar joint, and distal radial physeal injury, known as gymnast wrist (Hart et al., 2018).

2.2.3 Significance of adolescent sports injuries

The health benefits of PA come with some risks, of which musculoskeletal injuries are the most common, causing athletes to lose time or sometimes drop out of sports (Maffulli et al., 2010; Ristolainen et al., 2010). Additionally, participation in SCs has been shown to be a strong predictor of injury hospitalization in Finnish youth (Mattila et al., 2009).

The spectrum of sports injuries in young athletes differs from that of adults due to their still maturing skeleton. Growth cartilage is present at the articular surfaces, physes or growth plates, and apophyses at tendon-bone attachments of skeletally immature athletes. This tissue is more susceptible to injury than more immature or mature bone. Examples of this type of injury include osteochondritis dissecans, apophyseal injuries, such as Osgood-Schlatter disease and Sever's disease, and overuse injuries at the growth plates, for example, at the distal radius. (DiFiori, 2010.) Injuries damaging epiphyseal growth plates can result in bone growth disturbance and deformity (Maffulli & Bruns, 2000).

According to previous studies, 20 to 50% of injuries are recurrences of an earlier injury in the same area; in team sports, lateral ankle sprains especially have a tendency to recur (Emery & Tyreman, 2009; Emery et al., 2006; Pasanen et al., 2017; Pasanen et al., 2018). Knee injuries have been shown to be the most common sports injury causing permanent disability, defined as an impairment of optimal function (Kujala et al., 1995). Additionally, a higher incidence of knee and ankle osteoarthritis has been shown in high-impact sports players than in the normal population (Vannini et al., 2016).

2.2.4 Risk factors and prevention

Recognizing factors that increase the injury risk is an essential part of injury prevention (van Mechelen et al., 1992). Injury risk factors can be classified into two groups: intrinsic and extrinsic risk factors. The former are related to characteristics of the individual, and the latter occur independently of the individual (Meeuwisse, 1994). The occurrence of a sporting injury is a dynamic process in which each athlete is affected by their own intrinsic risk factors; exposure to extrinsic risk factors makes the athlete susceptible to injury. The final link between a susceptible athlete and injury is the inciting event (Meeuwisse, 1994). This process was further developed into a dynamic model that includes repeated participation in sports and possible adaptation to extrinsic risk factors, as well as possible alterations in the athletes' internal features as a result of the injury (Meeuwisse et al., 2007).

Some intrinsic risk factors cannot be modified (e.g., age, previous injury), whereas others are modifiable (physical fitness, neuromuscular control, strength). Further, examples of intrinsic risk factors are sex, body composition, anatomy, and psychological factors. Extrinsic risk factors include sports factors (e.g., rules, level of competition, training frequency), environment (e.g. weather, playing surface), protective equipment, and sports equipment. (Bahr & Krosshaug, 2005.)

Sports performance improves progressively with growth and maturation, and appropriate training enhances performance; however, youth sports are highly selective during the interval of puberty and the adolescent growth spurt (Bergeron et al., 2015). Growth related factors, such as unfused epiphyseal plates and apophyses, increased power, and a temporary decline in coordination and balance, may increase the injury risk in adolescent athletes; however, the relationship of growth and maturation with injury risk remains unclear. Studies regarding motor awkwardness and increased injury susceptibility in adolescence have yielded inconsistent results (Quatman-Yates et al., 2012). However, in a previous study among adolescents aged 8–14 years, functional movement screen (FMS) scores were found to be higher after puberty than before or during it (Paszkewicz et al., 2013).

There has been concern that high-intensity sports training can alter growth and maturation rates; the current consensus is that regular gymnastics training does not attenuate pubertal growth or maturation or compromise adult stature (Malina et al., 2013). An estimate of maturity status can be obtained from an estimate of the percentage of the predicted adult height at the time of observation. Maturity timing refers to the ages when specific maturational events occur, such as the age at peak height velocity and age at menarche. An estimate of maturity timing can be obtained from the predicted time before peak height velocity. (Bergeron, Mountjoy et al. 2015.)

2.3 Screening of musculoskeletal health in adolescents

Musculoskeletal screening tests can focus on different aspects of the locomotor system, such as posture, range of motion, strength, balance, or movement control. Musculoskeletal screening that focuses on movement quality involves identification and rating of functional compensations, asymmetries, impairments, or the efficiency of movement control through transitional (e.g., squats, lunge) or dynamic movement tasks (e.g., hopping, landing, cutting) (Whittaker et al., 2017).

Screening for injury risk is usually completed using a performance test to detect modifiable impairments that may predispose the individual to injury. Although a number of markers in musculoskeletal screening tests are associated with an increased risk of sustaining a sports injury, there is yet no evidence in support of screening athletes for injury risk. To obtain evidence, test properties need to be validated in different populations using appropriate statistical methods. It is also not known whether it is more beneficial to treat only high-risk athletes, rather than them all (Bahr, 2016).

2.3.1 Reliability of musculoskeletal screening tests

Before proposing to use a series of tests in clinical practice, the reliability of the tests needs to be established. The interrater reliability of FMS has previously been reviewed and found to be acceptable, but the reliability varies between different subtests (Bonazza et al., 2017; Moran et al., 2016). The vertical drop jump test (VDJ) has shown good inter- and intra-rater repeatability in real-time field and office conditions, suggesting that this test can be performed without significant training by physicians, as well as allied health professionals (Redler et al., 2016). Tester experience has been found to increase the reliability of the single leg squat test (Räisänen et al., 2016).

2.3.2 Yield of musculoskeletal screening

Different clinical tests to screen athletes' movement control, such as the FMS and star-excursion balance test, have been developed to evaluate the individual's risk of sustaining non-contact lower extremity injuries (Cook et al., 2014; Hegedus et al., 2015). In a research setting, both two- and three-dimensional motion analysis methods have been used to assess movement control (Leppänen et al., 2016; Räisänen et al., 2016).

Excessive or prolonged foot pronation has traditionally been linked to lower limb overuse injuries with the presumption that foot motion affects the more proximal structures; however, the direction of the dynamic coupling mechanism between the lower limb segments remains inconclusive (Chuter & Janse de Jonge, 2012). Recent investigations have been more focused on proximal control of the knee and lower extremity as risk factors for lower extremity injuries. Deficits in core stability and alterations in hip control are associated with an increased lower limb injury risk and knee injury risk, especially in females (Chuter & Janse de Jonge, 2012; Leppänen et al., 2020; Zazulak et al., 2007).

The Trendelenburg test is a commonly used clinical test to assess hip and pelvic control. A positive Trendelenburg sign is defined by the contralateral side of the pelvis dropping on the non-stance side when standing on one leg (Hardcastle & Nade, 1985). Several modifications of this test have been widely used in clinical practice, including assessment of the patient being able to remain in the correct position for 30 seconds, the hurdle step test in the FMS, and lateral movement in the one-leg stance (Cook et al., 2014; Hardcastle & Nade, 1985; Luomajoki et al., 2007). Decreased postural stability has been proposed to be a risk factor for lower extremity non-contact injuries (Dingenen et al., 2016).

Core stability has been defined by Kibler et al. (2006) as the ability to control the position and motion of the trunk over the pelvis and leg to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated kinetic chain activities (Kibler et al., 2006). Impaired core stability, seen as a side-by-side difference in postural control, decreased isometric hip extension: flexion ratio, and decreased abdominal core muscle endurance, are associated with an increased risk for lower extremity overuse injuries (De Blaiser et al., 2019).

The VDJ test is proposed to be a useful screening test for increased anterior cruciate ligament (ACL) rupture in female athletes. Stiff landings and medial knee displacement have been shown to be associated with increased ACL rupture risk; however, evidence does not support using these alone for screening players with a higher risk of ACL rupture (Hewett et al., 2005; Krosshaug et al., 2016; Leppänen et al., 2016). Core muscle strength, control of the lumbar spine neutral position, postural asymmetry, muscle balance, mobility, and dynamic joint stability are areas that can be evaluated in a PHE, and possibly future injuries could be prevented by training directed toward the improvement of weaknesses (Suni et al., 2013; Verrelst et al., 2014).

Posture control is defined as maintaining, achieving, or restoring a state of balance during any posture or activity (Pollock et al., 2000). Biological maturity has been found to be associated with static and dynamic postural control using the Balance Error Scoring System and Y-Balance Test in youth soccer players; those with a lower maturity offset status displayed better static and dynamic postural control (John et al., 2019). A previous study found that static and dynamic posture control were unrelated in healthy adolescents and were not related to strength. Given that injuries primarily occur during dynamic conditions, assessment should also be carried out under these conditions. (Granacher & Gollhofer, 2011.)

The results of physical performance tests can be affected by compensation movements. These types of tests most often have not been able to predict lower extremity injuries. Only components of the Star Excursion Balance Test and Y-Balance Tests have been associated with an increased risk of lower limb injuries. These tests measure dynamic balance, as well as other neuromuscular characteristics, such as lower extremity coordination, flexibility, and strength. (Hegedus et al., 2015; Plisky et al., 2006.) In a systematic review and meta-analysis, a score of ≤ 14 in the FMS was associated with a 2.74 times greater probability of sustaining an injury than those with a score > 14 (Bonazza et al., 2017).

2.4 Respiratory conditions, anemia, and iron deficiency

Maximum oxygen uptake ($V'O_{2max}$) is an important determinant of an athlete's performance, especially in endurance sports. Physiological factors that potentially limit $V'O_{2max}$ are pulmonary diffusing capacity, cardiac output, the oxygen carrying capacity of blood, and skeletal muscle function. Anemia and asthma are examples of medical conditions that can limit $V'O_{2max}$ (Bassett & Howley, 2000).

2.4.1 Allergies and atopy

During exercise, increased minute ventilation brings the nasal passages into contact with greater volumes of air, which can lead to more difficult symptoms caused by aeroallergens. Symptoms and signs of allergic rhinitis include nasal congestion, rhinorrhea, and itching of the upper airways and eyes. These symptoms may lead to cough, sinus pressure, mouth breathing, fatigue, and disruption in sleep patterns, which may impair athletic performance. (Komarow & Postolache, 2005.) Common conditions that are a part of the atopic march include allergic rhinitis, atopic dermatitis, and allergic asthma. The lifetime prevalence of allergies is 21.5%, and for atopy, the prevalence is 18.2% in young Finnish adults (Kilpeläinen et al., 2000).

2.4.2 Respiratory tract infections

Exercise has an effect on the function of the immune system (Simpson et al., 2020). Moderate amounts of PA have been demonstrated to protect against respiratory tract infections, whereas it is a common view that performing prolonged or intense PA increases the risk of infection (Martin et al. 2009). The role of exercise as an independent factor in suppressing immune function has recently been challenged. It was agreed that infection susceptibility is affected by numerous factors, such as anxiety, sleep disruption, travel, and nutritional deficits (Simpson et al., 2020).

Typically, adolescents undergo two to three common colds annually (Heikkinen & Jarvinen, 2003). Low training loads or no training, as well as high training loads, in recreational and sub-elite athletes, are associated with a higher risk of illness than moderate training loads; the latter may not be true in high-level elite athletes (Schwellnus et al., 2016).

Infective illnesses can reduce exercise performance through different mechanisms, and in addition to causing time loss from sports participation, complications of acute infective illnesses may have detrimental effects on the health of the athlete (Schwellnus et al., 2016). Myocarditis is an infection of the heart that is often associated with a respiratory tract infection, the global prevalence is estimated to be 22 of 100 000 patients annually (GBD 2015). The presence of cardiovascular symptoms during or soon after an infection necessitates an evaluation to rule out myocarditis (Eichhorn et al., 2020). Mononucleosis is common in adolescents and requires a longer break (3-4 weeks) from sports participation due to the risk of spleen rupture (Shephard, 2017).

General guidelines introduced in an IOC consensus statement for illness prevention in athletes include behavioral, lifestyle, and medical strategies, training and competition load management, psychological load management, and measuring and monitoring for early signs and symptoms of illness, over-reaching, and overtraining. The guidelines include but are not limited to the prevention of respiratory tract infections. (Schwellnus et al., 2016.)

2.4.3 Exercise-induced bronchoconstriction and asthma

In an average healthy individual at sea level, $\%Sa_{O2}$ (arterial oxygen saturation) remains around 95% during exercise (Powers et al., 1989). In highly motivated athletes the $\%Sa_{O2}$ has been reported to fall below resting values, this may be due to the very short red cell transit time in at least a portion of the pulmonary circulation (Dempsey at al., 1984). Powers and colleagues (1989) found that an exercise-induced reduction in Sa_{O2} to about 92-93% is sufficient to cause a measurable effect of $V'O_{2max}$, and on average this effect approximates about a 1% decrement in $V'O_{2max}$ for each 1% decrement in $\%Sa_{O2}$. Chronic pulmonary diseases, such as asthma, cause a reduction in arterial oxygen, consequently limiting sports performance (Bassett & Howley, 2000)

Asthma is a disease with chronic airway inflammation, variable air flow limitation, and varying respiratory symptoms. Symptoms include wheezing, shortness of breath, chest tightness, and a cough, symptoms are typically triggered by viral infections, exercise, allergen exposures, and irritants. Several subtypes of asthma have been recognized, and correct diagnosis is essential to ensure that the patient receives the appropriate treatment. (GINA, 2018; Larsson et al., 2020.) Exercise-induced bronchoconstriction refers to transient airway narrowing that occurs during or after physical exertion. This term is frequently used interchangeably with exercise-induced asthma (Molis & Molis, 2010.)

The prevalence of asthma in Finland and Sweden is about 5–10% among young adults, and symptoms suggestive of asthma are even more common (Borna et al., 2019; Kilpeläinen et al., 2000). Several conditions other than asthma may also cause exercise-induced respiratory symptoms. An important differential diagnosis is exercise-induced laryngeal obstruction, which is a common inspiratory breathing disorder found to occur especially in young athletes, more often in females. Exercise-induced bronchoconstriction and laryngeal obstruction may also overlap. (Carlsen et al., 2008.) Other comorbidities and differential diagnostics for asthma include rhinosinusitis, obesity, and gastro-intestinal reflux disease (GINA, 2018).

The pathophysiology of asthma in athletes is an interplay between hyperventilation, hyperosmolarity, and immune changes. These are capable of causing a multi-factorial bronchial inflammatory response, involving common pathways of allergic and asthmatic inflammation. The risk for exercise-induced asthma and bronchoconstriction is markedly increased in athletes, especially within endurance sports and winter sports, such as cross-country skiing and swimming. (Del Giacco et al., 2015; Mäki-Heikkilä et al., 2020.)

Increased bronchial responsiveness and asthma are strongly associated with atopic disposition and its severity in elite athletes (Helenius et al., 1998). However, among cross-country skiers, neutrophilic inflammation induced by repetitive exposure to cold dry air and a high ventilatory demand seems to more often be the underlying mechanism of asthma, rather than eosinophilic inflammation, which is often associated with allergies and atopy (Mäki-Heikkilä et al., 2020).

2.4.4 Iron metabolism, iron deficiency, and anemia

Hemoglobin carries oxygen in the red cells of the blood, and the mass of hemoglobin is associated with higher maximal oxygen uptake, which is an important determinant of an athlete's performance potential, especially in endurance sports. Depleted iron stores are known to cause a reduction in hemoglobin mass (Saunders et al., 2013). In addition to hemoglobin, iron is also an essential component of oxygen-binding myoglobin in muscle cells and of cytochromes and other enzymes involved in the oxidation or reduction of biologic substrates. Iron is also needed for normal neurological function. (Piñero & Connor, 2000.) Excessive iron is toxic and can cause organ damage, for example, to the liver (Dev & Babitt, 2017).

Iron is effectively conserved and recycled in the body. About 20–25 mg of iron is needed daily for the production of red blood cells and other needs. As the circulating pool of iron is only 2–4 mg, it must be turned over every few hours to meet this daily requirement. Red blood cells are lysed, and iron is stored in ferritin and exported to the bloodstream. Major storage sites for iron are iron recycling macrophages (about 600 mg) and liver hepatocytes (about 1 g). The iron that circulates in the blood is bound to transferrin, which delivers iron to the tissues for uptake by transferrin receptors. Approximately 20–40% of iron binding sites on transferrin are normally occupied by iron, corresponding to transferrin saturation. The majority of iron is delivered to the bone marrow (about 300 mg) for red blood cell production. Dietary absorption provides a smaller amount of iron (about 1–2 mg) via duodenal enterocytes. Iron loss (about 1–2 mg) is not regulated and occurs through desquamation of epithelial cells and blood loss. (Dev & Babitt, 2017.)

Systemic iron balance is regulated by controlling the uptake of dietary iron and by controlling iron release from recycling macrophages and hepatocytes. Previously, the main mechanism of iron loss caused by sports was considered to be mucosal bleeding due to microischemia of the gut during excessive training (Peters et al., 2001). Other proposed, but not as relevant mechanisms, include loss through excessive sweating or through the urinary tract. At the systemic level, the hormone hepcidin is an important regulator of iron balance. When hepcidin expression is stimulated, less iron is absorbed from the diet and less iron is released from body stores. (Dev & Babitt, 2017.) Iron loading, inflammation, and intensive exercise have been shown to increase hepcidin production in hepatocytes (Clénin et al., 2015).

Iron is stored largely in the form of ferritin, which is a less reactive form, in enterocytes and other cells. Circulating ferritin generally correlates with body iron stores, although inflammatory conditions, for example, can influence its levels (Dev & Babitt, 2017). In an unclear situation, a measurement of soluble transferrin receptor concentration may be helpful to detect iron deficiency (Clénin et al., 2015).

Iron stores are depleted, and ferritin levels are reduced when iron losses exceed absorption or when absorption falls below demand. When the stored iron is too low, soluble transferrin receptors are increased. In non-anemic iron deficiency, hemoglobin, mean cellular volume (MCV), and mean cellular hemoglobin (MCH) remain normal, indicating that hematopoiesis is not affected. If the iron balance remains negative, the youngest red blood cells will be insufficiently hemoglobinized, and thus appear as hypochromic and microcytic, resulting in below-normal MCV and MCH levels. Ultimately, iron deficiency anemia is established when hemoglobin levels fall below normal. (Clénin et al., 2015.) The causes of iron deficiency anemia include nutritional deficiency, malabsorption, increased requirements during growth, and increased blood loss during menstruation (Lopez et al., 2016).

2.5 Cardiovascular evaluation

Persistent aerobic training exceeding 3–4 hours per week alters the structure and electrophysiological function of the heart, and leads to other physiological changes in the cardiovascular system. Arteries feeding skeletal muscles adapt to regular dynamic training; the vessel diameter increases, and endothelial functioning improves. This type of training also leads to increased muscle capillary density and metabolic changes (Dickhuth et al., 2012). Already during childhood and adolescence, a higher amount of moderate to vigorous PA is associated with better cardio metabolic risk factors, such as waist circumference, systolic blood pressure (BP), fasting triglycerides, high-density lipoprotein cholesterol, and insulin (Ekelund et al., 2012).

2.5.1 Effects of training on the heart and cardiovascular evaluation

Adaptations to regular aerobic exercise in the heart are referred to as "athlete's heart," and they include enlargement of the heart cavities, hypertrophy of the myocardium, and an increase in parasympathetic tone. These changes are reflected in an electrocardiogram (ECG) (Drezner et al., 2013). Cardiovascular adaptations to exercise differ with respect to the type of conditioning, endurance, or strength training; however, most sports, to some extent, are a combination of these. Endurance exercise predominantly produces a volume load on the left ventricle, and strength exercise produces a pressure load (Maron & Pelliccia, 2006). As sudden death from intrinsic cardiac conditions remains the leading cause of mortality in athletes during sport (Drezner et al., 2008; Maron et al., 2009), it is clinically important to identify ECG changes that represent normal adaptation in athletes and differentiate them from truly pathological findings (Drezner, Sharma et al. 2017).

Adaptations to regular aerobic exercise within the heart can be seen in adolescent athletes. Changes that are frequently visible on the ECG include sinus bradycardia, sinus arrhythmia, first-degree atrioventricular block, early repolarization, incomplete right bundle branch block, and voltage criteria for left ventricular hypertrophy (LVH) (Pelliccia et al., 2007). In a study of 1,710 highly trained athletes aged 14–18 years, the PR interval, QRS duration, and corrected QT duration were longer in athletes than in non-athletes (Papadakis et al., 2009). Furthermore, in the same study, the Sokolow-Lyon voltage criterion for LVH and sinus bradycardia were more common in athletes (Papadakis et al., 2009).

The most common cause of cardiovascular sudden death in young competitive athletes has been found to be hypertrophic cardiomyopathy, accounting for one-third of all such deaths; the second most common being coronary artery anomalies, accounting for about 15%, followed by myocarditis, arrhythmogenic right ventricular cardiomyopathy, and ion channelopathies, such as long QT and Brugada syndrome (Maron et al., 2009). Sudden cardiac arrest related to exercise in adolescents most commonly occurs in 14–18-year-old athletes and more frequently in males than females; the survival rate remains poor (Drezner et al., 2008).

Preparticipation cardiovascular screening of athletes is fully endorsed by major medical societies (Corrado et al., 2005; Maron et al., 2007) and the IOC (Ljungqvist et al., 2009), although the most effective screening protocol remains debated (Maron et al., 2019). In a study of 3620 athletes with a median age of 16 years, a clinical evaluation, including personal and family medical history, heart auscultation, pulse palpation, and BP measurement, was compared to the ECG in identification of a cardiovascular disorder associated with sudden cardiac death. The sensitivity, specificity, and positive predictive value of the ECG was substantially higher than that obtained during the clinical evaluation with medical history evaluation and physical examination. (Williams et al., 2019.)

2.5.2 Effect of training on blood pressure

Arterial BP reflects the combined effects of arterial blood flow each minute (cardiac output) and resistance to that flow in the peripheral vasculature. The arterial BP can be expressed as: BP = cardiac output x total peripheral resistance. The systolic BP is the highest pressure generated by the heart during left ventricular contraction, and the diastolic BP is the pressure in the arteries during the cardiac cycle's relaxation phase. Diastolic pressure indicates the ease with which blood flows into the capillaries or the peripheral resistance. (McArdle, 2015.)

A higher amount of PA is associated with lower systolic BP in adolescents (Buchan et al., 2011; Ekelund et al., 2012), although high amounts of PA have also been associated with higher BP (Tsioufis et al., 2011). In a study of highly trained 13–19-year-old tennis players, athletes had lower systolic and diastolic BP readings compared to the controls (Basavarajaiah et al., 2007). However, hypertension was the most prevalent condition in a population of amateur and professional athletes aged 13-77 years (De Matos et al., 2011). In an athlete population, high BP response in an exercise test has been shown to predict the development of future hypertension (Caselli et al., 2019). However, highly trained young athletes may have 'spurious systolic hypertension' characterized by elevated brachial systolic BP and pulse pressure but normal aortic BP and diastolic BP. This is a non-pathologic finding resulting from an increased cardiac stroke volume combined with highly elastic arteries and a low peripheral vascular resistance (Mahmud & Feely, 2003).

3 PURPOSE OF THE STUDY

The goal of this dissertation was to investigate the amount of physical activity and physical health of adolescents participating in SCPs with a periodic health examination. A survey of acute and overuse injuries, musculoskeletal examination, measurement of hemoglobin and iron status markers, flow-volume spirometry, BP measurements, and ECGs were carried out on adolescents participating in ten of the most popular sports in Finland, and the results were compared to non-participants (NP) of the same age. Physical activity (PA) was also investigated by accelerometer recording for one week. The specific study aims were:

1. To describe the amount, intensity, and bout lengths of PA of SCPs and NPs and determine how the recommendations for PA are met (Study I)
2. To describe the scope of adolescents' acute and overuse sports injuries and examine training-related factors associated with an increased injury risk (Study II)
3. To examine the interrater reliability of a musculoskeletal examination and compare the posture, mobility, and movement control between SCPs and NPs (Study III)
4. To study the hemoglobin level, iron status, and lung function of SCPs and compare the findings with adolescents not participating in SCs. (Study IV)
5. To compare the BP and ECG findings between adolescents participating in endurance sports, non-endurance sports participants, and adolescents not participating in SCs (Study V)

4 RESEARCH METHODS

4.1 Research process and dissertation structure

This dissertation is based on five separate research articles, all based on the Finnish Health Promoting Sports Club (FHPSC) study. The first original article described the duration and patterns of different intensities of PA, the number of daily steps, and how PA recommendations were met in sports club participants (SCPs) and NPs. The second original article compared the occurrence of acute and overuse injuries in SCPs and NPs and reported training and competing habits associated with a higher injury risk in SCPs. In the third article, the aim was to study the interrater reliability of a comprehensive musculoskeletal examination and compare posture, mobility, and movement control between SCPs and NPs. The focus of the fourth article was investigating anemia, iron deficiency, and asthma by means of clinical laboratory tests among SCPs and NPs. The fifth article compared the BP and ECG findings between SCPs participating in endurance sports, non-endurance sports, and adolescents not participating in SCs.

4.2 Study design

The FHPSC study is a cross-sectional study conducted by the University of Jyväskylä in conjunction with six national Centers of Excellence in Sports Medicine, namely Clinic of Sports and Exercise Medicine (Helsinki), LIKES Foundation for Sport and Health Sciences/Mehiläinen Sports Clinic (Jyväskylä), Kuopio Research Institute of Exercise Medicine (Kuopio), Tampere Research Center of Sports Medicine (Tampere), Paavo Nurmi Centre (Turku), Department of Sports and Exercise Medicine, Oulu Deaconess Institute (Oulu), and the UKK-institute (Research Center for Health Promotion Research).

All adolescents participating in the study were aged 14–17 years and represented both genders. The information about injuries was collected by surveys via SCs and schools. The health status findings were collected in a health examination and laboratory tests. The PA levels were assessed using objective accelerometer measurements from those adolescents participating in the health examinations.

4.3 Data collection

Data collection was initiated with surveys in two rounds during 2013, from January to May, during the main competition season for winter sports, and from August to December, for summer sports. Comparison data for NPs was collected similarly in two stages via schools (9^{th} grade) within the same time frame. Complementary data were collected from SCPs and NPs in spring 2014. Health examinations were mainly performed between August 2013 and April 2014.

4.4 Sampling

Data sampling was carried out in a two-stage process, first with the clubs and second with the respondents and study participants. A similar procedure was carried out for school-based data.

4.4.1 Sports club sample

A total of 240 SCs were targeted from 10 sports disciplines, 24 from each sport. The SCs were divided into winter and summer sports depending on the main competition season and into team and individual sports. The most popular sports were then chosen. Winter sports were basketball, cross-country skiing, floorball, ice hockey, and skating, and summer sports were soccer, gymnastics, orienteering, swimming, and track and field. In study V, soccer, cross-country skiing, orienteering, and swimming were classified as endurance sports and other disciplines as non-endurance sports.

SCs were further stratified for each discipline depending on (1) geographic location (six areas of Centers of Excellence in Sports and Exercise Medicine in Finland), (2) magnitude (larger and smaller), (3) certification by the Young Finland Association (yes or no), and (4) area type (city or countryside). To ensure objective and representative sampling, discretionary rather than randomized sampling of the clubs was performed. A total of 154 SCs participated in the study. Cluster sampling of the sports clubs is shown in Figure 1.

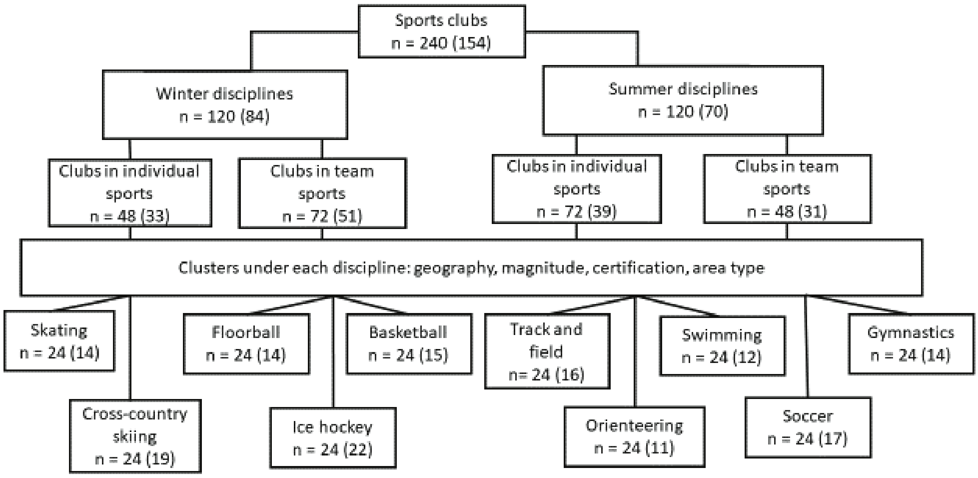

Figure 1. Cluster sampling of the sports clubs in the Finnish Health Promoting Sports Club study.

N indicates the number of targeted sports clubs and the number shown in parentheses indicates the number that participated successfully. Clubs were stratified separately for each discipline based on geographic location, magnitude, certification by The Young Finland Association, and area type. Adapted from Kokko et al. (2015).

4.4.2 Sampling of adolescents participating in health behavior and injury surveys

The sampling of adolescents in SCs participating in injury and health behavior surveys was tailored separately for team and individual sports and winter and summer sports. Fifteen-year-old youth (9th graders) were targeted; for winter sports, youth were born in 1997, and for summer sports, youth were born in 1998. From each club, three to five athletes per gender were sampled. For team sports, only one team was randomly selected for those clubs that had several teams. The researchers randomly selected the individuals from a given team and from all eligible individual athletes.

School-based survey data were collected following the SC data collection timing. Ten secondary schools from each of the six districts of the Centers of Excellence in Sports and Exercise Medicine were targeted. Equal portions of small and large schools and city versus countryside schools were sampled. Overall, 159 schools were contacted and 100 participated (63%). One randomly selected class of ninth graders was asked to respond from each school. Members of the school-based sample were asked about their SC participation, and club participants in the school data were treated as SCPs in the analysis.

A total of 1,889 youth completed the sports injury and musculoskeletal health questionnaire (1,077 SCPs via clubs and schools and 812 NPs). The formation of the final study group is shown in Figure 2.

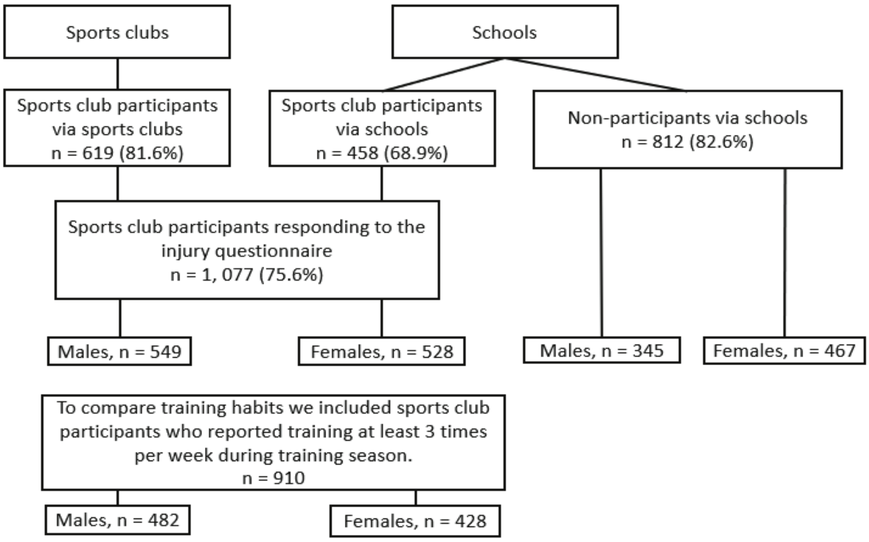

Figure 2. Final study group for the injury questionnaire.

N indicates the number of adolescents who responded to the questionnaire (Study II). The number in parentheses indicates the percentage of adolescents who responded to the questionnaire.

4.4.3 Sampling of adolescents participating in the physical activity measurement and health examination

The sample size for the health examination was power calculated using the prevalence of asthma (population 8% vs athletes 15%) with the DDS Research Researchers toolkit (August 2011). Six hundred youth were aimed at for the sample (372 SCPs and 288 NPs). The examinations were planned to be completed in different timeframes for summer and winter sports; these were both expanded to complete enough examinations. Each Center of Excellence in Sports and Exercise

Medicine was used to complete 100 health examinations. Youth who were invited to participate in the health examinations were randomly selected from the survey data, SCPs from SC-based data, and NPs from school-based data. The ratio between SCPs and NPs was not achieved as planned due to a lack of interest in participation among NPs. In early 2014, health examination data needed additional NPs, so an extra 15 schools were contacted, of which six participated. The structure of data collection at sports club and individual level is shown in Figure 3.

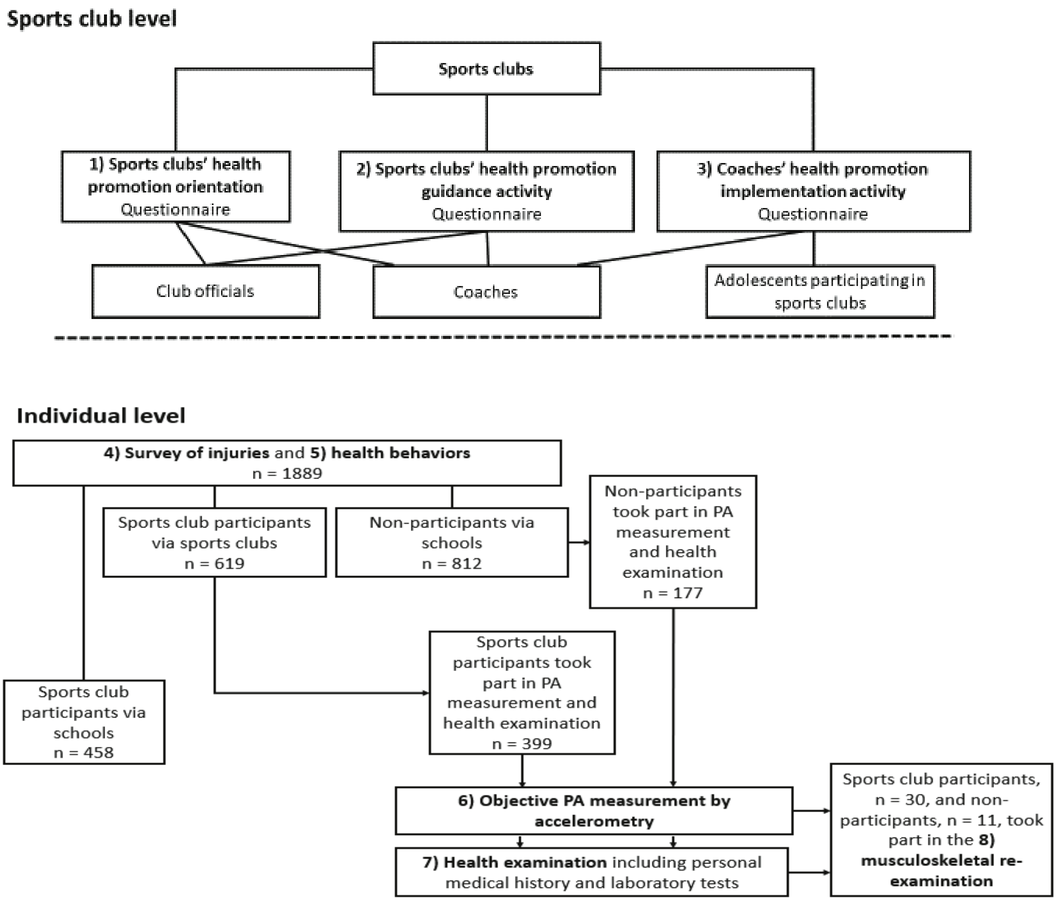

Figure 3. Structure of data collection at sports club level and individual level.

Realized data and study participants (n) of the Finnish Health Promoting Sports Club study. PA = physical activity. Modified from Kokko et al. (2015).

4.5 Measurements

4.5.1 Objective physical activity measurement

PA was measured with a hip-worn tri-axial Hookie AM 20-accelerometer (Hookie Technologies Ltd, Helsinki, Finland), which has been shown to be valid among adults (Vähä-Ypyä et al., 2015) and adolescents (Aittasalo et al., 2015a). The accelerometer collected and stored tri-axial data (in raw mode) in g-units. The intensity of PA was calculated for 6 s epoch data from the accelerometer as the MAD of the resultant acceleration; this is a validated measure to allow comparison between different studies (Vähä-Ypyä et al., 2015). MAD values were converted to METs (metabolic equivalent, 1 MET = 3.5 ml (O2)/kg/min) and intensity was calculated as the one-minute exponential moving average of epoch-wise MET values. The 1-minute epoch is the most commonly used epoch in other studies (Clemente et al., 2016), but 6 s epochs are also used (Husu et al., 2016).

The MET values were categorized as follows:
Moderate to vigorous PA (MVPA) ≥3 MET
Moderate PA (MPA) 3–6 MET
Vigorous PA (VPA) ≥ 6–9 MET
Very vigorous PA (vVPA) ≥ 9 MET

Upon the first study visit, the accelerometer was fitted, and guidance was given to attach the elastic belt at the level of the iliac crest. The accelerometers were returned one week later on a study visit or later by mail. In addition, PA was recorded in a structured diary, in which the adolescents were asked to record the time of waking up and going to bed, as well as the types and intensities of all PA performed during the day. For the SCP group, we classified days with competitions, organized training, training during school, and independent training as training days. Days not including any of these were classified as non-training days. Those adolescents who had not recorded PA in the diary were excluded from the analysis.

Accelerometry measurements have been studied in relation to energy expenditure while walking and running (Freedson et al., 1998). Thus, MET values are not directly applicable during tasks performed on skates, skis, or bicycles. In sports that are not performed on foot, the amount of vigorous PA is underestimated by the accelerometer. These sports were included in the analysis because a significant amount of training is usually performed on foot, and also the amount of MVPA should be accurate in these sports. However, swimmers were excluded from the analysis, as they did not wear the accelerometer during training. Sports disciplines with eight or more same-sex participants were included in the analysis of meeting the PA recommendations and step count. Sports with fewer than eight participants of the same sex were included in the bout length analysis, in which both sexes were analyzed together. Ten SCPs reported participating in a sport other than the one originally reported. They may have switched sports during the study and were, therefore, excluded from the analyses. Additionally, two SCPs did not report participating in any sports and were excluded from the analysis.

4.5.2 Surveys

The injury and musculoskeletal health survey and health behavior survey were internet-based and answered online by SCPs in their spare time and by pupils during the school day in class supervised by a teacher.

The questions in the surveys were compiled from previously validated questionnaires (Eloranta & Tittonen, 2006; Karhula & Pakkanen, 2005; S. K. Kokko, Lasse et al., 2011; Pasanen et al., 2008; Ristolainen et al., 2010). In the injury questionnaire, the respondents reported the number of acute and overuse injuries they had sustained within the past 12 months. The following definitions were used for acute and overuse injuries:

Acute injury: an acute sports injury occurs suddenly or accidentally, interrupting exercise or causing an identifiable trauma, and keeps one away from exercise for at least one day or requires physician's care.

Overuse injury: an injury that causes increasing pain during or after exercise without any noticeable external cause of injury and possibly even completely prevents exercise (Arnason et al., 2004; Brukner & Bennell, 1997; Hawkins & Fuller, 1999; Ristolainen et al., 2010).

The participants also reported the anatomical location of the injury, the type of injury, and the circumstances under which the injury occurred. Additional questions were asked from SCPs concerning their main sport and training habits.

The self-evaluated PA was obtained from the health behavior questionnaire. We used the question "How many hours of vigorous exercise/ PA do you usually do per week in your leisure time (after school lessons)?" for both groups.

The health examination medical history survey was directed to those adolescents participating in the health examination. It included questions about the family history of diseases, growth, nutrition, sleep, and health status of the adolescents. This questionnaire was filled in at home with the parents, and informed written consent was included.

4.5.3 Health examination

The health examination protocol consisted of a main session and a feedback session. The main session lasted approximately 2 h 30 min. Before the examination, time was allocated for filling in the injury questionnaire for those who had not previously filled this in. The following measurements were made in the following order: height, weight, resting BP, resting ECG, fasting blood samples, and spirometry with a bronchodilation test. This was followed by a health examination performed by a sports and exercise medicine physician. The examination consisted of reviewing the medical history survey and a general clinical and musculoskeletal examination.

4.5.3.1 Musculoskeletal examination

A musculoskeletal examination including previously well documented posture, mobility, and movement control tests was performed. See Table 1 for tests, scoring, and references. A scoliometer (OSI-scoliometer Orthopedic Systems) was used to measure height asymmetry at the acromioclavicular joint level and the angle of trunk rotation. The number of musculoskeletal examinations performed was 576. The participation percentage of those asked to take part in the health examination was 37% for SCPs and 34% for NPs.

The interrater reliability assessment protocol consisted of the main session and a repeated musculoskeletal examination included in the feedback session within two weeks from the main session. Sixty youth (the first ten from each of the centers) were invited for the repeated examination. Forty-one examinations were completed by another sports and exercise medicine physician for 30 sports participants and 11 NPs. In all, there were 12 physicians completing the examinations. The results of the

Trendelenburg test results are not presented in this thesis, as there was a misunderstanding in how to record the results of the test.

Table 1. Musculoskeletal screening tests (Study III).

Test	Scoring
Posture	
Shoulder posture	Protrusion of one or both shoulders by inspection from the side, scoliometer reading at acromioclavicular joint level.
Forward bend	Scoliometer reading from the level of the sacrum, iliac crest, and lower scapula.
Iliac crest height	Presence of asymmetry by palpation and inspection from the front.
Mobility	
Shoulder mobility	Dowel on raised straight arms, second dowel fits between head and arms. Highest score—with ease. Middle score—with mild resistance. Lowest score—compensates with cervical protrusion.
Modified Thomas Test[a]	Presence of marked iliopsoas tightness on one or both sides.
Navicular Drop[b]	≥ 10 mm on either or both sides, side difference ≥ 2 mm.
Beighton and Horan joint mobility index[c]	Generalized joint laxity ≥ 4 points*[d]
Movement control	
30 s plank[e]	Ability to remain in correct position for 30 s
Deep squat[f]	Highest score—lumbar spine remains in neutral zone and heels on the floor, dowel on raised straight arms. Middle score—lumbar spine control not assessed, heels remain on floor, hands behind neck. Lowest score—heels lifted from floor, hands behind neck.
Trendelenburg test[g]	20 cm stance, positive Trendelenburg sign—pelvis tilts toward raised leg.
One-leg stance[h]	20 cm stance, normal performance: lateral movement <13 cm, side difference ≤ 2 cm
Vertical drop jump[i]	First and second landing assessed[j], rating good-reduced-poor control[k]

[a] (Harvey, 1998), [b] (Shultz et al., 2006), [c] (Beighton et al., 1973), [d] (Clinch et al., 2011), [e] (Strand et al., 2014), [f] (Cook et al., 2014), [g] (Hardcastle & Nade, 1985), [h] (Luomajoki et al., 2007), [i] (Ford et al., 2003), [j] (Bates et al., 2013), [k] (Nilstad et al., 2014)

*Ability to put hands flat on the floor with knees straight, elbow and knee hyper extended > 10°, ability to bend thumb onto the front of forearm, ability to bend little finger up at 90° to the back of hand.

4.5.3.2 Flow-volume spirometry with bronchodilation

Flow-volume spirometry was measured according to American Thoracic Society/ European Respiratory Society guidelines (Miller et al., 2005) using a Medikro Pro 909 Spirometer (Kuopio, Finland). Salbutamol (0.4 μg) was used for the bronchodilation test. Finnish reference values for children were used (Koillinen et al., 1998). The criteria for baseline obstruction were FEV% z-score < -1.65 and for new asthma diagnosis FEV1 or FVC +12% in the bronchodilation test (Pellegrino et al., 2005).

The quality of the spirometry recordings was evaluated according to recommendations by the Finnish Society of Clinical Physiology and the Finnish Respiratory Society (Sovijärvi et al., 2011). Subjects who reported using asthma medication (n = 48) were excluded from the analysis, as well as those with poor quality results (n = 63). In addition, 21 subjects had poor quality results only after bronchodilator administration; these were also excluded. Having a previous asthma diagnosis was not an exclusion criterion if the person was not using asthma medication regularly. The number of spirometry exams included in the analysis was 515.

4.5.3.3 Blood sample

Venous blood samples were taken after an at least 10 h fasting period. The blood cell counts were analyzed using a standard automatic hematology analyzer. Serum was separated by standard procedures and stored at -75° Celsius prior to analysis. Blood chemistry, serum ferritin, and transferrin receptor analyses were carried out on a Cobas 8000 modular analyzer (Roche Diagnostics) in an SFS-EN ISO 15189:2013 accredited laboratory.

Anemia was defined by Hb < 120 g/l for females and males under 15 years old; the threshold for males 15 years or older was < 130 g/l, as recommended by the WHO (WHO, 2001). The threshold used for iron deficiency was ferritin < 15 μg/l, and a higher cutoff value of 30 μg/l was also used because absence of iron stores has been associated with signs of an iron deficient erythropoiesis starting already at serum ferritin 35-40 μg/l (Hallberg, Bengtsson, et al., 1993; WHO, 2001). Frequently, a lower ferritin threshold to indicate iron deficiency is used for females because of the higher iron requirements and lower iron stores among menstruating women (Looker et al., 1997). The laboratory-specific reference range for the serum transferrin receptor was 2.2–5.0 mg/l for males and 1.9–4.4 mg/l for females.

Subjects with C-reactive protein levels above 5 mg/l, indicating inflammation, were excluded from ferritin analyses, and subjects taking iron supplements who had normal ferritin levels (> 30 μg/l) were excluded from ferritin and transferrin receptor analyses. Ferritin values were obtained from 561 subjects, and transferrin receptor values were obtained from 567 participants.

4.5.3.4 Resting ECG

A standard 12-lead resting ECG was recorded after a 5-minute rest in a supine position. To ensure consistency in the precordial lead locations, the electrodes were carefully placed. The paper speed was 25 mm/s with a 10 mm/mV gain. Amplitudes were recorded to the nearest 100^{th} of a millivolt and times to the nearest millisecond (Gorodeski et al., 2009). The digital ECG measures were reviewed by a separate physician in each Sports and Exercise Medicine Center, and manual measurements were taken.

Seven quantitative ECG measurements were extracted for each participant. Heart rate (HR), PR interval, QRS duration and axis, T axis, and QT interval were analyzed digitally using the ECG recorder's own software. These measurements are believed to be correlated with HR, conduction, and repolarization. The S wave in V1 and the maximum R wave in lead V5 or V6 were measured using a millimeter ruler to evaluate left ventricular mass. (Gorodeski et al., 2009.)

Sinus bradycardia was defined as an HR below 60 beats/min. The normal range for the PR interval was 120–200 ms. The normal QRS duration was ≤ 120 ms. Left QRS-axis deviation was defined as a QRS more negative than 0° and a right QRS axis more positive than 105°. Left T-axis deviation was defined as a T-axis more negative than 15° and right T-axis more positive than 105°. Bazett's formula was used to correct the QT interval for HR (QTc). A QTc longer than 460 ms was considered abnormally prolonged. The Sokolow-Lyon voltage amplitude criterion was used to identify LVH, which was the sum of the S wave in V1 and the maximum R wave in lead V5 or V6 exceeding 3.5 mV.

4.5.3.5 Blood pressure

BP was measured according to the American Heart Association's recommendations (Pickering et al., 2005) using a similar validated, cutoff-style oscillometric (automated) device (Omron M6W, Kyoto, Japan) in each Sports and Exercise

Medicine Center. Resting BP was measured in a sitting position from the left arm after a 5-min rest. An appropriately sized brachial cuff was placed on the arm with the lower edge 2–3 cm above the elbow crease. The device recorded the oscillations of pressure in the cuff during gradual deflation. Systolic and diastolic pressures were estimated indirectly according to an empirically derived algorithm (Pickering et al., 2005). Two independent consecutive measurements were taken at an interval of 1 min. If there was > 10 mm Hg difference in systolic or diastolic pressure between the first and second measurements, a third reading was obtained after an interval of 1 min. The mean of these 2–3 measurements was calculated. The pulse pressure was calculated as the difference between systolic and diastolic pressure (Asmar et al., 2003). Elevated BP was defined as systolic BP equal to or higher than 120 mmHg or diastolic BP equal to or higher than 80 mmHg (Riley et al., 2018).

4.6 Statistical methods

In all studies, means were calculated for continuous variables, and the assumption of a normal distribution was confirmed by visual inspection for each continuous variable. Dichotomous variables are shown as numbers and percentages for SCPs and NPs, separately for each of the sexes. Odds ratios (ORs) and coefficients were reported with a 95% confidence interval (CI). All statistical analyses were two-sided, and a probability value of less than 0.05 was considered significant.

In studies I and II, the differences between SCPs and NPs were assessed using crosstabs and the chi-square and t-test when appropriate. In study IV, for continuous variables, either a normal or gamma distribution was used, depending on the normality of the outcome variable. For dichotomous variables, a binomial distribution was used to obtain ORs.

In study III, when testing interrater repeatability, the percentage agreement and Cohen's Kappa value were calculated. The thresholds of acceptable interrater reliability were defined as coefficient values corresponding to moderate reliability ($\varkappa \geq 0.4$), which were sufficient for observing human movement for screening purposes (Moran et al., 2016). A Kappa of 0.41–0.60 indicates moderate agreement, 0.61–0.80 indicates substantial agreement, and 0.81–1 indicates almost perfect agreement (Landis & Koch, 1977). The sample size also affects the interpretation of $\varkappa$ (Sim & Wright, 2005).

In study II, logistic regression was used to study the associations between injuries, sports participation, and sex. In studies I, III, IV, and V, a generalized linear mixed model (GLMM) or linear mixed model (LMM) was used. Multilevel data structure allowed for the clustering of values within each center and in studies I and V within the sport in which the SCP participated.

In all five studies, statistical analyses were performed using SPSS software (IBM SPSS statistics Version 22 for study II, v 24 for study III, v 25 for study V, and v 26 for studies I and IV.

4.7 Ethical issues

The study was carried out in conformance with the Declaration of Helsinki. A positive statement from the Ethics Committee of the Health Care District of Central Finland was received (record number 23U/2012). All SCs participated in the study of their own volition. This was secured by requesting club permission at the beginning of the study.

Written informed consent was requested from the participating youth for the questionnaire and health examination. Written consent on behalf of participants below the age of 16 was obtained from the parental/legal guardian. All respondents were notified that they had a right to refuse to participate and withdraw from the study at any time.

All permission papers included detailed information about the study. The consent for the health examination included five separate items: (1) approval for participation in the study and permission to use the information for research purposes, (2) permission for the information gathered in the surveys and preparticipation screening to be linked with existing nationwide health registers, (3) permission for the blood samples to be saved and analyzed over the next 15 years, (4) permission for the researchers to later contact the participant to ask if he/she would be interested in participating in a longitudinal study, and (5) permission for the information gathered in the study to be used in international research collaboration.

National and international standards and recommendations concerning research involving children and young people were followed. Specially trained staff members were responsible for the examinations and measurements, and measuring instruments were regularly calibrated. The personal data of the study participants were protected using code numbers.

5 RESULTS

5.1 Basic characteristics of study participants

The mean age of SCPs and NPs participating in the health examinations was similar (15.6 and 15.7 years). SCPs were slightly taller than NPs (171 cm vs 169 cm, $p = 0.001$). The mean height and weight of SCPs and NPs were similar when males and females were analyzed separately. Having a normal body mass index was more common in SCPs than NPs (87% vs 73%, $p < 0.001$). SCP females reached menarche at a higher age than NPs (12.6 years vs 12.3 years, $p = 0.013$). The basic characteristics of the study participants in the physical activity measurement and health examination are shown in Table 2. The mean amount of training for SCPs was approximately 9.5 hours per week.

Table 2. Basic characteristics of study participants participating in the health examination (Study III).

Statistically significant results are indicated in bold. The p-value indicates a difference between sports club participants (SCPs) and non-participants (NPs).

	Males (n=261)			Females (n=315)			Total (n=576)		
	SCP (n=198)	NP (n=63)	p-value	SCP (n=201)	NP (n=114)	p-value	SCP (n=399)	NP (n=177)	p-value
Age, years	15.7	15.7	0.451	15.6	15.6	0.619	15.6	15.7	0.491
Height, cm	175.6	173.7	0.073	166.8	165.9	0.231	**171.1**	**168.7**	**0.001**
Weight, kg	64.4	62.4	0.246	58.3	59.8	0.151	61.3	60.7	0.484
BMI[1] 18,5-24,9, %	**88.4**	**71.4**	**0.002**	**84.6**	**73.7**	**0.026**	**86.5**	**72.9**	**<0.001**
Age at menarche, mean				**12.6**	**12.3**	**0.013**			

[1] International revised child BMI (body mass index) cutoffs according to the IOTF (now known as the World Obesity Clinical Care) criteria were used, and the results are presented to correspond to the BMI cutoffs used from age 18 onwards, http://www.worldobesity.org/resources/child-obesity/newchildcutoffs/

5.2 Physical activity measured by accelerometry (I)

5.2.1 Meeting the physical activity recommendations

The percentage of SCPs participating in different sports and NPs who reached the PA recommendations was reported in three ways: reaching an average of 60 min of MVPA on each measuring day, accumulating 60 min of MVPA on each measuring day, and accumulating 60 min on MVPA on all but one measuring day. When looking at the daily mean MVPA time, 60 minutes was reached by 84.9% of SCPs and 45.3% of NPs ($p < 0.001$). Sixty minutes of MVPA each day was reached by 20.1% of SCPs and 5% of NPs ($p < 0.001$). Vigorous PA (> 6 MET) on at least three days was incorporated by 96.1% of SCPs and 80.6% of NPs ($p < 0.001$). When one resting day was accepted, the percentage of SCPs accumulating 60 min of MVPA each day was 48.9%. For comparing MVPA times and how PA recommendations are met between different sports disciplines and non-participants, see Table 3.

Table 3. Reaching the physical activity recommendations and daily average moderate to vigorous physical activity (MVPA) time in sports club participants and non-participants during all days (Study I).

		60 min MVPA per day, mean, (%)	p-value[1]	60 min MVPA each day (%)	p-value[1]	60 min MVPA, 1 rest day, (%)	p-value[1]	>6 MET at least 3x/ week, (%)	p-value[1]	Daily MVPA (min)	p-value[1]	p-value[2]
Soccer	Males (n=25)	96	<0.001*	8	0.82	48	0.02*	100	0.02*	110 ± 29	<0.001*	0.01*
	Females (n=18)	83	<0.001*	11	0.47	33	0.13	100	0.003*	84 ± 34	0.001*	
Floorball	Males (n=25)	96	<0.001*	8	0.82	72	<0.001*	100	0.02*	97 ± 21	0.001*	0.18
	Females (n=8)	88	<0.001*	13	0.56	38	0.21	88	0.55	83 ± 31	0.02*	
Basketball	Males (n=19)	90	0.001*	37	0.01*	68	<0.001*	95	0.12	123 ± 35	<0.001*	0.005*
	Females (n=8)	88	<0.001*	13	0.56	25	0.55	100	0.02*	81 ± 31	0.03*	
Ice hockey †	Males (n=31)	94	<0.001*	36	0.002*	52	0.004*	97	0.04*	103 ± 34	<0.001*	
Skating †	Females (n=26)	92	<0.001*	15	0.19	58	<0.001*	96	0.02*	83 ± 23	<0.001*	
Gymnastics	Females (n=29)	48	0.57	7	0.73	31	0.10	90	0.18	67 ± 24	0.22	
Track and field	Males (n=20)	90	0.001*	15	0.36	55	0.01*	100	0.02*	100 ± 37	<0.001*	0.26
	Females (n=21)	76	0.002*	29	0.02*	57	<0.001*	95	0.03*	86 ± 40	<0.001*	
Orienteering	Females (n=26)	85	<0.001*	23	0.01*	35	0.06	100	0.01*	83 ± 25	<0.001*	
Cross country skiing †	Males (n=13)	92	0.001*	39	0.03*	54	0.03*	85	0.79	114 ± 32	<0.001*	0.005*
	Females (n=15)	80	0.001*	33	0.03*	40	0.07	93	0.11	84 ± 22	0.001*	
Non-participants	Males (n=49)	51		6		20		81		65 ± 27		0.04*
	Females (n=90)	42		4		16		80		60 ± 24		

n = sample size, MVPA = moderate to vigorous physical activity, MET = metabolic equivalent, min = minutes,

* indicates statistical significance.

† indicates a sport that is not performed on foot, which underestimates the amount of vigorous PA

[1] indicates the p-value for statistical significance between sports club participants and non-participants.

[2] indicates the p-value for statistical significance between males and females.

5.2.2 Moderate to vigorous physical activity by sports discipline and gender

The daily time spent in MVPA in SCPs when comparing all days in males ranged from 123 ± 35 min in basketball players to 97 ± 21 min in floorball players. In females, it ranged from 84 ± 22 min in cross-country skiers to 67 ± 24 min in gymnasts. When looking at training days only, MVPA time among SCPs ranged from 153 ± 39 min in males and 109 ± 35 min in females participating in basketball to 113 ± 33 min in males participating in floorball and 83 ± 32 min in females participating in gymnastics. See Table 3.

During training days, males spent more time in MVPA than females participating in soccer (141 ± 35 min vs 100 ± 40 min, respectively, $p = 0.001$), basketball (153 ± 39 min vs 109 ± 35 min, respectively, $p = 0.01$), and cross-country skiing (129 ± 38 min vs 100 ± 21 min, respectively, $p = 0.02$). During non-training days, the time spent in MVPA was similar between males and females participating in sports clubs. During non-training days, males participating cross-country skiing and females participating in track and field spent more time in MVPA than NPs. See Table 4.

5.2.3 Intensity of physical activity during training days

The time spent in moderate PA (3–6 MET) during training days among males ranged from 117 ± 30 min in basketball players to 83 ± 20 min in floorball players and among females, from 85 ± 15 min in floorball players to 64 ± 25 min in orienteerers. The time spent in PA with an MET of 6–9 in SCP males ranged from 31 ± 14 min in soccer players to 6 ± 5 min in ice hockey players and among females, from 21 ± 16 min in soccer players to 6 ± 5 min in skaters. Time spent in very vigorous PA (> 9 MET) among males ranged from 12 ± 6 min in cross-country skiers to 4 ± 5 min in ice hockey players and among females, from 20 ± 12 min in orienteerers to 3 ± 5 min in gymnasts.
See Table 4.

Table 4. Daily time and intensity of physical activity on training days and non-training days in sports participants and non-participants (Study I).

		Training days									Non-training days		
		3–6 MET (min)	p-value[1]	6–9 MET (min)	p-value[1]	>9MET (min)	p-value[1]	MVPA (min)	p-value[1]	p-value[2]	MVPA (min)	p-value[1]	p-value[2]
Soccer	Males (n=25)	101 ±28	0.002*	31 ± 14	<0.001*	9 ± 6	0.01*	141 ± 35	<0.001*	0.002*	63 ± 43	0.90	0.75
	Females (n=18)	72 ±28	0.25	21 ± 16	<0.001*	7 ± 7	0.44	100 ± 40	0.009*		59 ± 28	0.74	
Floorball	Males (n=25)	83 ± 20	0.25	20 ± 12	<0.001*	10 ± 8	0.002*	113 ± 33	0.006*	0.51	78 ± 36	0.07	0.27
	Females (n=8)	85 ± 15	0.05*	12 ± 9	0.06	7 ± 8	0.44	104 ± 29	0.02*		61 ± 26	0.67	
Basketball	Males (n=19)	117 ± 30	<0.001*	29 ± 17	<0.001*	6 ± 4	0.19	153 ±39	<0.001*	0.01*	60 ± 32	0.93	0.59
	Females (n=8)	84 ± 27	0.04*	15 ± 10	0.002*	10 ± 11	0.10	109 ± 35	0.003*		53 ± 21	0.74	
Ice hockey†	Males (n=31)	102 ± 32	0.002	6 ± 5	0.86	4 ± 5	0.52	113 ± 36	0.003*		77 ± 36	0.09	
Skating†	Females (n=26)	78 ± 22	0.03*	6 ± 5	0.69	4 ± 4	0.65	88 ± 25	0.05		66 ± 29	0.14	
Gymnastics	Females (n=29)	71 ± 27	0.20	8 ± 8	0.11	3 ± 5	0.60	83 ± 32	0.11		46 ± 20	0.08	
Track and field	Males (n=20)	94 ± 31	0.02*	13 ± 7	0.02*	9 ± 8	0.01*	116 ± 40	0.002*	0.08	58 ± 28	0.81	0.24
	Females (n=21)	72 ± 36	0.16	9 ± 7	0.06	10 ± 8	0.02*	92 ± 46	0.02*		73 ± 37	0.01*	
Orienteering	Females (n=26)	64 ± 25	0.78	15 ± 9	<0.001*	20 ± 12	<0.001*	99 ± 27	0.002*		57 ± 30	0.93	
Cross country skiing†	Males (n=13)	107 ± 43	0.001*	11 ± 8	0.20	12 ± 6	0.002*	129 ± 38	<0.001*	0.02*	88 ± 44	0.02*	0.06
	Females (n=15)	80 ± 22	0.03*	14 ± 13	<0.001*	5 ± 6	0.81	100 ± 21	0.005*		59 ± 26	0.77	
Non-participants	Males (n=49)	68 ± 31		6 ± 7		3 ± 7		77 ± 32		0.06	61 ± 29		0.05*
	Females (n=90)	61 ± 27		5 ± 6		5 ± 6		71 ± 31			57 ± 24		

n = sample size

MVPA = moderate to vigorous physical activity

MET = metabolic equivalent, min = minutes

* indicates statistical significance. † indicates a sport that is not performed on foot, which underestimates the amount of vigorous and very vigorous PA

[1] indicates the p-value for statistical significance between sports club participants and non-participants.

[2] indicates the p-value for statistical significance between females and males.

5.2.4 Length of physical activity bouts

Basketball players attained significantly longer MVPA times during training days than during non-training days in all bout lengths (Figure 4). Among orienteerers, the difference between training and non-training days was significant in bouts of ten minutes or longer, and among cross-country skiers and soccer players, the difference was significant in bouts of three minutes or longer. Among gymnasts and floorball players, the difference between training and non-training days was significant in bouts shorter than 10 minutes (Figure 4).

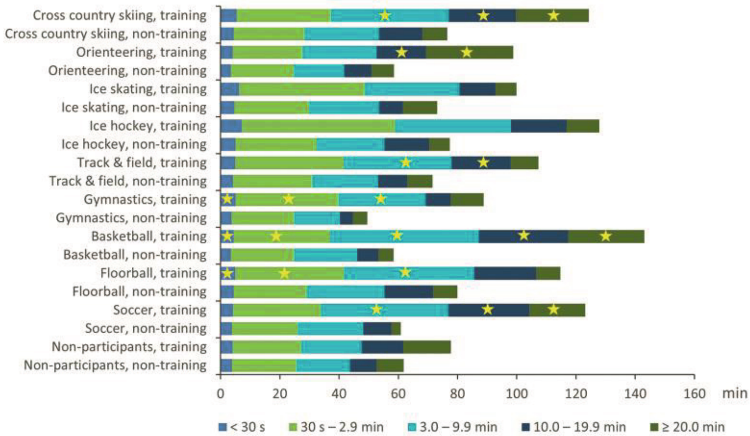

Figure 4. Comparison of the length of moderate to vigorous physical activity bouts between training and non-training days among males and females participating in different organized sports and non-participants using the one-minute exponential moving average (Study I).

Significant differences between training and non-training days are indicated with a star. Note: s = seconds, min = minutes

5.2.5 Accumulation of steps

The hour-by-hour figure of the daily accumulation of steps revealed that the difference between SCPs and NPs in step accumulation increased slightly earlier during the afternoon in males than females when looking at all days together and training days only. During non-training days, the accumulation of steps was similar between SCPs and NPs. The total average step count for SCPs and NPs together was 9,220 (SD 3,000) for males and 8,740 (SD 2,950) for females ($p = 0.03$). See Figure 5.

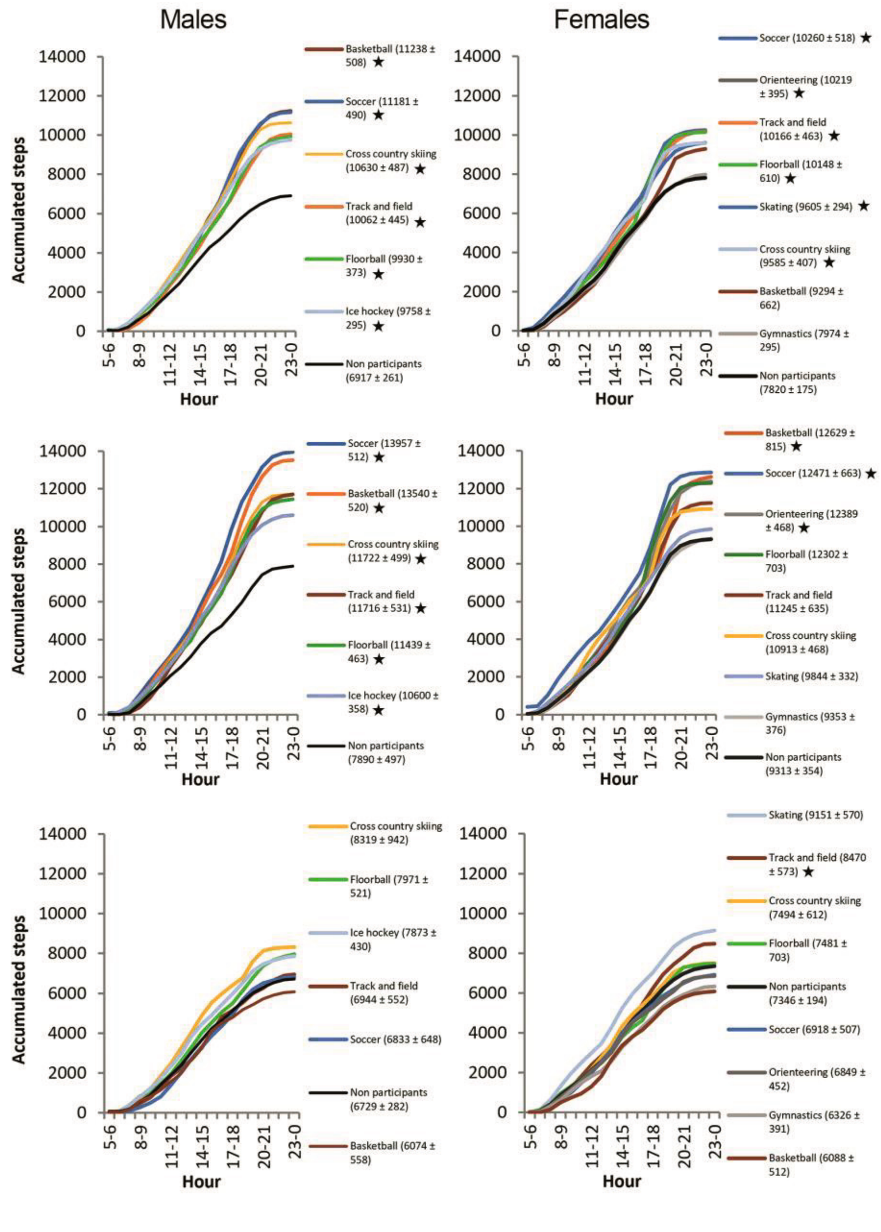

Figure 5. Daily accumulation of steps on all days (top row), training days (middle row), and non-training days (bottom row) (Study I).

Males are shown on the left side and females on the right side. Statistical significance between sports club participants and non-participants is shown with a star.

5.3 Acute and overuse injuries (II)

At least one acute or overuse injury was reported by 60% of SCPs and 31% of NPs within the past 12 months (sex-adjusted p < 0.001). At least one acute injury was reported by 44% of SCPs and at least one overuse injury by 35% of SCPs within the past 12 months. The difference in injury incidence between males and females was not statistically significant in SCPs or NPs. See Table 5. However, when adjusting for SC participation, males were more likely to report acute injuries than females (OR 1.31, 95% CI 1.08–1.59, p = 0.006). The difference between males and females was not statistically significant for reporting at least one overuse injury.

5.3.1 Occurrence of injuries

Training at least three times per week during the training season within the past year was reported by 84% of SCPs; in this group, the sex adjusted OR for reporting at least one acute injury was 3.49 (95% CI 2.81–4.34, p < 0.001) compared to NPs. Within this subgroup, the sex-adjusted OR for reporting at least one overuse injury was 2.84 (95% CI 2.26-3.56, p < 0.001). Among SCPs, adolescents participating in individual sports were less likely to report acute injuries than team and contact sports participants (OR 0.59, 95% CI 0.37–0.65, p < 0.001). For overuse injuries, the difference was not statistically significant between individual and team sports.

Table 5. Acute and overuse injuries by sports club participation (Study II).

	SCPs				NPs				
	All n=1077 (%)	Males n=549 (%)	Females n=528 (%)	P Value*	All n=812 (%)	Males n=345 (%)	Females n=467 (%)	P Value*	P Value#
At least one acute injury	474 (44.0)	256 (46.6)	218 (41.3)	0.077	161 (19.8)	73 (21.2)	88 (18.8)	0.413	<0.001
At least one overuse injury	378 (35.1)	188 (34.2)	190 (36.0)	0.550	141 (17.4)	51 (14.8)	90 (19.3)	0.095	<0.001
At least one acute or overuse injury	649 (60.3)	339 (61.7)	310 (58.7)	0.339	250 (30.8)	105 (30.4)	145 (31)	0.851	<0.001

*P values for statistical difference for the occurrence of injuries between males and females

#P values for statistical difference for the occurrence of injuries between sports club participants (SCPs) and non-participants (NPs) derived from logistic regression analysis adjusted for sex.

5.3.2 Anatomic location of injuries

The number and percentage of acute and overuse injuries in different anatomic locations is shown in Table 6. The most common location of an acute injury was the wrist and hand for both SCPs (13.6%) and NPs (15.1%). The second most common acute injury location was the ankle for SCPs and knee for NPs (11.7% and 11.0%, respectively). The third most common location for both groups was the foot (11.5% of SCP acute injuries and 9.9% of NP acute injuries).

The most common overuse injury location was the knee for SCPs (16.8%) and the wrist or hand for NPs (12.8%). The second most common overuse injury location for SCPs was the hip, groin, gluteal, and pelvis area (11.1%), followed by the wrist and hand (10.0%). The second most common overuse injury location for NPs was the foot (11.8%), followed by the knee (11.1%).

Table 6. The total number of acute and overuse injuries and percentages (%) in different anatomical locations among sports club participants (SCPs) and non-participants (NPs) (Study II).

	SCPs (n = 1077)			NPs (n = 812)			SCPs (n = 1077)			NPs (n = 812)		
	Number of acute injuries						Number of overuse injuries					
	n	%*	%**	n	%*	%**	n	%*	%**	n	%*	%**
Head	49	4.5	2.7	20	2.5	2.9						
Face. teeth. eye area	79	7.3	4.4	32	3.9	4.7						
Shoulder. upper arm. clavicle	121	11.2	6.8	44	5.4	6.4	46	4.3	4.3	32	3.9	5.5
Elbow. forearm	58	5.4	3.2	29	3.6	4.2	33	3.1	3.1	21	2.6	3.6
Wrist and hand	244	22.7	13.6	104	12.8	15.1	106	9.8	10.0	75	9.2	12.8
Neck. neck region	66	6.1	3.7	35	4.3	5.1	46	4.3	4.3	38	4.7	6.5
Upper back	35	3.2	2.0	19	2.3	2.8	29	2.7	2.7	20	2.5	3.4
Low back	85	7.9	4.7	38	4.7	5.5	94	8.7	8.9	42	5.2	7.2
Chest	33	3.1	1.8	19	2.3	2.8	18	1.7	1.7	12	1.5	2.0
Abdomen	29	2.7	1.6	17	2.1	2.5	15	1.4	1.4	13	1.6	2.2
Hip, groin, gluteals, pelvis	182	16.9	10.2	53	6.5	7.7	118	11.0	11.1	61	7.5	10.4
Thigh	109	10.1	6.1	32	3.9	4.7	80	7.4	7.6	37	4.6	6.3
Knee	170	15.8	9.5	76	9.4	11.0	178	16.5	16.8	65	8.0	11.1
Calf and shin	79	7.3	4.4	30	3.7	4.4	94	8.7	8.9	38	4.7	6.5
Ankle	210	19.5	11.7	57	7.0	8.3	70	6.5	6.6	46	5.7	7.8
Achilles tendon	35	3.2	2.0	15	1.8	2.2	28	2.6	2.6	18	2.2	3.1
Foot	206	19.1	11.5	68	8.4	9.9	104	7.8	9.8	69	8.5	11.8
All injuries	1790			688			1059			587		

*Percentage of SCPs and NPs having sustained an injury in this anatomical area

** Percentage of the injuries in each area out of all acute or overuse injuries among SCPs and NPs.

Among SCPs acute injuries to certain areas were more common among males than females, these were the thigh (8.9% vs. 4.9%, p = 0.016), hip, groin, gluteal, and pelvis area (11.3% vs. 6.3%, p = 0.008), and chest area (4.0% vs 1.7%, p = 0.028). In the NP group, males reported more acute injuries to the shoulder, upper arm, and clavicle area than females (4.6% vs 1.7%, p = 0.018). Females participating in sports reported more overuse injuries of the wrist and hand than males (7.4% vs 4.2%, p = 0.034).

5.3.3 Injury types

Sprain injuries were the most common acute injury type in both groups: 31.6% of SCPs reported a sprain injury in the past 12 months compared to 13.5% of NPs (p < 0.001). Contusions/bruises to areas other than the head were the second most common type of injury in both groups (SCPs 17.1% vs. NPs 7.6%, p < 0.001). The third most common acute injury type in SCPs was a muscle injury, and it was reported more often by SCPs than NPs (13.5% vs. 4.7%). Among NPs, 4.8% reported sustaining a fracture within the past year, this being the third most common type of acute injury for this group.

The most common overuse injury type was muscle injury in both groups; 16.6% of SCPs and 10.1% of NPs reported at least one muscle injury (p < 0.001). Overuse injuries of the bone were more prevalent among SCPs than NPs (9.8% vs. 4.7%, p < 0.001). However, no statistically significant difference was seen in stress fractures between SCPs and NPs (2.9% vs. 1.6%, p = 0.075).

5.3.4 Injury-related factors

Setting. The most common setting for acute injuries in SCPs was organized training (25.4%), followed by matches or competitions (22.2%). Acute injuries in matches or competitions were more common in SCP males than females (27.7% vs. 16.5%, p < 0.001). There was no difference between SCPs and NPs in acute injuries occurring during leisure time activities (16.0% vs. 17.1%) or school sports (7.4% vs. 7.0%). Among NPs, males were more likely to report an acute injury during leisure time activities than females (21.2% vs. 14.1%, p = 0.028).

Cause. In both groups, the main cause for an acute injury was falling/ stumbling (SCPs 16.8% vs. NPs 10.3%, p < 0.001). In the SCP group, other common reasons for an acute injury were tackling (11.0% vs. 2.3%, $p < 0.001$ compared to NPs) and running (10.3% vs. 4.3%, $p < 0.001$).

Training history and habits. For those with training history for more than five years and training at least twice a week, the sex-adjusted OR for an acute injury was 1.38 compared to those who had trained actively for 0–4 years ($p = 0.029$). Adolescents with weekly training for 7–14 h during the training season were 1.61-fold more likely to report an acute injury ($p = 0.001$) compared to adolescents who trained 3–6 h per week. Having an overuse injury was 1.63-fold more likely ($p = 0.001$) in adolescents who trained 7–14 h weekly during the preceding training season compared to those training 3–6 h.

Competitions. SCPs with 40 competitions or more per year were more likely to report an acute injury compared to those having 7–19 competitions a year, $p = 0.028$. This was observed among males ($p = 0.007$) but not among females ($p = 0.809$). The mean number of competitions in the past 12 months was higher among males than females (30.1 vs. 15.1, $p < 0.001$). Adolescents participating in at least 40 competitions annually were significantly more likely to report an overuse injury ($p = 0.038$) compared to those participating in 7–19 competitions.

Self-reported physical activity. We found that among all adolescents, the probability of an acute injury for those who reported 'PA for about 30 min per week' was 7.8-fold ($p = 0.007$) and for those who reported '7 h or more PA per week' it was 20.3-fold ($p < 0.001$) compared to those who reported 'no PA.' When we included SC participation in the model, the sex-adjusted probability for reporting an acute injury for NPs who reported '7 h or more PA per week' was 10.1-fold ($p = 0.002$) and for SCPs it was 2.4-fold ($p < 0.001$) compared to those reporting 'no PA.'

The probability of reporting an overuse injury among all adolescents for those who reported 'PA for about 30 min per week' was 3.7-fold ($p = 0.045$) compared to those not reporting any PA, and the likeliness increased with increasing PA. For those who reported '7 h or more PA per week,' it was 9.8-fold ($p < 0.001$) compared to those who reported 'no PA.' When we included SC participation in the model, the sex-adjusted probability for reporting an overuse injury for NPs who reported '7 h or more PA per week' was 6.5-fold higher ($p = 0.002$) and for SCPs, it was 1.7-fold higher ($p < 0.001$) compared to those reporting 'no PA.'

5.4 Repeatability and results of the musculoskeletal examination (III)

5.4.1 Interrater repeatability

Posture. The interrater repeatability for evaluating iliac crest height asymmetry was almost perfect (ϰ 0.93), and the interrater repeatability for shoulder protrusion was substantial (ϰ 0.63). The following posture tests had moderate interrater agreement: a scoliometer reading of ≥ 3° at the acromioclavicular-joint (ϰ 0.56) and ≥ 3° from the back (0.58). The percentage of agreement for scoliosis ≥ 7° from the back was 81% (ϰ 0.09).

Mobility. The interrater repeatability was substantial for marked iliopsoas tightness on both sides (ϰ 0.66). The following mobility tests had moderate interrater repeatability: the shoulder mobility test (ϰ 0.42), Beighton and Horan mobility index (ϰ 0.47), and heels lifted from the floor in the deep squat test (ϰ 0.55).

Movement control. The deep squat test as a whole had substantial interrater repeatability (ϰ 0.66), and the repeatability was best for receiving the highest score (ϰ 0.81). The VDJ test as a whole had moderate interrater repeatability (ϰ 0.45), and the repeatability was substantial for poor control (ϰ 0.66). The one-leg stance test had moderate interrater repeatability (ϰ 0.48–0.60). A ϰ value of ≥ 0.4 was not obtained in the 30 s plank test; however, agreement was > 80%. The Kappa value for the navicular drop test was < 0.40 and agreement was < 80%.

See Table 7 for agreement (%) and Kappa-values for the musculoskeletal tests.

Table 7. Interrater repeatability of musculoskeletal tests (Study III).

Test	Agreement (%)	Kappa value
Shoulder posture		
Shoulder protrusion on one or both sides	68	0.63
Scoliometer reading ≥ 3° at the acromioclavicular-joint level (yes/no)	83	0.56
Forward bend		
Scoliometer reading ≥ 3° from the back	73	0.58
Scoliometer reading ≥ 7° from the back	81	0.09
Asymmetry in iliac crest height	97	0.93
Shoulder mobility	68	0.42
Good	76	0.49
Satisfactory	81	0.22
Poor	81	0.47
Modified Thomas test		
Marked iliopsoas tightness on one side	93	0.36
Marked iliopsoas tightness on both sides	90	0.66
Navicular drop		
Side-to-side difference ≥ 2 mm	66	0.30
≥ 10 mm	71	0.15
Generalized joint laxity	81	0.47
30 second plank	85	0.32
Deep squat	81	0.66
Highest score	93	0.81
Middle score	81	0.60
Lowest score	88	0.55
Trendelenburg sign positive	63	-0,13
One leg stance		
>2 cm side-to-side difference	83	0.48
≥13 cm	83	0.60
Vertical drop jump	61	0.45
Good control	71	0.35
Impaired control	71	0.41
Poor control	90	0.66

Posture. Having one shoulder protruded (8.0% vs 4.0%, OR 2.81, 95% CI 1.16–6.81) was more common in SCPs than in NPs. In males, having iliac crests at different levels was less common in SCPs than NPs (14.9% vs 31.1%) (OR 0.43, 95% CI 0.21–0.89). See Table 8.

Table 8. Posture differences between sports participants (SCPs) and non-participants (NPs) (Study III).

Statistically significant results are indicated in bold.

Test	Males (n=261)			Females (n=315)			Total (n=576)		
	SCP (n=198)	NP (n=63)	OR (95% CI)	SCP (n=201)	NP (n=114)	OR (95% CI)	SCP (n=399)	NP (n=177)	OR (95% CI)
Shoulder Posture									
One shoulder protruded (%)	7.6	1.6	7.29 (0.905–9.30)	8.5	5.3	1.94 (0.69–5.46)	**8.0**	**4.0**	**2.81 (1.16–6.81)**
Both shoulders protruded (%)	32.3	28.6	1.13 (0.58–2.20)	21.4	14.9	1.33 (0.69–2.57)	26.8	19.8	1.34 (0.85–2.12)
Scoliometer reading ≥3° at AC- joint level (%)	16.7	20.6	0.76 (0.37–1.57)	13.9	12.3	1.15 (0.58–2.29)	15.3	15.3	1.00 (0.61–1.64)
Forward Bend									
Scoliometer reading ≥3° at back (%)	41.4	49.2	0.73 (0.41–1.30)	41.8	41.2	1.23 (0.75–2.02)	41.6	44.1	0.97 (-0.67–1.40)
Scoliometer reading ≥7° at back (%)	4.0	6.3	0.74 (0.23–2.34)	5.0	4.4	1.10 (0.40–2.93)	4.5	5.1	0.93 (0.44–1.96)
Asymmetry in iliac crest height (%)	**14.9**	**31.1**	**0.43 (0.21–0.89)**	14.1	9.3	1.68 (0.74–3.82)	14.5	17.2	0.90 (0.53–1.53)

AC = acromioclavicular

Mobility. Among males, poor shoulder mobility was less common in SCPs than NPs (30.3% vs 46.0%, OR 0.54, 95% CI 0.29– 0.99). See Table 9. Limited ankle mobility in the deep squat test was less common in SCPs than NPs; 21.8% of SCPs compared with 37.3% of NPs were not able to perform the deep squat test with heels remaining on the floor (OR 0.48, 95% CI 0.32–0.71). See Table 10.

Table 9. Mobility differences between sports participants (SCPs) and non-participants (NPs) (Study III).

Statistically significant results indicated in bold.

Test	Males (n=261)			Females (n=315)			Total (n=576)		
	SCP (n=198)	NP (n=63)	OR (95% CI)	SCP (n=201)	NP (n=114)	OR (95% CI)	SCP (n=399)	NP (n=177)	OR (95% CI)
Shoulder Mobility									
Good (%)	42.4	33.3	1.31 (0.70–2.45)	64.2	62.3	1.07 (0.63–1.81)	53.6	52.0	0.97 (0.66–1.43)
Satisfactory (%)	25.8	20.6	1.37 (0.68–2.76)	17.9	14.0	1.17 (0.61–2.36)	21.8	16.6	1.39 (0.86–2.24)
Poor (%)	**30.3**	**46.0**	**0.54 (0.29–0.99)**	16.9	23.7	0.78 (0.42–1.43)	23.6	31.6	0.75 (0.50–1.14)
Modified Thomas Test									
Marked iliopsoas tightness on one side (%)	5.6	1.6	1.77 (0.42–7.41)	5.0	3.5	1.23 (0.44–3.44)	5.3	2.8	1.40 (0.62–3.19)
Marked iliopsoas tightness on both sides (%)	27.3	23.8	1.14 (0.55–2.37)	12.4	13.2	0.87 (0.41–1.84)	19.8	16.9	1.24 (0.75–2.05)
Generalized Joint Laxity (%)	11.6	11.1	0.97 (0.37–2.57)	45.7	40.7	1.51 (0.91–2.51)	28.7	30.1	0.99 (0.66–1.50)

Movement control. SCPs had better core muscle control, with 86.3% being able to remain in the correct plank position for 30 s compared with 68.6% of NPs (OR 2.70, 95% CI 1.67–4.36). In the deep squat test, good lumbar spine control was maintained similarly in both groups (in 35.8% of SCPs and 38.4% of NPs). Of SCPs and NPs, 41.6% and 22.6%, respectively, were able to perform the deep squat test with heels remaining on the floor when lumbar spine control was not assessed (OR 2.52, 95% CI 1.65–3.86).

In the one-leg stance test, SCP females showed better lateral control of the trunk, and 7.5% had lateral movement of ≥ 13 cm compared with 13.2% of NP females (OR 0.38, 95% CI 0.15–0.94). Good knee control was more common in SCPs than NPs (45.9% vs 31.6% respectively, OR 1.99, 95% CI 1.29–3.06). Of SCPs, 12% had poor knee control in the two-legged VDJ test compared with 26% of NPs (OR 0.36, 95% CI 0.22–0.58). See Table 10.

Table 10. Movement control differences between sports club participants (SCPs) and non-participants (NPs) (Study III).

Statistically significant results are indicated in bold.

Test	Males (n=261)			Females (n=315)			Total (n=576)		
	SCP (n=198)	NP (n=63)	OR (95% CI)	SCP (n=201)	NP (n=114)	OR (95% CI)	SCP (n=399)	NP (n=177)	OR (95% CI)
Able to Perform 30 Second Plank (%)	**85.1**	**66.7**	**2.84 (1.36–5.93)**	**87.4**	**69.6**	**2.60 (1.36–4.95)**	**86.3**	**68.6**	**2.70 (1.67–4.36)**
Deep Squat									
Highest score (%)	36.4	39.7	0.87 (0.47–1.61)	35.3	37.7	0.91 (0.53–1.56)	35.8	38.4	0.87 (0.58–1.29)
Middle score (%)	**42.9**	**25.4**	**2.42 (1.24–4.73)**	**40.3**	**21.1**	**2.39 (1.36–4.20)**	**41.6**	**22.6**	**2.52 (1.65–3.86)**
Lowest score (%)	**20.7**	**34.9**	**0.46 (0.24–0.88)**	**22.9**	**38.6**	**0.49 (0.30–0.83)**	**21.8**	**37.3**	**0.48 (0.32–0.71)**
One Leg Stance									
>2 cm side-to-side difference (%)	12.6	7.9	1.68 (0.60–4.70)	10.0	11.4	0.89 (0.43–1.84)	11.3	10.2	1.16 (0.66–2.06)
≥13 cm on one side (%)	5.6	0.0		5.5	3.5	1.62 (0.49–5.41)	5.5	2.3	2.38 (0.79–7.17)
≥13 cm on both sides (%)	6.6	3.2	1.38 (0.28–6.84)	**7.5**	**13.2**	**0.38 (0.15–0.94)**	7.0	9.6	0.53 (0.26–1.09)
Vertical Drop Jump									
Good control (%)	53.0	46.0	1.17 (0.84–3.37)	**38.8**	**23.7**	**1.99 (1.11–3.56)**	**45.9**	**31.6**	**1.99 (1.29–3.06)**
Impaired control (%)	40.4	36.5	1.09 (0.55–2.16)	41.8	43.9	1.02 (0.63–1.65)	41.1	41.2	1.07 (0.73–1.58)
Poor control (%)	**5.6**	**15.9**	**0.28 (0.11–0.73)**	**18.4**	**31.6**	**0.47 (0.27–0.83)**	**12.0**	**26.0**	**0.36 (0.22–0.58)**

5.5 Lung function, hemoglobin, and iron status (IV)

5.5.1 Respiratory symptoms, medication use, and lung function

SCPs tended to use asthma medication more frequently than NPs (9.8% vs 5.2%); the difference was not statistically significant (OR 1.74, 95% CI 0.86–3.53). In baseline spirometry, a low FEV%, suggestive of pulmonary obstruction, was found in 16.5% of SCPs and 15.3% of NPs. A significant bronchodilator response was observed in 7% of SCPs and 6.4% of NPs (OR 1.17, 95% CI 0.54–2.54); those using asthma medication were excluded from the analysis. Females who reported dyspnea during exercise were more likely to have a significant bronchodilator response in flow-volume spirometry (OR 3.17, 95% CI 1.12–9.02). When jointly analyzing males and females, this finding was not statistically significant (OR 2.05, 95% CI 0.80–5.27). None of the 13 males who reported dyspnea during exercise had a significant bronchodilator response. A recurrent skin rash was less common in SCPs than NPs (15.1% vs 23.6%, OR 0.63, 95% CI 0.40–0.99). More than three respiratory tract infections per year were reported by 36% of SCPs and NPs. See table 11.

Table 11. Respiratory symptoms, medication use, and lung function in sports club participants (SCPs) and non-participants (NPs) (Study IV). Statistically significant results are indicated in bold.

	Males (n=261)			Females (n=317)			Total (n=578)		
Number of missing results in brackets below	SCPs (n=199)	NPs (n=62)	OR (95% CI)	SCPs (n=203)	NPs (n=114)	OR (95% CI)	SCPs (n=402)	NPs (n=176)	OR (95% CI)
Asthma in family, n, (%), (15)	83 (43.2)	30 (50.0)	0.76 (0.43–1.37)	99 (49.7)	66 (58.9)	0.69 (0.43–1.10)	182 (46.5)	96 (55.8)	0.72 (0.50–1.03)
Regular use of allergy medication[1], n, (%), (5)	42 (21.3)	13 (21.3)	0.99 (0.49–2.00)	39 (19.3)	15 (13.3)	1.51 (0.78–2.92)	81 (20.3)	28 (16.1)	1.26 (0.78–2.05)
Regular use of asthma medication, n, (%), (5)	16 (8.1)	4 (6.6)	1.20 (0.40–3.58)	23 (11.4)	5 (4.4)	2.65 (0.97–7.27)	39 (9.8)	9 (5.2)	1.74 (0.86–3.53)
Recurrent respiratory tract infections[2], n, (%), (9)	63 (32.1)	21 (35.0)	0.88 (0.48–1.62)	80 (40.0)	42 (37.2)	1.13 (0.70–1.82)	143 (36.1)	63 (36.4)	1.03 (0.71–1.50)
Recurrent skin rash, n, (%), (7)	21 (10.7)	10 (16.4)	0.60 (0.26–1.36)	39 (19.4)	31 (27.4)	0.64 (0.37–1.11)	**60 (15.1)**	**41 (23.6)**	**0.63 (0.40–0.99)**
Dyspnea during exertion, n, (%) (19)	18 (8.4)	9 (14.8)	0.62 (0.26–1.46)	45 (23.1)	21 (18.8)	1.30 (0.73–2.33)	63 (16.3)	30 (17.3)	1.04 (0.64–1.69)
Pulmonary obstruction (FEV% z-score <-1.65, n, (%), (63)	33 (18.9)	13 (22.8)	0.75 (0.36–1.56)	25 (14.1)	12 (11.3)	1.29 (0.62–2.71)	58 (16.5)	25 (15.3)	1.07 (0.64–1.78)
Significant bronchodilator response (FEV1 or FVC ≥+12%, (84)	13 (7.6)	3 (5.6)	1.43 (0.38–5.41)	11 (6.4)	7 (6.9)	0.95 (0.37–2.43)	24 (7.0)	10 (6.4)	1.17 (0.54–2.54)

FEV = forced expiratory volume, FVC = forced vital capacity

1 Antihistamine in the spring. For example, nasal corticosteroid if used together with antihistamine, allergy eye medication, medication for hyposensitization

2 Common cold, sore throat, rhinitis, or bronchitis more than three times per year

5.5.2 Hemoglobin and iron status

Hemoglobin < 120/130 was present in 5.8% of SCPs and 5.1% of NPs (OR 1.20, 95% CI 0.54 to 2.68). Ferritin concentrations < 15 μg/L was found in 22.7% of both SCP and NP females. Ferritin < 30 μg/l was found in 26.5% of SCP males and 30.2% of NP males (OR 0.76 (95% CI 0.40-1.47). The use of an iron supplement was rare in all groups. The hemoglobin values, iron parameters and iron supplement use are presented in more detail in Table 12.

Table 12. Clinical laboratory data and iron supplement use in sports club participants (SCP) and non-participants (NP) (Study IV).

	Males (n=261)			Females (n=317)			Total (n=578)		
Number of missing results in brackets	SCPs (n=199)	NPs (n=62)	Coefficient/ OR (95% CI)	SCPs (n=203)	NPs (n=114)	Coefficient/ OR (95% CI)	SCPs (n=402)	NPs (n=176)	Coefficient/ OR (95% CI)
Hemoglobin, mean (6)	147	149	-0.01 (-0.03–0.004)	132	132	-0.00 (-0.02–0.01)	140	138	0.01 (-0.01–0.02)
Hemoglobin < 120/130	7 (3.5)	1 (1.6)	1.34 (0.31–5.79)	16 (8.1)	8 (7.1)	1.19 (0.49–2.92)	23 (5.8)	9 (5.1)	1.20 (0.54–2.68)
Ferritin, mean, (17)	47	44	0.08 (-0.07–0.24)	31	32	-0.03 (-0.19–0.13)	39	36	0.08 (-0.04–0.19)
Ferritin <30, n, (%)	49 (26.5)	19 (30.2)	0.76 (0.40–1.47)	117 (60.3)	62 (56.4)	1.15 (0.71–1.86)	166 (43.8)	81 (46.8)	0.86 (0.60–1.23)
Ferritin <15, n, (%)	9 (4.9)	5 (7.9)	0.67 (0.23–1.99)	44 (22.7)	25 (22.7)	1.02 (0.58–1.79)	53 (14)	30 (17.3)	0.77 (0.47–1.27)
Transferrin receptor, mean (11)	3.28	3.18	0.03 (-0.04–0.10)	3.14	3.09	0.01 (-0.08–0.11)	3.35	3.30	0.01 (-0.05–0.08)
Elevated transferrin receptor, n, (%)	7 (3.7)	1 (1.6)	1.37 (0.32–5.97)	29 (14.9)	11 (10.0)	1.52 (0.73–3.18)	36 (9.4)	12 (6.9)	1.30 (0.67–2.51)
Use of iron supplement (%), (5)	3 (1.5)	0	1.30 (0.24–6.97)	7 (3.5)	0	1.75 (0.49–6.28)	10 (2.5)	0	1.56 (0.56–4.34)

OR = odds ratio

5.6 Resting electrocardiogram and blood pressure (V)

5.6.1 Resting electrocardiogram

Resting ECG characteristics of SCPs participating in endurance sports, non-endurance sports, and NPs are presented in Table 13. There were no differences in the mean resting HR, PR interval, QRS duration, QRS axis, QRS amplitude, T axis, or corrected QT interval between SCPs participating in endurance and non-endurance sports ($p > 0.05$). The resting HR of endurance ($p < 0.001$) and non-endurance ($p < 0.001$) SCPs was lower than that in NPs. The PR interval was longer in endurance SCPs than NPs ($p = 0.05$). The QRS amplitude was higher in non-endurance SCPs ($p = 0.03$) but not in endurance SCPs ($p = 0.06$) when compared to non-athletes. Endurance (2.85, 1.81–4.50) and non-endurance SCPs (2.19, 1.43–3.35) were more likely to have sinus bradycardia than NPs.

Sex modified the difference in resting HR between non-endurance SCPs and NPs ($p = 0.04$). The mean difference in resting HR between non-endurance SCPs and NPs was 7.5 (± 1.6) and 2.6 (± 1.6) beats per minute in males and females, respectively. Similarly, sex modified the difference in bradycardia between non-endurance SCPs and NPs ($p = 0.03$).

Table 13. Resting electrocardiogram characteristics in sports club participants (SCPs) in endurance sports, non-endurance sports, and non-participants (NPs) (Study V).

Values are mean ± SD or number (%).

	Endurance SCPs (n=169)	Non-endurance SCPs (n=241)	NPs (n=164)	P-value/ OR (95% CI)[1]	P-value/ OR (95% CI)[2]	P-value/ OR (95% CI)[3]
Heart rate, beats/min	60.0 ± 8.9	61.0 ± 10.7	66.6 ± 12.1	p=0.35	**p=<0.001**	**p=<0.001**
PR interval, ms	150.6 ± 20.5	148.9 ± 22.4	146.2 ± 19.0	p=0.41	**p=0.05**	p=0.20
QRS duration, ms	91.4 ± 9.2	92.0 ± 10.2	89.4 ± 8.3	p=0.58	p=0.32	p=0.15
QRS axis, degrees	64.6 ± 32.4	65.0 ± 21.9	65.1 ± 26.6	p=0.89	p=0.86	p=0.96
T axis, degrees	35.7 ± 16.6	36.7 ± 14.8	38.2 ± 15.7	p=0.53	p=0.14	p=0.33
Corrected QT interval, ms	415.2 ± 25.6	413.4 ± 34.7	414.2 ± 23.7	p=0.54	p=0.76	p=0.78
QRS amplitude, mm	27.0 ± 8.3	27.2 ± 8.3	23.6 ± 7.1	p=0.69	p=0.06	**p=0.03**
Sinus bradycardia, n (%)	89 (52.7)	111 (46.1)	46 (28.0)	0.77 (0.52–1.14)	**2.85 (1.81–4.50)**	**2.19 (1.43–3.35)**
Prolonged PR interval, n (%)	4 (2.4)	4 (1.7)	1 (0.6)	0.97 (0.61–1.52)	1.09 (0.66–1.79)	1.05 (0.67–1.67)
Widened QRS complex, n (%)	0 (0.0)	1 (0.4)	0 (0.0)	1.02 (0.65–1.61)	1.00 (0.61–1.64)	1.02 (0.65– 1.62)
Left QRS axis deviation, n (%)	7 (4.1)	4 (1.7)	3 (1.8)	0.69 (0.27–1.77)	1.41 (0.50–3.99)	0.97 (0.35–2.74)
Right QRS axis deviation, n (%)	2 (1.2)	1 (0.4)	0 (0.0)	0.96 (0.61–1.52)	1.06 (0.64–1.74)	1.02 (0.65–1.62)
Left T axis deviation, n (%)	0 (0.0)	1 (0.4)	0 (0.0)	1.02 (0.65–1.61)	1.00 (0.61–1.65)	1.02 (0.65–1.62)
Prolonged corrected QT interval, n (%)	9 (5.3)	17 (7.1)	4 (2.4)	1.09 (0.69–1.72)	1.15 (0.70–1.89)	1.25 (0.79–1.98)
Left ventricular hypertrophy, n (%)	26 (15.4)	34 (14.1)	14 (8.5)	0.94 (0.60–1.48)	1.40 (0.85–2.29)	1.31 (0.83–2.08)
Short PR interval, n (%)	2 (1.2)	17 (7.1)	9 (5.5)	1.33 (0.85–2.10)	0.81 (0.49–1.33)	1.08 (0.68–1.71)
Left anterior hemiblock, n (%)	1 (0.6)	0 (0.0)	0 (0.0)	0.97 (0.62–1.53)	1.03 (0.63–1.69)	1.00 (0.63–1.58)
Left posterior hemiblock, n (%)	1 (0.6)	1 (0.4)	0 (0.0)	0.99 (0.63–1.56)	1.03 (0.63–1.69)	1.02 (0.65–1.62)

ms = millisecond.

1 indicates the statistical significance between endurance and non-endurance SCPs,

2 indicates the statistical significance between endurance SCPs and NPs, and

3 indicates the statistical significance between non-endurance SCPs and NPs

5.6.2 Blood pressure

The resting BP of endurance and non-endurance SCPs and NPs is presented in table 14. There were no differences in systolic BP, diastolic BP, or pulse pressure between endurance and non-endurance SCPs ($p > 0.05$). Systolic BP was higher in non-endurance SCPs than in NPs ($p = 0.04$). Diastolic BP in endurance ($p = 0.002$) and non-endurance SCPs ($p = 0.02$) was lower than in NPs. The pulse pressure in non-endurance SCPs was higher than in NPs ($p = 0.04$), but there was no difference between endurance SCPs and NPs ($p = 0.07$). Non-endurance SCPs were more likely to have elevated systolic BP than endurance SCPs (OR 1.70, 95% CI 1.07–2.72) and NPs (OR 1.73, 95% CI 1.04–2.87). There was no difference in the prevalence of elevated diastolic BP between the groups. Sex did not modify the difference in any of the BP variables ($p > 0.05$).

Table 14. Resting blood pressure in sports club participants (SCPs) in endurance sports, non-endurance sports, and non-participants (NPs) (Study V).

Values are mean ± SD or number (%).

	Endurance SCPs (n=169)	**Non-Endurance SCPs (n=241)**	**NPs (n=164)**	**P-value/ OR (95% CI)[1]**	**P-value/ OR (95% CI)[2]**	**P-value/ OR (95% CI)[3]**
Systolic blood pressure, mmHg	114.3 ± 9.7	115.7 ± 10.6	113.5 ± 10.2	0.19	0.48	**0.04**
Diastolic blood pressure, mmHg	64.1 ± 7.1	64.8 ± 7.8	66.1 ± 7.8	0.36	**0.002**	**0.02**
Pulse pressure, mmHg	47.4 ± 9.8	48.0 ± 10.0	44.9 ± 9.7	0.85	0.07	**0.04**
Elevated systolic blood pressure, n (%)	42 (24.9)	87 (36.1)	41 (25.0)	**1.70 (1.07–2.72)**	1.01 (0.58–1.78)	**1.73 (1.04–2.87)**
Elevated diastolic blood pressure, n (%)	4 (2.4)	7 (2.9)	6 (3.7)	1.03 (0.65–1.62)	0.94 (0.57–1.54)	0.96 (0.61–1.53)

1 indicates the statistical significance between endurance and non-endurance SCPs,

2 indicates the statistical significance between endurance SCPs and NPs, and

3 indicates the statistical significance between non-endurance SCPs and NPs

6 DISCUSSION

6.1 Physical activity in adolescents

As expected, adolescents participating in many organized sports in SCs accumulated more PA than NPs; this was observed in meeting the PA recommendations, total amount of PA at different intensities, and step count. Eighty-five percent of SCPs and 45% of NPs reached the current Finnish and WHO PA recommendation of at least an average of 60 minutes per day of MVPA. However, it is recommended that athletes have at least one resting day from training or competition every week. When one resting day was accepted, the percentage of SCPs accumulating 60 min of MVPA each day was 48.9%.

Participation in organized sports is popular among Finnish adolescents, with 69% of 7–14-year-olds reportedly taking part in SC activities. However, participation declines with increasing age (Husu et al., 2016). In a recent accelerometer-based study of Finnish adolescents, 13–15-year-old males took an average of 9,270 steps per day and females took 8,836 steps; the number of daily steps was found to decrease with increasing age (Vasankari et al., 2020). Based on accelerometer measurements carried out in Canada in 2014–2015, 33.2% of young people aged 6–17 attained, on average, 60 min of MVPA per day, and 5.5% attained this every day (Colley et al., 2017). Similar results were found in our study. In a recent survey of Finnish 9th grade adolescents, 18% reported 60 minutes of daily MVPA, and 30% reported 60 minutes of MVPA on 5–6 days per week; males were more likely than females to report MVPA every day (Mehtälä et al., 2020).

In many studies, males have been found to be more physically active than females (Colley et al., 2017; Husu et al., 2016; Vasankari et al., 2020). This was also found in our study when combining all days and on training days alone in adolescents participating in soccer, basketball, and cross-country skiing. During non-training days, there was no difference between males and females in the average daily time spent in MVPA. The difference in MVPA accumulation between males and females was observable in soccer, basketball, and cross-country skiing. For example, males participating in basketball spent, on average, 42 min more in MVPA daily than females, which would result in 5 h 45 min per week or about 255 h/year.

Participation in organized sports contributes to achieving the daily PA recommendations, especially among males (Marques et al., 2016).

Organized sports participation has been found to be associated with better cardiovascular endurance in 10–16 year old adolescents (Carlisle et al., 2019). The differences in PA behavior between different individuals is largely explained by biological and genetic factors, in addition to social and environmental determinants, such as participation in organized sports (Lightfoot et al., 2018). In our study, more than 80% of all adolescents accumulated vigorous PA on at least three days during the measurement period. This was measured using the 1-minute analysis period, enabling relatively short bouts of vigorous PA to become detectable.

There was variety in the sport in which sports participants reached the highest levels of PA, depending on the intensity that was examined. The length of the analysis period used when measuring PA with accelerometry deserves attention due to the different kinetics of the cardiorespiratory, endocrine, and metabolic responses (Caspersen et al., 1985; De Feo et al., 2003; Phillips et al., 1995). We chose to look at the 1-min exponential moving average because we did not want to include very short bouts of PA. The length of accumulated activity time becomes longer when a shorter analysis period is used, owing to the fact that shorter bouts of PA subsequently become detectable.

The amount of PA recorded in a specific sport also depends on the characteristics of the sport, the size of the area it is performed on, and the time of the training season. When comparing PA levels between athletes participating in different sports, the varying demands of the sport also need to be considered. The length of activity bouts found in this study reflect the type of training carried out in each sport during the measurement period.

In a study comparing PA across different domains in children, school hours contributed to 46% of the objectively measured MVPA, whereas sporting activities contributed to only 24% (Sprengeler et al., 2017). In this study, we found that the differences between SCPs and NPs were greater in the evening, especially on training days. Furthermore, the difference between SCPs and NPs in step accumulation increased slightly earlier during the afternoon in males than females when looking at all days together and training days alone. This could be explained by females spending more time with homework after school and by later training hours.

6.2 Adolescents' sports injuries

Sixty percent of SCPs and 30% of NPs reported at least one acute or overuse injury in the past 12 months. The probability of sustaining an acute or overuse injury increased with the increasing number of training hours and competitions among SCPs. Acute injuries were reported more often in contact and team sports than in individual sports among SCPs.

The incidence of injuries within the past year found in this study was in line with previous studies (Emery & Tyreman, 2009; Emery et al., 2006; Pickett et al., 2005). The higher number of sports injuries in SCPs can be explained by the longer exposure time and higher intensity of sports activities. Earlier studies have also reported that greater sports participation is associated with an increased risk of injury in adolescents (Michaud et al., 2001; Richmond et al., 2013). Furthermore, people who are not regularly physically active are more likely to sustain more severe injuries when engaging in PA (Diener-Martin et al., 2011).

Intense training and participation in multiple sports during the same season may also increase the risk for acute and overuse injuries (Adirim & Cheng, 2003). Sport specialization is also associated with an increased risk for overuse injuries, especially among females (Biese et al., 2020). In this study, having less than three resting days per week did not increase the odds for having sustained an injury, although a low number of recovery days has been associated with overuse injuries in other studies (Ristolainen et al., 2014).

In accordance with earlier research (Beachy & Rauh, 2014), a higher absolute number of acute injuries occurred during organized training than in matches or competitions. Conversely, a higher injury rate per exposure time in competitions than in practice has also been reported in both genders (DiStefano et al., 2018; Kerr et al., 2018). Among SCPs, weekly training for over seven hours was associated with a higher risk of acute injuries in males and females. However, the amount of overuse injuries was not significantly increased in females training over seven hours per week. As reported previously (Theisen et al., 2013), the number of competitions is associated with the annual incidence of injury, particularly in team sports. In our study, males reported having taken part in twice as many competitions during the preceding year as females did.

In this study, acute injuries were more common among team sports than among individual sports participants; however, the difference in overuse injuries was not significant. Thiesen et al. (2013) found that youth team sports had a higher incidence of both acute and overuse injuries than individual sports (Theisen et al., 2013). The most frequently reported cause for an acute injury was falling or stumbling in both groups in the present study.

The most common site for acute injuries for SCPs and NPs in this study was rather surprisingly the wrist and hand, and the second most common acute injury site for SCPs was the ankle. In a study of acute time-loss injuries in Finnish junior floorball league players, 81% of injuries affected the lower limbs, with 37% ankle injuries and 18% knee injuries (Pasanen et al., 2018). Ankle sprains are also the most common type of acute injury in young soccer players (Sokka et al., 2020), basketball players (Pasanen et al., 2017), and gymnasts (Hart et al., 2018). In a registry study of youth ice-hockey injuries at a pediatric trauma center, the most common injury type was concussion, followed by upper extremity fractures and sprains of the spine (Polites et al., 2014). The knee was the second most common acute injury location in NPs, whereas in SCPs, it was the fifth most common injury location. Acute knee injuries may be relatively less common among SCPs as a result of neuromuscular training targeted at injury prevention (Dargo et al., 2017).

Leppänen et al. (2015) studied overuse injuries among adolescent basketball and floorball players using a self-reported questionnaire. Among basketball players, the knee was the most common site for an overuse injury, and among floorball players, the lower back/pelvis was the most common site. In this study, the knee was the most common site for an overuse injury, and the hip/groin/gluteal and pelvis area was the second most common site among SCPs. In previous studies, Osgood-Schlatter disease, patellofemoral pain, and other unspecified knee pain were common in adolescents participating in sports (Orava & Virtanen, 1982).

Different sports disciplines have their specific typical acute and overuse injuries (Kujala et al., 1995; Ristolainen et al., 2010). For optimal preventive measures, sports-specific injury profiles need to be known. Sprains or strains and bruises were the most common injury types found in our study, as well as in previous studies (Emery et al., 2006; Kujala et al., 1995). In this study, 31.6% of SCPs reported a sprain injury within the past year, this being the most common injury type in both groups, followed by contusions/bruises to areas other than the head. The third most common acute injury type in SCPs was muscle injury and fractures in NPs. The most commonly fractured body sites in high school sports are the hand/finger, lower leg, and wrist, and more fractures are sustained by males than females (Swenson et al., 2012).

The most common type of overuse injury was muscle injury in both groups. This injury type includes chronic exertional compartment syndrome and delayed onset muscle soreness. However, it can be argued whether delayed onset muscle soreness

(DOMS) should be classified as an overuse injury. DOMS is primarily caused by eccentric contractions that produce the greatest muscle tension (Flores et al., 2018). Significantly more overuse injuries of bone tissue, such as Osgood-Schlatter disease, were reported by SCPs than NPs. Stress fractures were not significantly more common in SCPs. A potential cause for this may be that this type of injury may have caused withdrawal from SC activities. Additionally, only a small minority of SCPs participated in intensive elite-level training. Earlier studies found that participation in gymnastics and other high-impact activities carries a higher risk for stress fractures, especially in females (Hart et al., 2018; Sonneville et al., 2012)

The injury risk varies remarkably between different sports and other leisure time activities (Parkkari et al., 2004). McQuillan and Campbell (2006) reported that sports-related injuries increase sharply with increasing age from childhood to adolescence; the male to female ratio remained constant with age in non-sporting injuries, and there was no gender difference in injuries sustained in school physical education classes. These results agree with the findings of this study. Although SCPs may have better balance because of their more versatile training methods, this did not cause a difference in the number of injuries in school sports. This may be due to SCPs participating more intensively in school sports compared to NPs.

We also surveyed the leisure-time PA of both groups. Only 30 min of weekly PA was found to significantly increase the likelihood of both acute and overuse injuries. Those reporting one hour of PA per week had the lowest injury risk, and injuries were further increased with increasing leisure-time PA in those completing 2 h or more of PA per week; this was seen more clearly in SCPs.

6.3 Musculoskeletal examination

Ten of the 11 musculoskeletal screening tests used in this study had at least moderate interrater reliability. These tests can be considered reliable for trained physicians to evaluate the posture, mobility, and movement control of adolescents as part of a PHE. The navicular drop test was not found to have acceptable repeatability; thus, we do not recommend using this test in a musculoskeletal examination.

This study also showed that SCPs more often had a normal BMI, better shoulder and ankle mobility, and better knee control in the VDJ test compared with NPs. Core muscle control was better in SCPs than NPs, as was lateral control of the trunk in the one-leg stance test for females. We found no difference between SCPs and NPs in the deep squat test. Shortfalls in mobility, posture, and movement control were common in both groups. These deficits, such as shoulder protrusion, marked iliopsoas tightness, and poor lumbar spine control, were speculated to be associated with sedentary behavior, monotonous training, or both. In a previous study comparing FMS and Y-Balance Test scores between college-aged athletes and general college students, no difference was found in composite FMS scores between the groups. Only in the deep squat did female athletes score higher. In the Y-Balance Test, female athletes scored higher than non-athletes, whereas no difference was found in males. (Engquist et al., 2015.)

There is some evidence from prospective cohort studies that musculoskeletal examination and tests identify elements that are associated with future injuries or re-injuries (Hietamo et al., 2021; Leppänen, Pasanen, Krosshaug, et al., 2017; Leppänen et al., 2016; Leppänen, Pasanen, Kujala, et al., 2017; Leppänen et al., 2020; Rossi et al., 2021; Rossi et al., 2020; Räisänen, Pasanen, et al., 2018). In some studies, no association was found between performance in musculoskeletal tests and future injuries (Rossi et al., 2021; Räisänen et al., 2020; Räisänen, Pasanen, et al., 2018). However, the sensitivity and specificity of these tests seems to be insufficient to support individual screening of injury risk (Bahr, 2016; Garrick, 2004; Hietamo et al., 2021; Leppänen et al., 2020; Räisänen, Pasanen, et al., 2018). In a systematic review of physical exam risk factors for lower extremity injuries in high school-aged athletes, minimal prospective evidence was found to either support or refute the use of functional musculoskeletal examination to assess lower extremity injury risk. Multidirectional balance and physical maturation status were predictive of overall injury risk, knee hyperextension of ACL injury risk, hip external:internal rotator strength ratio of patellofemoral pain syndrome, and foot posture index of ankle overuse injury. (Onate et al., 2016.) According to a recent review, musculoskeletal screening or functional movement testing has not been proven effective in identifying athletes with a higher injury risk (Andujo et al., 2020).

The musculoskeletal examination also serves purposes other than attempting to screen for injury risk factors. For example, poor posture has been associated with depletion in respiratory functions (Kang et al., 2016; Zafar et al., 2018). Additionally, techniques in movements that are an essential part of training in almost any sport, such as core strength and squat quality, can be individually assessed in the examination. Training programs enhance neuromuscular control, proprioception, and strength, which are effective in acute and overuse injury prevention and can be recommended, for example, as a warm-up routine before practice (Lauersen et al., 2014; Olsen et al., 2005; Parkkari et al., 2011; Pasanen et al., 2008). Although performing a movement in an office setting may not reflect actual movement patterns during training or competition, the office setting is valuable in adding awareness of these factors. Furthermore, as an acute injury results in intrinsic changes (Fulton et al., 2014), the athlete's characteristics and capabilities need to be considered after the injury prior to returning to participation and to prevent re-injury.

6.4 Respiratory conditions, anemia, and iron deficiency

The prevalence of allergies, atopy, and asthma found in this study were similar to those reported previously (Kilpeläinen et al., 2000). The presence of rhinitis should also make the physician aware of the possibility of concomitant asthma in the athlete (Carlsen et al., 2008). In a recent systematic review and meta-analysis of asthma in competitive cross-country skiers, the prevalence of self-reported physician-diagnosed asthma was found to be 21%, which is significantly higher than in the general population (Mäki-Heikkilä et al., 2020).

Previously, the use of antiallergic drugs has been found to be more common in athletes than in non-athletes (Alaranta et al., 2005); however, no significant difference was found in the present study. Only half of the athletes who reported allergic rhinitis used anti-allergic medication within the past year, with endurance athletes being more likely to use allergy medication than other athletes or non-athletes (Alaranta et al., 2005). Allergen immunotherapy should be considered for the treatment of allergic rhinitis in athletes if symptoms are not controlled with conventional treatment; it can also prevent the development of asthma (Jutel et al., 2015).

Diagnostic tests for asthma to confirm variable expiratory airflow limitation include spirometry with a bronchial reversibility test, peak expiratory flow test for two weeks, exercise challenge test, bronchial challenge tests, such as the methacholine test and eucapnic voluntary hyperventilation (EVH) test, and the anti-inflammatory treatment test (GINA, 2018). Asthma can be suspected, and diagnostic tests initiated in a PHE based on typical asthma symptoms. A spirometry result is suggestive of possible asthma, in addition to participation in a sport with a high risk of asthma or a family history of asthma.

In this study, 16% of SCPs reported dyspnea during exercise. Among females, this was associated with a bronchodilator response consistent with asthma, which was found in 7% of SCPs not using asthma medication. In a cross-sectional study of adolescent athletes in Sweden, 20.4% of athletes reported dyspnea during exercise; a positive test for exercise-induced bronchoconstriction (≥ 10% postexercise fall in

FEV1) was found in 24.5% of athletes and exercise laryngeal obstruction was found in 10.1% of athletes (Ersson et al., 2020). A precise and early diagnosis and optimal treatment of exercise-induced asthma or bronchoconstriction is important, so that the asthmatic child and adolescent would be able to participate in PA on an equal level with their peers. Adequate follow-up also needs to be planned. (Del Giacco et al., 2015.)

Iron deficiency was a common finding in both SCPs and NPs. The serum ferritin concentrations used to define iron deficiency vary between studies, frequently falling within the 15–30 μg/L range (Hallberg, Bengtsson, et al., 1993; Hallberg, Hultén, et al., 1993; Nabhan et al., 2019; WHO, 2001). Previous studies have revealed iron deficiency using a ferritin cutoff of 16 μg/l in 52–40% of adolescent female athletes, and iron-deficiency anemia in 5–10% (Hallberg, Hultén, et al., 1993; Sandstrom et al., 2012). In a study of young elite athletes, Koehler et al. (2012) found that iron depletion occurred in 31% of male and 57% of female young elite athletes when using a ferritin threshold of < 35 μg/L; these were similar to the results of this study when using the < 30 μg/L threshold for iron deficiency.

Iron deficiency in athletes is thought to be more common in elite athletes; this could be caused by reduced dietary iron and the increased requirements associated with exercise (Clénin et al., 2015; Koehler et al., 2012). In this study, the prevalence of iron deficiency was not greater among SCPs than NPs; similar results were found previously by Sandstrom et al. in a study of adolescent female top-level athletes (Sandstrom et al., 2012).

Iron deficiency is more common in females than males across studies, as well as in our study (Fallon, 2004; Nabhan et al., 2019), and the onset and duration of menstruation has been demonstrated to affect iron status (Milman et al., 1998). Koehler et al. (2012) retrospectively investigated the gender-dependent influences of diet and exercise on iron status and found that most female athletes failed to meet the recommended daily intake of iron, although dietary iron density was higher than that in males. Reduced ferritin levels in females were associated with lower dietary iron density and, in males, higher estimated energy expenditure. In addition to intake, the bioavailability of ingested iron is crucial when evaluating dietary iron adequacy, as certain nutritional factors enhance or inhibit iron absorption (Hoppe et al., 2008).

The recommended dietary intake of iron for adolescents according to Finnish dietary recommendations is 11 mg/day for males aged 10–17 years. For females, 11 mg/day is recommended in 10- to 13-year-olds and 15 mg/day from age 14 until menopause. For men over 18 years old, the recommendation is 9 mg/day. Only 15%

of dietary iron is absorbed (Fogelholm & Hakala, 2014). The roles of several minerals and trace elements in improving athletic performance have been studied, with iron and magnesium having the strongest quality evidence (Heffernan et al., 2019). In this study, iron supplement use was reported by only 3.5% of SCP females and 1.5% of SCP males. Iron supplementation has also previously been found to be more common among female athletes than male athletes (Knapik et al., 2016). In a recent review by Heffernan et al. (2019), the majority of studies showed benefits of iron supplementation on measures of iron status and outcomes related to endurance performance in individuals with low baseline ferritin levels, whereas there was little evidence for beneficial effects when the iron status was not compromised. Moreover, iron supplementation showed some benefits on functional performance in individuals with low baseline ferritin levels, as well as some improvements in fatigue resistance and strength in females with a varying iron status. (Heffernan et al., 2019.)

6.5 Cardiovascular evaluation

The results of this study suggested that ECG findings in adolescents participating in organized sports are similar regardless of the type of sport. However, the resting HR was lower in both endurance and non-endurance SCPs than in NPs, and SCPs had sinus bradycardia more often than NPs. Furthermore, non-endurance SCPs had a higher QRS amplitude compared to NPs. Endurance SCPs had a longer PR interval than NPs. Adolescent non-endurance SCPs were more likely to have an elevated systolic BP compared to endurance SCPs and NPs. The diastolic BP was lower in both groups of SCPs compared to NPs. Pulse pressure was higher in non-endurance SCPs than NPs.

The resting HR did not differ between endurance and non-endurance SCPs but was significantly lower in both groups when compared to NPs. The latter finding is consistent with previous observations in young athletes (Drezner et al., 2013). In the present study, sinus bradycardia was more prevalent in endurance and non-endurance SCPs than NPs. The most pronounced ECG features have usually been seen in endurance athletes, and bradycardia was expected in that group. However, non-endurance SCPs also exhibited bradycardia. This is not surprising considering that some sports disciplines categorized as non-endurance sports included ‘endurance-like’ characteristics.

Increases in ventricular chamber size, wall thickness, and mass are common findings in adolescent athletes, although exhibiting the Sokolow-Lyon voltage criteria, found in up to 50% of male adolescent soccer players, rather poorly correlates with echocardiographic findings (Somauroo et al., 2001). In the present study, LVH was more prevalent in SCPs than NPs, but the difference was not statistically significant. However, non-endurance SCPs had higher QRS amplitudes compared to NPs, and the association was on the borderline of significance between endurance SCPs and NPs. Our finding that adolescent endurance SCPs had longer PR intervals than NPs was consistent with previous findings in adolescents (Drezner et al., 2013). We did not observe a difference in QRS duration or in QT interval between SCPs and NPs; some studies have found QRS duration and QT interval to be longer in athletes than in non-athletes (Papadakis et al., 2009).

According to a systematic review and meta-analysis, the 12-lead ECG interpreted using modern criteria is the most effective way to screen for cardiovascular disease in athletes (Harmon, Zigman et al. 2015, Drezner, Sharma et al. 2017). In a cross-sectional study of 2,261 male peripubertal soccer players, an ECG performed in preparticipation screening revealed abnormalities unrelated to training in 2.9% of players. In this study, the ECG identified all cardiac cases requiring sport disqualification. An echocardiography was also performed. (Calò, Martino et al. 2019.) Previous resting 12-lead ECGs are also useful if myocarditis is suspected.

Although the ECG seems to be effective in screening for cardiac disease, it has not been shown to be effective in preventing cardiac death. In a study of 11,168 adolescent male elite soccer players in England who underwent cardiovascular screening, including echocardiography, a total of 42 athletes were found to have cardiac disorders associated with sudden death, and 225 athletes were diagnosed with other cardiac disorders. During the follow-up time of ten years, cardiac conditions accounted for eight deaths, which were sudden and occurred during exercise. Of these deaths, six were in athletes with normal findings during the preliminary screening. (Malhotra and Sharma 2018.) Additionally, it has been proposed that greater energy and resources should be devoted to targeted history and physical examinations during the primary medical care of those young people who do not take part in competitive sports, as in the United States, sudden deaths due to cardiovascular disease in non-athletes are more common than in athletes (Maron et al., 2019).

Resting systolic and diastolic BP were mostly at a low-normal level, which was consistent with other studies in adolescents (Berge et al., 2015; Papadakis et al., 2009; Tsioufis et al., 2011). A recent review including athletes mostly aged 18–40 years reported lower systolic and diastolic BP in endurance-trained athletes compared to strength-trained athletes (Berge et al., 2015). Although non-endurance SCPs in our study did not solely represent strength-trained athletes, our results are congruent with the review. However, in contrast to our findings, in the review, no significant difference in BP between athletes and non-athletes was found (Berge et al., 2015). In the same review, a trend towards a higher BP in athletes training more than 10 hours per week compared to those who trained less was observed (Berge et al., 2015). Furthermore, in adolescents, intense PA has been associated with higher systolic BP and pulse pressure (Tsioufis et al., 2011).

The cutoff level for elevated BP in adolescents used in this study was 120/80 mmHg (Riley et al., 2018). The prevalence of elevated BP was higher in non-endurance SCPs than endurance SCPs or NPs. The cutoff level for hypertension is most frequently set at 140/90 mmHg (Berge et al., 2015), and the prevalence in studies varies from 0% in Olympic endurance athletes to 83% in a subgroup of male strength sport athletes (Berge et al., 2015). In the general population aged 18–35, when using a cutoff value of ≥ 140/90 mmHg, elevated BP was reported in 11% of young adults, largely related to male sex, adiposity, and dietary habits (Bruno et al., 2016) .

Lower BP associated with PA in the general population is usually related to lower amounts of PA than what is carried out by elite or professional athletes. High BP in athletes could be caused by mental stress associated with high levels of competition, spurious systolic hypertension, and the use of BP-elevating medications (Berge et al., 2015). BP measurement is recommended in health examinations, as hypertension may be primary or, rather rarely, secondary to renal disease, coarctation of the aorta, or endocrinologic disease. However, the current evidence is insufficient to assess the balance of benefits and risks of screening for high BP in children and adolescents (Krist et al., 2020).

As expected, the average pulse pressure was normal in all study groups, while there were some high values as well. Pulse pressure was determined by ventricular ejection and arterial stiffness, which typically rises gradually during aging and predicts the risk of cardiovascular disease (Asmar et al., 2003). The normal value for pulse pressure may be considered to be 50 mmHg (Asmar et al., 2001).

6.6 Strengths and limitations of the study

The study population was a representative and relatively large sample of adolescents from different regions of Finland. Ten of the most popular sports, including both summer and winter, as well as individual and team sports, were equally represented in the study (Kokko et al., 2006). Due to the cross-sectional nature of the study, conclusions cannot be drawn about the causality of the health benefits or shortcomings associated with SC participation.

In study I, it is possible that the most sedentary individuals did not wear the accelerometer for the minimum number of days required. Swimmers did not wear the accelerometer during training in the water; therefore, we excluded swimmers from the analysis. However, based on training diaries, swimmers trained 79–88 min per day. Additionally, vigorous PA performed on skates or skis is underestimated when using an accelerometer. Conversely, a significant amount of training in this type of sports is also performed on the foot.

Studies II–V were at least partly based on self-reported questionnaire data, which is always subject to recall bias. The ability of the subject to remember and report information correctly is a potential issue. However, the accuracy in data recall should be similar between the two study groups. Study II was based on questionnaire data only, while in studies III–V, sports and exercise medicine physicians reviewed all the questions with the study subjects, which should improve the accuracy of the collected data.

In study II, it is possible that sports participants remembered their injury history better. Furthermore, there may be a risk that injured athletes had withdrawn themselves from SC activities because of an injury or injuries and would be classified as NPs with an injury sustained in an SC setting. However, at the age of 15, only a few injuries are so severe that they cause withdrawal from sports participation.

The terms acute injury and overuse injury were defined in the questionnaire (see methods section), and the questions used in study II were compiled from previously validated questionnaires (Eloranta & Tittonen, 2006; Karhula & Pakkanen, 2005; S. K. Kokko, Lasse et al., 2011; Pasanen et al., 2008; Ristolainen et al., 2010). There may be a risk that SCPs understood the terms an acute and overuse injury more clearly than NPs, but the definitions were written out and their differences were underlined to minimize the risk of misunderstanding. Additionally, there is the risk of not knowing the correct name of the anatomic location of the injured area, but this is the case in both study groups, and thus, the results should be comparable.

A further limitation of study II is that training details were only inquired from the SCP group, since reporting training hours may have a different meaning and be less valid among NPs. We also carried out additional analysis of the occurrence of injuries in SCPs and NPs using an identical question on leisure-time PA volume for both groups.

In study III, it is unlikely that subjects developed their skills in the tests or underwent posture changes due to growth during the two-week period between the musculoskeletal examination and re-examination. However, it is possible that the subject had day-to-day variations in alertness, and this may have affected their performance.

In study V, the robust classification to categorize sport disciplines as endurance and non-endurance sports allowed for comparison of ECG findings in adolescent SCPs across different types of sports. However, this study encompassed only ten of the most popular sports for youth in Finland, and our results are not generalizable beyond them.

Additionally, since the dropout rate from sports participation is high in adolescence, it is possible that a proportion of the NPs had recently withdrawn from SC activities, thus blurring the difference between SCPs and NPs. It should also be conceded that regarding SCPs as a single homogenous group ignores the difference in the frequency and intensity of PA between individuals and different sports. However, the age at which one typically specializes and reaches their highest competitive level varies across the different sports included in this study; therefore, we did not divide the sports participants into subgroups according to training volume or competition level in this study.

6.7 Future perspectives

In addition to screening the athlete for medical conditions that may place an athlete at risk for unsafe participation, a PHE offers a good opportunity to ensure that all current health problems are managed appropriately and that all asymptomatic conditions that may influence sports performance are identified (Ljungqvist et al., 2009). This can be accomplished by performing a comprehensive health examination, including an interview of personal and family medical history and health behavior, clinical examination, ECG, basic blood count, and ferritin tests, as well as flow-volume spirometry with bronchodilation.

It is common for physicians working with athletes to encounter conditions that are not cardiac or related to injuries (Grissom et al., 2006; Ruedl et al., 2016). Relative energy deficiency (RED-S) in sports and the female athlete triad are common health problems among athletes that may be suspected or discovered in a PHE when combining information obtained from the interview, clinical examination, and laboratory tests (Mountjoy et al., 2014, 2015). Eating disorders may also be associated with RED-S (Giel et al., 2016). Other important areas of a PHE that were not reported in this dissertation are vaccinations (Boston & Bryan, 2018), nutritional supplement use (Knapik et al., 2016; Ng et al., 2017), sleep (Mäkelä et al., 2016), mental well-being (Reardon et al., 2019), substance abuse (Ng et al., 2017), musculoskeletal symptoms (Pasanen et al., 2015), medication use, and therapeutic use exemptions (Alaranta et al., 2008). Baseline testing can also be carried out during a PHE, for example, the Sport Concussion Assessment Tool (SCAT) in sports with an increased risk for head injury (Hänninen et al., 2021).

Although evidence does not distinctly support performing musculoskeletal examinations or tests to find an individual athlete who will suffer a future injury, the musculoskeletal examination can be used to assess the increased risk of injury, examine the recovery from a previous injury, and evaluate movement quality and musculoskeletal control. The examiner can evaluate the strategies being used in injury prevention, as well as give the athlete personal advice on appropriate movement techniques. Furthermore, neuromuscular training (NMT) programs that develop strength and proprioception have been shown to be effective in preventing acute and overuse sports injuries (Lauersen et al., 2014; Olsen et al., 2005). Including this type of training as a part of physical education in schools would also aid adolescents not participating in SC activities to meet PA guidelines without injuries (Bull et al., 2020; Richmond et al., 2016).

The optimal age for the first athletes' health examination depends on the sport; commonly, age 10–16 is recommended. In some sports, such as gymnastics and skating, training volumes are high, and specialization in one sport commonly happens at an early age. In other sports, especially endurance sports, specialization may take place during or after puberty. Long-term sports performance prediction and optimal athlete development remain a challenge in the field of sports medicine and coaching. Specializing in a single sport, higher training volumes, and a greater weekly ratio than 2:1 of organized sports participation vs free leisure time PA have been found to be associated with a higher risk of serious overuse injuries in young athletes (Jayanthi et al., 2015).

The time children spend being sedentary increases with age from childhood to adolescence (Husu et al., 2016). Encouraging active transport to school and/or training sessions is a good way to increase PA in adolescents; this is important for maintaining basic endurance and aiding recovery. However, it is extremely important to take care of safety issues in this field to prevent traffic-related accidents.

An important goal of a PHE is to maximize the number of healthy training days, as time loss from training affects the ability of the athlete to achieve his/her goals (Raysmith & Drew, 2016). A too rapid increase in acute vs. chronic training load increases the risk of injury; however, gradual progress in chronic workload may increase the athletes' resilience to both high-intensity training and injury risk (Bowen et al., 2020; Bowen et al., 2017). Training load management is especially important for athletes participating in several sports or teams within the same sport. A PHE is also a good opportunity to ensure that the athlete has a systematic tool for monitoring fatigue and recovery (Targett & Clarsen, 2019).

Many adolescents with clinical health conditions participate in organized sports and this group requires special attention in a PHE. The diagnosis, severity, and progression of the condition need to be evaluated, in addition to the burden the condition causes to the athlete. The condition itself or its treatment may cause limitations in performance and/or health risks for the athlete. Medications need to be reviewed and an application for a Therapeutic Use Exemption completed if required by WADA (Bergeron et al., 2015). Ideally, a PHE would be carried out in the medical home of the athlete. However, adolescents with clinical health conditions, such as diabetes or epilepsy, are often treated in special health care facilities.

It is important that the athlete gets feedback after a PHE and can be referred to a physical therapist, psychologist, dietician, or specialist doctor if needed. Regular dental checkups are also recommended. With the athlete's permission, it is also possible for the coach to participate in the health examination. A PHE is typically the entry point for the medical care of a young athlete, and it offers a viable opportunity to comprehensively assess the athlete's health status and establish a contact in the healthcare system that can also be used in case of future injury or illness (Ljungqvist et al., 2009).

The development of a template for an athlete's PHE requires careful planning. This is also a good opportunity for all members of the sports medicine team and coaching staff to work together. When developing the template of a health evaluation, one should consider the goals of the evaluation, the target group, the time, place, and person who is going to carry out the evaluations, the content of the evaluation, and any other issues. The medical professional performing the assessment needs to understand the physical and mental demands of the sport in question, as well as its regulations (Targett & Clarsen, 2019).

The IOC did not take any position regarding whether a PHE should be recommended as compulsory for sports participation; this decision was left for sports authorities to make (Ljungqvist et al. 2009). The American Academy of Pediatrics has published a resource for medical providers with guidance on the proper timing, setting, and structure of the preparticipation physical evaluation (2019).

In Finland, SCs are a common way for children and adolescents to participate in organized sports. Information should be given to families about how to support the development of their child to promote lifelong PA and health. As regular daily PA, as well as frequent vigorous PA, is recommended for all adolescents, it is justified to conclude that more effort should be made to systematically promote safety in PA and assess symptoms associated with PA in all adolescents in their regular medical checkups.

In 2020, the IOC made a consensus statement to encourage consistency in the definitions and methodology of injury and illness surveillance studies for protecting the health of the athlete. The recommended surveillance system of symptoms and changes in performance will capture more health problems (Bahr et al., 2020). However, not all athletes' health problems limit their ability to participate or require medical attention. For athletes, a visit to the sports physician can be thought to represent the tip of the iceberg. The surveillance system has been suggested for SC settings to better understand the full spectrum of sports injuries and their prevention (Ekegren et al., 2016).

7 CONCLUSIONS AND RECOMMENDATIONS

1. Eighty-five percent of SCPs and 45 % of NPs aged 14–17 reach the current Finnish and WHO PA recommendations for good health.
2. Sports participants were twice as likely to have sustained an acute or overuse injury within the past year, with the probability of injury increasing with the increasing number of training hours and competitions. Sprain injuries were the most common acute injury type.
3. Posture, mobility, and movement control can be assessed in adolescents by a trained sports and exercise medicine physician with adequate repeatability. Sports participation is associated with better mobility and movement control.
4. Iron deficiency is undertreated and equally common among SCPs and NPs. Spirometry consistent with asthma is present in 7% of adolescents who are not using asthma medication.
5. Physiological adaptations are visible in the ECGs of adolescent athletes.

PHEs in an adolescent athlete also offer a good opportunity to discuss sufficient recovery and training load management to prevent injuries and illness. In the future, PA patterns in adolescents should be analyzed separately during sport-specific training and during time outside practice. Moreover, PA monitoring can be used at the team or individual level to aid in ensuring appropriate training loads.

PHEs include a comprehensive assessment of the athlete's current health status and are recommended for adolescent athletes. Findings that may compromise health and sports performance, such as musculoskeletal complaints, iron deficiency and spirometry suggestive of asthma, are relatively common in adolescents. The PHE typically serves as an entry point for medical care of the athlete and due to PHE content, it is recommended to be performed by a physician who is qualified in sports and exercise medicine. Additionally, more attention to PA-related issues should be given in health examinations performed in schools' health care systems. The aim of the athlete's health evaluation is to ensure safe and enjoyable participation in sports and other physical activities. Active transport, independent training, and other leisure time PA should be encouraged in all those who do not get sufficient PA for athletic development or general health.

Musculoskeletal evaluation can be performed by a physician or physical therapist. It should include an assessment of posture, mobility, and movement control, as well as careful evaluation of previously injured areas. Although evidence does not support screening individuals for increased injury risk, the musculoskeletal examination in the PHE is a viable opportunity to assess the musculoskeletal function of the athlete and give advice to correctly perform the strength and neuromuscular control exercises performed by all athletes to prevent injuries and improve sports performance as well as to draw attention to musculoskeletal conditions that may require further diagnostics and follow-up.

Basic blood count and ferritin measurement are recommended for all athletes to screen for iron deficiency. Heavy menstruation can be treated, dietary advice can be provided, and iron supplementation can be recommended upon need. Screening for asthma should be considered for athletes participating in a sport with a high risk of asthma, especially if there is asthma in the family or the athlete suffers from allergies, atopy, or recurrent respiratory tract infections. Diagnostic evaluation for asthma is recommended for adolescents with symptoms suggestive of airway obstruction and in cases of unexplained loss of exercise capacity, especially if risk factors for asthma are present.

An ECG adds to the value of the medical history and clinical examination in detecting a cardiac disease that could potentially endanger adolescents' health. An ECG can also be used as a reference film in cases of future suspicion of cardiac disease, such as myocarditis. BP measurement is a part of the cardiovascular evaluation of both athletes and non-athletes.

After a PHE, it is important that the athlete and all future health care providers have access to the information collected in the evaluation. After the evaluation, the athlete may get recommendations to make changes in training habits or other living habits. The results and recommendations of a PHE should be available to the coach and members of the sports medicine support team with the athlete's consent. If needed, the athlete may be referred to another specialist physician.

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PUBLICATION
I

Physical activity measured by accelerometry among adolescents participating in sports clubs and non-participating peers.

Toivo K, Vähä-Ypyä H, Kannus P, Tokola K, Alanko L, Heinonen OJ, Korpelainen R, Parkkari J, Savonen K, Selänne H, Kannas L, Kokko S, Kujala UM, Villberg J, Vasankari T

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Acute and overuse injuries among sports club members and non-members: the Finnish Health Promoting Sports Club (FHPSC) study

Ristolainen L, Toivo K, Parkkari J, Kokko S, Alanko L, Heinonen OJ, Korpelainen R, Savonen K, Selänne H, Vasankari T, Kannas L, Villberg J, Kujala UM

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RESEARCH ARTICLE

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Acute and overuse injuries among sports club members and non-members: the Finnish Health Promoting Sports Club (FHPSC) study

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Abstract

Background: Physical activity in adolescence is promoted for its multi-dimensional health benefits. However, too intensive sports participation is associated with an increased injury risk. Our aim was to compare the occurrence of acute and overuse injuries in Finnish sports club members and non-members and to report training and competing habits associated with a higher injury risk in sports club members.

Methods: In this cross-sectional survey targeted at 14–16-year-old adolescents, a structured questionnaire was completed by 1077 sports club members and 812 non-members. The main outcome measures were self-reported acute and overuse injuries, their location and type.

Results: At least one acute injury in the past year was reported by 44.0% of sports club members and 19.8% of non-members ($P < 0.001$). The sex-adjusted odds ratio (OR) for acute injury in sports club members compared to non-members was 3.13 (95% confidence interval (95% CI) 2.54–3.87). Thirty-five percent of sports club members and 17.4% of non-members ($P < 0.001$) reported at least one overuse injury during the past year. The overuse injury OR for sports club members was 2.61 (95% CI 2.09–3.26). Sports club members who trained 7–14 h per week during training (OR 1.61, 95% CI 1.21–2.12, $P = 0.001$) or competition season (OR 1.55, 95% CI 1.18–2.06, $P = 0.002$) were more likely to report an injury compared to members who trained 3–6 h per week. Those sports club members who participated in forty competitions or more compared to 7–19 competitions per year were more likely to report an acute injury (OR 1.55, 95% CI 1.05–2.08, $P = 0.028$) or for an overuse injury (OR 1.53, 95% CI 1.02–2.30, $P = 0.038$).

Conclusions: Both acute and overuse injuries are common among youth sports club members, and the number increases along with increasing amounts of training and competitions. More effective injury prevention is needed both for adolescents engaging in sports club activities and for other adolescents.

Keywords: Athletic injury, Acute injury, Overuse injury, Adolescent, Sports club member, Non-member

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Background

Physical activity in adolescence provides multidimensional health benefits [1, 2]. However, the risk of sports injuries increases along with the increasing volume, intensity, and competitiveness of the sports activities [3]. Youth team sports carry a higher injury risk than individual sports [4]. Some earlier studies have focused only on acute [5] or overuse injuries [6] only on either sex [7, 8] or on a specific injury, such as anterior cruciate ligament rupture [9, 10]. There are scattered studies on adolescents covering various different sports and different types of injuries. The occurrence and risk factors of different types of unintentional injuries among Finnish adolescents have previously been studied [11]. The sports injuries of adolescent sports club members have been studied previously [12–14], but studies comparing injuries between sports club members and non-members are rare [13]. Furthermore, the occurrence of overuse injuries has been studied less than that of acute injuries. The American Medical Society for Sports Medicine has made a position statement concerning overuse injuries and burnout, which are common problems in youth sports [15].

Sports clubs are a common way to participate in organized sports in Finland. Nearly half of the adolescent population reported to participate in organized sports in year 2013 [16] and according to the newest report this has raised to as much as 62% [17]. This cross-sectional study is a part of the Finnish Health Promoting Sports Club (FHPSC) study [18]. The purpose of this report is to compare the occurrence of self-reported acute and overuse injuries in Finnish adolescent sports club members and non-members. We also compared the anatomic locations of acute and overuse injuries and the injury types and studied the association between training and competing habits with the risk of injury. The injury definitions used in the questionnaire were obtained from an earlier Finnish study [19]. An acute injury was defined as an injury occurring suddenly keeping one away from exercise for at least one day or requiring a physician's care [20, 21]. An overuse injury was defined as an injury that causes gradually increasing pain during exercise loading without any noticeable external cause possibly stopping exercise completely [20, 22].

Methods

The FHPSC study

The aim of the FHPSC study was to survey health promotion orientation and activity of youth sports clubs and coaches. In addition to surveys, a clinical health examination was performed and the health behavior and health status of youth participating in sports clubs was compared to their non-participating peers.

Data collection

The FHPSC data were collected during 2013 in two rounds, from January to May for winter sports, and from August to December for summer sports. The comparison data for non-members were collected accordingly in two rounds via schools (9th grade, 14–16-year-old adolescents). For more details, see Kokko et al. [18].

Participants

The sports club sample

To obtain a nationally representative sample a total of 240 youth sports clubs from the ten most popular sports disciplines for youth were targeted. Sports clubs were stratified by the following criteria: 1) winter and summer sports, and 2) team and individual sports. Thereafter, the most popular disciplines (basketball, cross-country skiing, floorball, gymnastics, ice hockey, orienteering, skating, soccer, swimming, and track and field) were chosen. The main sports of the sports club members are shown in Additional file 1: Table S1. In total, 1077 youth sports club members (a participation rate of 64%) were included (Fig. 1).

The school-based sample

To compare the acute and overuse injuries of youths participating in organized sports clubs (i.e., members) with their non-participating counterparts (i.e., non-members) separate data were collected via schools. These data were also collected in two rounds (winter and summer). Overall, 159 schools were contacted and 100 participated (63%). Members of the school-based sample ($n = 1648$) were asked about their sports club participation, and sports club members in the school data ($n = 458$) were treated as sports club members in the following analysis. The final study sample included 812 non-members and 1077 sports club members (Fig. 1).

Surveys

Two surveys were conducted for all participants. The first survey focused on the health behaviors, including self-evaluated physical activity. The second survey focused on the adolescents' injuries and musculoskeletal health, and these questions were identical for both groups. The questions used in the surveys were compiled from previously validated questionnaires (Additional file 2: Table S2) [19, 23–26].

In the injury questionnaire the participants reported the number of acute and overuse injuries they had suffered within the preceding twelve months, the location of the injury, the type of injury, and the circumstances under which they occurred. Additional questions concerning the main sport and training habits were directed to sports club members. Participants who responded to the injury-questionnaire ($n = 1797$, 95%) also responded

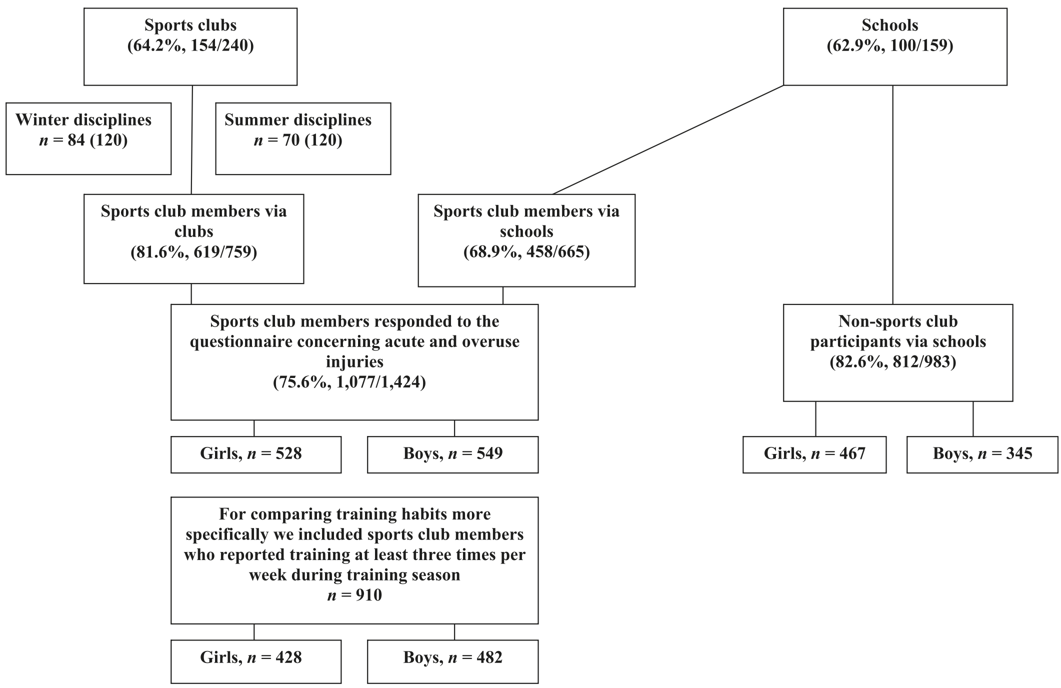

Fig. 1 Data collection and the final study group

to a questionnaire on leisure-time physical activity [18]. For more details of the structured questionnaire, see Additional file 2: Table S2. We used the question "How many hours of vigorous exercise/physical activity do you usually do per week in your leisure time (after school lessons)" for both groups to assess the amount of physical activity in order to compare the effect of the physical activity level on the acute or overuse injury risk [27].

"The term "acute injury" was defined as an acute sports injury which occurs suddenly or accidentally interrupting exercise or causing an identifiable trauma, and keeps one away from exercise for at least one day, or requires a physician's care. The term "overuse injury" was defined as an injury that causes increasing pain during or after exercise without any noticeable external cause of injury and possibly even completely prevents exercise" [19–22].

The study is carried out in conformance with the declaration of Helsinki. A positive statement from the Ethics Committee of Health Care District of Central Finland was received (record number 23 U/2012). All sports clubs participated free-willingly to the study. This was secured by requesting clubs permission at the beginning of study. Thereafter, all adult respondents were notified that they had a right to refuse to participate and withdraw from the study at any time.

Statistical analysis

Differences between sports club members and non-members were assessed using crosstabs and the chi-squared test and *t*-test when appropriate. Logistic regression was applied to study the associations between injuries (acute and overuse) and sports club membership and sex. Odds ratios (ORs) and their 95% CIs (95% Confidence Intervals) were calculated for the occurrence of acute and overuse injuries, anatomic location, and type of injuries in sports club members compared to non-members and the logistic regression analysis was adjusted for sex. Logistic regression analysis was also applied to study the associations between the injuries and the characteristics of training and competing among the sports club members. Odds ratios and their 95% CIs were also calculated for the occurrence of acute and overuse injury (at least one injury) by sports club participation and by volume of reported leisure-time physical activity, the logistic regression analysis was adjusted for sex. We also more specifically compared the occurrence of acute and overuse injuries and their anatomic location between sports club members training three times per

Table 1 At least one acute, one overuse injury or at least one acute or overuse injury among sports club members and non-members

	Sports club member				Non-member				
	All	Boys	Girls		All	Boys	Girls		
	n = 1077	*n* = 549	*n* = 528		*n* = 812	*n* = 345	*n* = 467		
	n (%)	*n* (%)	*n* (%)	*P* Value*	*n* (%)	*n* (%)	*n* (%)	*P* Value*	*P* Value#
At least one acute injury	474 (44.0)	256 (46.6)	218 (41.3)	0.077	161 (19.8)	73 (21.2)	88 (18.8)	0.413	< 0.001
At least one overuse injury	378 (35.1)	188 (34.2)	190 (36.0)	0.550	141 (17.4)	51 (14.8)	90 (19.3)	0.095	< 0.001
At least one acute or overuse injury	649 (60.3)	339 (61.7)	310 (58.7)	0.339	250 (30.8)	105(30.4)	145 (31)	0.851	< 0.001

*P Values for statistical difference for the occurrence of injuries between boys and girls among sports club members and non-members
#P Values for statistical difference for the occurrence of injuries between all sports club members and non-members derived from logistic regression analysis adjusted for sex

week or more in the training season ($n = 910$) and non-members ($n = 812$). The statistically significant threshold was accepted at $P \leq 0.05$ (two-tailed). IBM SPSS Statistics (version 22.0) was used to carry out all analyses except the total number of acute and overuse injuries and injury rates in different anatomical locations.

Results

Fifty-one percent of sports club members (549 of 1077) and 42.5% (345 of 812) of non-members were boys ($P < 0.001$; Fig. 1). Eighty-four percent ($n = 910$: 428 boys and 482 girls) of sports club members reported training at least three times weekly during the training season in the past year.

Occurrence of acute and overuse injuries

The total number of reported acute injuries in adolescents within the past 12 months was 2478 (Table 1). Forty-four percent of sports club members and 19.8% of non-members ($P < 0.001$) reported at least one acute injury in the past twelve months (Table 1). Boys were more likely to report acute injuries than girls (club membership-adjusted OR 1.31, 95% CI 1.08–1.59, $P = 0.006$). Among sports club members, individual sports' participants were less likely to report an acute injury than team and contact sports participants (OR 0.59, 95% CI 0.37–0.65, $P < 0.001$). In the sub-group of sports club members training at least three times weekly during the training season, compared to non-members, the sex adjusted OR for reporting at least one acute injury was 3.49 (95% CI 2.81–4.34, $P < 0.001$).

The total number of reported overuse injuries within the past 12 months was 1646. Thirty-five percent of sports club members and 17.4% of non-members ($P < 0.001$) reported at least one overuse injury during the past twelve months (Table 1). The difference between boys and girls was not statistically significant for reporting at least one overuse injury. Compared to the non-members, among the sub-group of sports club members training at least three times weekly during the training season, the sex-adjusted OR for reporting at least one overuse injury was 2.84 (95% CI 2.26–3.56, $P < 0.001$).

Sixty percent of sports club members and 30.8% of non-members reported either an acute or an overuse injury during past year (sex-adjusted $P < 0.001$). For more details, see Table 1.

Injuries by anatomic location

Out of the 1790 acute injuries reported by sports club members the most (13.6%) were injuries of the wrist or hand. This was also the most common acute injury location for non-members (15.1%). The second most common location was the ankle for sports club members and knee for non-members (11.7 and 11.0% respectively) (Table 2). The third most common location for an acute injury in both groups was the foot, 11.5% of all acute injuries for sports club members and 9.9% for non-members were injuries of the foot (Table 2).

The most common overuse injury location was the knee for sports club members (16.8% out of all overuse injuries in sports club members), this was the third most common location for non-members (11.1%). The second most common location for overuse injury was the hip, groin, gluteal and pelvis area for sports club members (11.1%) followed by the wrist and hand (10.0%). The most common location for an overuse injury for non-sports club members was the wrist or hand (Table 2).

The distributions of at least one injury by sports club membership, anatomic location, and sex are shown in Additional file 3: Table S3 for acute injuries and in Additional file 4: Table S4 for overuse injuries. Additional file 5: Table S5 shows the sex-adjusted details of at least one acute or overuse injury and its location in sports club members training more than three times compared to non-members.

Injury types

The most common acute injuries in both groups were sprains 31.6% of sports club members reported a sprain

Table 2 The total number of acute and overuse injuries and percentages (%) in different anatomical locations among sports club members and non-members

	Sports club members ($n = 1.077$)			Non-members ($n = 812$)			Sports club members ($n = 1.077$)			Non-members ($n = 812$)		
	Number of acute injuries						Number of overuse injuries					
	n	%*	%**	*n*	%*	%**	*n*	%*	%**	*n*	%*	%**
Head	49	4.5	2.7	20	2.5	2.9						
Face. teeth. Eye area	79	7.3	4.4	32	3.9	4.7						
Shoulder. upper arm. Clavicle	121	11.2	6.8	44	5.4	6.4	46	4.3	4.3	32	3.9	5.5
Elbow. forearm	58	5.4	3.2	29	3.6	4.2	33	3.1	3.1	21	2.6	3.6
Wrist and hand	244	22.7	13.6	104	12.8	15.1	106	9.8	10.0	75	9.2	12.8
Neck. neck region	66	6.1	3.7	35	4.3	5.1	46	4.3	4.3	38	4.7	6.5
Upper back	35	3.2	2.0	19	2.3	2.8	29	2.7	2.7	20	2.5	3.4
Low back	85	7.9	4.7	38	4.7	5.5	94	8.7	8.9	42	5.2	7.2
Chest	33	3.1	1.8	19	2.3	2.8	18	1.7	1.7	12	1.5	2.0
Abdomen	29	2.7	1.6	17	2.1	2.5	15	1.4	1.4	13	1.6	2.2
Hip. groin. Gluteals. pelvis	182	16.9	10.2	53	6.5	7.7	118	11.0	11.1	61	7.5	10.4
Thigh	109	10.1	6.1	32	3.9	4.7	80	7.4	7.6	37	4.6	6.3
Knee	170	15.8	9.5	76	9.4	11.0	178	16.5	16.8	65	8.0	11.1
Calf and shin	79	7.3	4.4	30	3.7	4.4	94	8.7	8.9	38	4.7	6.5
Ankle	210	19.5	11.7	57	7.0	8.3	70	6.5	6.6	46	5.7	7.8
Achilles tendon	35	3.2	2.0	15	1.8	2.2	28	2.6	2.6	18	2.2	3.1
Foot	206	19.1	11.5	68	8.4	9.9	104	7.8	9.8	69	8.5	11.8
All injuries	1790			688			1059			587		

* percentage of sports club members and non-members having sustained an injury in this anatomical area ** percentage of the injuries in each area out of all acute or overuse injuries among sports club members and non-members

during the past 12-month, compared to 13.5% of non-members ($P < 0.001$). Contusions/bruises other than the head were the second most common type of injury in both groups (sports club members 17.1% vs. non-members 7.6%, $P < 0.001$). The third most common acute injury type in sports club members was a muscle injury, and it was reported more often by members than non-members (13.5% vs. 4.7%). Out of non-members, 4.8% reported sustaining a fracture within the past year, this being the third most common type of acute injury for this group.

The most common overuse injury type was muscle injury among both sports club members and non-members (16.6% of sports club members and 10.1% of non-members reported at least one muscle injury, $P <$ 0,001). Overuse injuries of the bone were more prevalent among sports club members than non-members (9.8% vs. 4.7%, $P < 0.001$). However, no statistically significant difference was seen in stress fractures between sports club members and non-members (2.9% vs. 1.6%, $P = 0.075$).

Circumstances and causes of acute injuries

The most common setting for acute injuries in sports club members was organized training (25.4%) followed by matches or competitions (22.2%). Among sports club members, acute injuries in matches or competitions were more common in boys than girls (27.7% vs. 16.5%, $P < 0.001$). There was no difference between sports club members and non-members in acute injuries occurring during leisure time activities (16.0% vs. 17.1%) or school sports (7.4% vs. 7.0%). Among non-members, boys were more likely to report an acute injury during leisure time activities than girls (21.2%vs. 14.1%, $P = 0.028$). In both groups, the main cause for an acute injury was falling/ stumbling (sports club members 16.8% vs. non-members 10.3%, $P < 0.001$). In sports club members, other common reasons for an acute injury were tackling (11.0% vs. 2.3%, $P < 0.001$ compared to non-members) and running (10.3% vs. 4.3%, $P < 0.001$).

Training habits and injuries in sports club members

For those with training history for more than five years, training at least twice a week, the sex-adjusted OR for an acute injury was 1.38 compared to those who had trained actively for 0–4 years ($P = 0.029$; Table 3). Adolescents with weekly training for 7–14 h during the training season were 1.61 fold more likely to report an acute injury ($P = 0.001$) compared to adolescents who trained 3–6 h per week.

Table 3 Odds ratios (ORs) for at least one acute injury during the past twelve months in sports club members

	All (*n* = 1077)			Sports club members Boys (*n* = 549)			Girls (*n* = 528)		
Training Characteristics	OR*	95% CI	*P* Value#	OR	95% CI	*P* Value§	OR	95% CI	*P* Value¤
Main sports									
Team and contact sports	1.0			1.0			1.0		
Individual sports	0.59	0.37–0.65	< 0.001	0.45	0.28–0.72	0.001	0.70	0.48–1.01	0.059
Starting training (age)									
4–7 years old	1.0			1.0			1.0		
8–11 years old	0.99	0.76–1.31	0.978	0.82	0.56–1.20	0.305	1.24	0.82–1.86	0.304
12–15 years old	0.60	0.42–0.85	0.004	0.59	0.36–0.97	0.037	0.65	0.39–1.07	0.090
Active training years at least 2 times/week									
0–4 years	1.0			1.0			1.0		
5–8 years	1.38	1.03–1.83	0.029	1.55	1.01–2.37	0.045	1.24	0.84–1.83	0.274
9–11 years	1.84	1.31–2.58	< 0.001	1.89	1.19–2.98	0.007	1.88	1.13–3.14	0.016
Training hours per week during training season									
3–6 h/week	1.0			1.0			1.0		
7–14 h/week	1.61	1.21–2.12	0.001	1.57	1.06–2.32	0.025	1.65	1.11–2.45	0.014
15 h or more/week	2.12	1.42–3.15	< 0.001	2.16	1.28–3.64	0.004	2.04	1.10–3.76	0.023
Training hours per week during competition season									
3–6 h/week	1.0			1.0			1.0		
7–14 h/week	1.55	1.18–2.06	0.002	1.39	0.94–2.04	0.097	1.77	1.17–2.67	0.006
15 h or more/week	1.78	1.20–2.63	0.004	1.67	0.99–2.81	0.055	1.91	1.05–3.48	0.033
The amount of competitions during last 12 months									
7–19 competitions	1.0			1.0			1.0		
20–39 competitions	1.34	0.93–1.92	0.118	1.48	0.89–2.47	0.132	1.29	0.77–2.15	0.331
40 competitions or more	1.55	1.05–2.28	0.028	2.02	1.21–3.37	0.007	0.92	0.48–1.77	0.809
Resting days per week during training season									
3 resting days/week	1.0			1.0			1.0		
2 resting days/week	1.13	0.79–1.59	0.507	1.25	0.77–2.02	0.371	1.00	0.61–1.67	0.977
1 resting day/week	1.35	0.95–1.93	0.098	1.54	0.94–2.53	0.088	1.18	0.70–1.96	0.538
0 resting day/week	1.62	0.61–4.26	0.333	1.30	0.36–4.78	0.688	2.16	0.49–9.53	0.310

* OR = Odds Ratio, 95% CI = 95% Confidence Interval
#*P* Values in all sports club members derived from logistic regression adjusted for sex
§*P* Values in boys derived from logistic regression
¤ *P* Values in girls derived from logistic regression

Sports club members participating in 40 competitions or more per year were more likely to report an acute injury ($P = 0.028$) compared to those having 7–19 competitions a year. This was seen particularly among boys ($P = 0.007$) but not among girls ($P = 0.809$; Table 3). The mean amount of competitions during the past twelve months was higher among boys than girls (30.1 vs. 15.1, $P < 0.001$).

Having an overuse injury was 1.63 fold more likely ($P = 0.001$) in adolescents who trained 7–14 h weekly during the preceding training season compared to those training 3–6 h. Those adolescents participating in 40 competitions or more per year were significantly more likely to report an overuse injury in all adolescents ($P = 0.038$) compared to those participating in 7–19 competitions (Table 4).

Overall leisure-time physical activity and injuries by sport club membership

The distributions of leisure-time physical activity between sports club members and non-members is shown in Additional file 6: Table S6. We found that the probability of an acute injury for those who reported "physical activity for about 30 min per week"

Table 4 Odds ratios (ORs) for at least one overuse injury during the past twelve months in sports club members

	Sports club members								
	All (*n* = 1077)			Boys (*n* = 549)			Girls (*n* = 528)		
Training Characteristics	OR*	95% CI	*P* Value#	OR	95% CI	*P* Value §	OR	95% CI	*P* Value¤
Main sports									
Team and contact sports	1.0			1.0			1.0		
Individual sports	0.88	0.66–1.18	0.401	0.99	0.62–1.58	0.981	0.81	0.56–1.19	0.288
Starting training (age)									
4–7 years old	1.0			1.0			1.0		
8–11 years old	0.93	0.70–1.23	0.595	0.73	0.49–1.09	0.123	1.14	0.75–1.72	0.549
12–15 years old	0.77	0.54–1.10	0.155	1.02	0.62–1.69	0.923	0.64	0.38–1.07	0.086
Active training years at least 2 times/week									
0–4 years	1.0			1.0			1.0		
5–8 years	1.33	0.99–1.79	0.056	1.17	0.75–1.82	0.488	1.49	1.00–2.21	0.048
9–11 years	1.02	0.72–1.46	0.898	1.03	0.64–1.67	0.894	0.94	0.55–1.63	0.835
Training hours per week during training season									
3–6 h/week	1.0			1.0			1.0		
7–14 h/week	1.63	1.21–2.18	0.001	1.91	1.24–2.94	0.003	1.42	0.95–2.11	0.088
15 h or more/week	1.66	1.11–2.50	0.014	2.14	1.24–3.71	0.007	1.23	0.66–2.30	0.513
Training hours per week during competition season									
3–6 h/week	1.0			1.0			1.0		
7–14 h/week	1.48	1.10–1.98	0.009	1.64	1.08–2.49	0.021	1.33	0.88–2.01	0.173
15 h or more/week	1.97	1.32–2.94	0.001	2.26	1.31–3.90	0.003	1.68	0.92–3.05	0.091
The amount of competitions during last 12 months									
7–19 competitions	1.0			1.0			1.0		
20–39 competitions	1.39	0.96–2.02	0.085	1.21	0.71–2.06	0.492	1.60	0.95–2.71	0.080
40 competitions or more	1.53	1.02–2.30	0.038	1.42	0.83–2.41	0.197	1.57	0.81–3.05	0.178
Resting days per week during training season									
3 resting days/week	1.0			1.0			1.0		
2 resting days/week	1.15	0.80–1.65	0.448	1.07	0.64–1.77	0.807	1.25	0.75–2.08	0.400
1 resting day/week	1.21	0.84–1.75	0.312	1.30	0.78–2.18	0.312	1.11	0.66–1.88	0.689
0 resting day/week	1.17	0.44–3.16	0.750	1.30	0.34–4.89	0.702	1.04	0.23–4.59	0.961

* OR = Odds Ratio, 95% CI = 95% Confidence Interval
#*P* Values in all sports club members derived from logistic regression adjusted for sex
§*P* Values in boys derived from logistic regression
¤ *P* Values in girls derived from logistic regression

was 7.8 fold ($P = 0.007$) and for those who reported "7 h or more physical activity per week" it was 20.3 fold ($P < 0.001$) compared to those who reported "no physical activity". When we included sports club participation in the model the sex-adjusted probability for reporting an acute injury for those non-members who reported "7 h or more physical activity per week" was 10.1 fold ($P = 0.002$) and for those who participated in sports clubs it was 2.4 fold ($P < 0.001$) (Additional file 7: Table S7).

The probability of reporting an overuse injury for those who reported "physical activity for about 30 min per week" was 3.7 fold ($P = 0.045$) compared to those not reporting any physical activity and the likeliness increased with increasing physical activity. For those who reported "7 h or more physical activity per week" it was 9.8 fold ($P < 0.001$) compared to those who reported "no physical activity". When we included sports club participation in the model the sex-adjusted probability for reporting an overuse injury for those non-members who reported "7 h or more physical activity per week" was 6.5 fold higher ($P = 0.002$) and for those who participated in sports clubs it was 1.7 fold higher ($P < 0.001$) (Additional file 7: Table S7).

Discussion

Sixty percent of sports club members and 30 % of non-members reported at least one acute or overuse injury during the past twelve months. The probability for sustaining an acute or overuse injury increased with the increasing number of training hours and competitions among sports club members. However, having less than three resting days per week did not increase an injury. Acute injuries were reported more often in contact and team sports than in individual sports among sports club members.

The sports club members and non-members formed a representative sample of the different regions of Finland and the sports club sample covered the 10 most popular sports in Finland. Both individual and team sports and summer and winter sports were equally represented [28]. Both groups should have similar accuracy in injury data and recall. The terms “acute injury” and “overuse injury” were defined in the questionnaire—as validated earlier [19, 25, 26] —to make the answers more reliable, and acute and overuse injuries were looked at separately.

One limitation of our study is the cross-sectional nature of this study. Also the self-reported questionnaire may cause recall bias and sports club members may remember their injury history better. However, the questionnaires used in these surveys were compiled from previously validated questions [19, 23–26]. The non-respondents were 9th grade students as were those who took part in the study, we do not have further details concerning the non-respondents. We believe that the risk for either participating or not participating is the same for both injured and non-injured adolescents. However, there may be a risk that injured athletes had withdrawn themselves from sports club activities because of an injury/injuries and would be non-members with an injury sustained in a sports club setting. Although, at the age of 15 only a few injuries are so severe that they cause withdrawal from sports participation. There may also be a risk that sports club members understood the terms an acute and an overuse injury more clearly than non-members, but the definitions were written clearly and their differences were underlined to minimize the risk of misunderstanding. In the self-reported questionnaire there is always a risk that adolescent is not aware of the name of the anatomic location that is injures, but this is the case in the both study groups, and thus, the results should be comparable. A further limitation is that training details were only inquired from the sports club member group, since reporting training hours may have a different meaning and be less valid among non-members. We also carried out an additional analysis of the occurrence of injuries in both sports club members and non-members using an identical question on leisure-time physical activity volume for both groups.

Injury occurrence and profile

Different sports disciplines have their specific typical acute and overuse injuries. For optimal preventive measures, sports-specific injury profiles need to be known. Taking into account the intensity and type of sports performed by the Finnish adolescents, our results concerning athletic injuries in young people who are participating in sports are in line with previous findings [6, 29–32].

Leppänen et al. [6] studied overuse injuries among adolescent basketball and floorball players using a self-reported questionnaire. Among floorball players the knee was the most common site for an overuse injury, the same finding was made in our study. Bostrom et al. [29] studied seven different sports and found that nearly half of the young adults had been injured during the past 12 months, which is close to 44% of adolescents having sustained at least one acute injury in our study. In both studies boys were more often injured than girls. However, in the study by Bostrom et al. [29] an acute injury was defined by an absence time of one week from sports compared to one day in our study. In a study of high school athletes by Kahlenberg et al. [30] those with a higher total number of hours per year of sports participation had a higher risk of injury. In our study, both acute and overuse injury was significantly increased with 15 h or more of training per week.

In our study, the acute injury incidence rate was significantly higher in team and contact sports compared to individual sports, which is in accordance with previous studies [4, 5, 33, 34], and acute injuries occurred more frequently to boys than to girls. This reflects the sports type distribution among Finnish adolescents, which explains why this result deviates from the findings seen in specific sports with a similar degree of competitiveness, where girls have a higher incidence of injury than boys [35–37]. In our study individual sports that were more often performed by girls were orienteering, riding, dancing, gymnastics, and skating.

In our study, sports club members reported on average one overuse injury per year. This was more than in non-members, but the reported 0.7 overuse injuries per year among non-members also needs to be recognized. Our result is in line with that reported by Malisoux et al. [31], but again the risk for an overuse injury depends on the sport type [6].

The most common acutely injured location for both sports club members and non-members was the wrist and hand combined. The most common more specific location among sports club members were the ankle and foot, again in accordance with previous research [35, 38]. In our study, the most common site for an overuse injury was the knee for sports club members and the wrist and hand for non-members.

Earlier studies have reported that the knee is commonly injured in adolescents [39] and 18–35 year old adults [40] especially in ball games and running. The knee was second most common acute injury location in non-members whereas in sports club members it was the 5th most common injury location. Acute knee injuries may be relatively less common among sports-club members as a result of neuromuscular training targeted at injury prevention [41]. Acute knee injuries were reported by 12% of all participants, there was no difference between boys and girls but a greater number of acute knee injuries were reported by sports club members than non-members. Most acute knee injuries occurred in ball games and among girls in synchronized skating and gymnastics. In a previous study by Pasanen et al. [42] 18% of acute injuries in floorball were knee injuries, including 7 ACL injuries. In our study no ACL injuries were reported. None of the knee injuries reported in our study required more than three days away from normal training or competition, so we can assume they were minor injuries.

In our study 12% of overuse injuries were knee injuries, significantly more of these were reported by sports club members. In previous studies it has also been found that Osgood-Schlatter disease, patellofemoral pain, and other unspecified knee pain are common in adolescents participating in sports [43–45]. Leppänen et al. [46] found in previous study of overuse injuries in basketball and floorball players that 35% of overuse injuries were injuries of the knee, however the age group in this study was 12–20 years. In our study knee overuse injuries were most common in ball game players.

In line with previous research [35, 47, 48] the most common acute injury type in both groups was sprains followed by contusions or bruises. The most common type of overuse injury was muscle injury in both groups. This injury type includes, for example, chronic exertional compartment syndrome and delayed onset muscle soreness. However, it can be argued whether delayed onset muscle soreness (DOMS) should be classified as an overuse injury. DOMS is primarily caused by eccentric contractions that produce the greatest muscle tension [49]. Sports club members reported significantly more overuse injuries of the bone tissue than non-members. Included in these injuries may be, for example, Osgood-Schlatter disease. Stress fractures were not statistically significantly more common in sports club members. A potential cause for this may be that this type of injury may have caused withdrawal from sports club activities. Also only a small minority of sports club participants participated in intensive elite level training. Many earlier studies have found that participation in gymnastics, dance, and other high-impact activity carries a higher risk for stress fractures, especially in girls [50, 51].

Injury circumstances and the need for prevention

The injury risk varies between different sports and other leisure time activities [52]. In accordance with earlier research [3, 35, 53] organized training was found to be the most common setting for acute injuries in sports club members, followed by matches or competitions. However, the injury risk is not always higher in organized sports. Monroe et al. [13] found that players taking part in organized soccer had a higher prevalence of injury compared to players of non-organized soccer. On the contrary, in basketball non-organized players had a higher prevalence of injury compared to players of organized basketball [13].

McQuillan and Campbell [34] reported that sports caused 32% of the injuries in 12–17-year-old adolescents. In non-members, most acute injuries occurred during leisure time. Abernethy and MacAuley [54] reported that 51% of accidental injuries occur during school sports, which was much more than in our study. In addition to formal physical education class, school sports included organized and casual sports performed at school. Although sports club members may have better balance because of their more versatile training methods, this does not cause a difference in the amount of injuries in school sports. This may be due to sports club members participating more intensively in school sports compared to non-members. The most frequently reported cause for an acute injury was falling or stumbling in both groups. Sports club members were more likely than non-members to sustain acute injuries in tackling situations. This can be explained by the high participation rate in team and contact sports [55].

Earlier studies have reported that greater sports participation is associated with an increased risk of injury both in adolescents and adults [19, 56]. In accordance with the results of our study, Richmond et al. [57] found that adolescents had a greater risk of a sports-related injury with increasing hours of play. In our study, training details were inquired only from sports club members, and we found that weekly training for over seven hours was associated with a higher amount of acute injuries in boys and girls. However, the amount of overuse injuries was significantly increased only among boys when training over seven hours per week. It has also been found that low levels of habitual physical activity increase the injury risk in children when exposure time is taken into account [58]. As reported earlier [4], the number of competitions is associated with the yearly incidence of injury, particularly in team games. In our study, boys reported having taken part in twice as many competitions during the preceding year than girls did.

We also surveyed the leisure-time physical activity from both groups. Only 30 min of weekly physical activity was found to significantly increase the likeliness of both the acute and overuse injuries. Injuries were further increased with increasing leisure-time physical activity in those completing 2 h or more of physical activity per week. This was seen more clearly in sports club members. This result is in agreement with previous research showing that more competitive forms of physical activity are associated with higher injury risk. [59, 60].

Effective preventive measures targeted at risk factors for both acute and overuse injuries are needed in both organized and non-organized sports in order to prevent injuries. Poor knee alignment and control during jump-landing may increase the risk of injury. However, these risk factors does not seem to change in young athletes by time by simply playing the sport. Improvement of knee stability needs specific neuromuscular exercises [39].

Physical activity programs that develop strength and proprioception have been shown to be effective in preventing acute and overuse sports injuries [61, 62]. Including this type of training as a part of physical education would also aid adolescents not participating in sports club activities to meet physical activity guidelines without injuries [63, 64].

Conclusions

Physical activity provides a balance to the nowadays common sedentary lifestyle common among adolescents. Our study shows the quantity of the combined extent of acute and overuse injuries among adolescent sports club members compared to non-members. The sports type, such as team and contact sports, training, and competing habits influence this among adolescents. Injury prevention is needed, both in organized and non-organized sports.

Additional files

Additional files 1: Table S1. Main sports reported by sports club members. (DOC 61 kb)

Additional files 2: Table S2. The main structured questions in the questionnaire. (DOC 43 kb)

Additional files 3: Table S3. Anatomical site of at least one acute injury in boys and girls among sports club members and non-members. (DOC 70 kb)

Additional files 4: Table S4. Anatomical site of at least one overuse injury in boys and girls among sports club members and non-members. (DOC 67 kb)

Additional files 5: Table S5. Comparison of at least one acute or overuse injury in sports club members (training three times or more per week during the training season) and non-members in the past twelve months. (DOC 62 kb)

Additional files 6: Table S6. Reported leisure-time physical activity volumes among sports club members and non-members. (DOC 50 kb)

Additional files 7: Table S7. Odds ratios for the occurrence of acute and overuse injury (at least one injury) by sports club participation and by volume of reported leisure-time physical activity derived from logistic regression analysis adjusted for sex. (DOC 62 kb)

Abbreviations

ACL: Anterior cruciate ligament; CI:: Confidence Interval; DOMS: Delayed onset muscle soreness; FHPSC: The Finnish Health Promoting Sports Club (FHPSC); OR: Odds ratio

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Availability of data and materials

The datasets generated and/or analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

Authors' contributions

All authors (LR, KT, JP, SK, LA, OH, RK, KS, HS, TV, LK, JV, UK) contributed to study conception and design. SK and JP coordinated and managed all parts of the study. LR and KT carried out the literature search. SK and JV conducted data collection and performed preliminary data preparations. LR, KT and JV conducted data analyses and all the authors contributed to the interpretation of data. LR, KT, UK and JP wrote the first draft of the paper and all authors provided substantive feedback on the paper and contributed to the final manuscript. All authors have approved the submitted version of the manuscript. JP is the guarantor.

Ethics approval and consent to participate

The Ethics Committee of Health Care District of Central Finland was received (record number 23 U/2012). All sports clubs participated free-willingly to the study. This was secured by requesting clubs permission at the beginning of study and by written informed consent from the participating youth for the questionnaire. Written consent on behalf of participants below the age of 16 was obtained from the parental/legal guardian. Thereafter, all respondents were notified that they had a right to refuse to participate and withdraw from the study at any time.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

Publisher's Note

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PUBLICATION
III

Musculoskeletal examination in young athletes and non-athletes: the Finnish Health Promoting Sports Club (FHPSC) study.

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Musculoskeletal examination in young athletes and non-athletes: the Finnish Health Promoting Sports Club (FHPSC) study

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ABSTRACT

Objectives To determine the inter-rater repeatability of a musculoskeletal examination and to compare findings between adolescent athletes and non-athletes in Finland.

Methods In this cross-sectional study, a musculoskeletal examination assessing posture, mobility and movement control was carried out by a sports and exercise medicine physician on 399 athletes aged 14–17 years and 177 non-athletes. Within 2 weeks another sports and exercise medicine physician repeated the examination for 41 adolescents to test the inter-rater repeatability.

Results In total, 10 of the 11 tests performed had at least moderate inter-rater reliability (κ ≥0.4 or percentage agreement >80%). Athletes more often than non-athletes had one shoulder protruded (8.0% vs 4.0%, OR 2.81, 95% CI 1.16 to 6.81). Forty-six per cent of athletes had good knee control in the two-legged vertical drop jump test compared with 32% of non-athletes (OR 1.99, 95% CI 1.29 to 3.06). Athletes had better core muscle control with 86.3% being able to remain in the correct plank position for 30 s compared with 68.6% of non-athletes (OR 2.70, 95% CI 1.67 to 4.36). In the deep squat test, good lumbar spine control was maintained only by 35.8% of athletes and 38.4% of non-athletes.

Conclusion A basic musculoskeletal examination is sufficiently reliable to be performed by trained physicians as a part of a periodic health evaluation. Shortfalls in mobility, posture and movement control are common in both athletes and non-athletes. These deficits could have been caused by sedentary behaviour, monotonous training, or both.

What are the new findings?

- Posture, mobility and movement control can be tested with adequate repeatability from adolescent athletes and non-athletes in a periodic health evaluation performed by a sports and exercise medicine physician.
- Participation in sports is associated with better shoulder and ankle mobility, knee control in the vertical drop jump test and better core muscle control.
- Fewer than 40% of athletes and non-athletes are able to maintain good lumbar spine control and heels on the floor in the deep squat test with dowel on raised straight arms.

BACKGROUND

Injury risk assessment through a musculoskeletal examination has been a long-standing goal for sports medicine practitioners. An athlete's periodic health evaluation (PHE) includes a comprehensive assessment of her/his current health status and is typically the entry point for the medical care of a young athlete.[1]

Physical performance tests and their ability to determine a risk level for injuries have been in focus but most often they have not been able to predict lower extremity injuries.[2 3] These types of tests have used quantifiable performance outcomes, and the results could have been affected by compensation movements.

On the other hand, musculoskeletal screening can also focus on movement quality. This involves identification and rating of functional compensations, asymmetries, impairments or efficiency of movement control through transitional (eg, squats, sit-to-stand, lunge) or dynamic movement (eg, hopping, walking, running, landing, cutting) tasks.[4] Posture control is defined as maintaining, achieving or restoring a state of balance during any posture or activity.[5] A previous study found that static and dynamic posture control appears to be unrelated in healthy adolescents and is not related to strength. Given that injuries primarily occur during dynamic conditions, assessment should also be carried out under dynamic conditions.[6]

Before proposing to use a series of tests in clinical practice, the reliability of the tests needs to be established. Tester experience

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increases the reliability of the test.[7] The reliability of the functional movement screen (FMS) has previously been reviewed and found to vary between different subtests.[8] Previous studies have compared injury risk factors between college-aged athletes and the general population,[9] and reviewed physical examination risk factors for lower extremity injuries in high-school-aged athletes.[10] To our knowledge, posture, mobility and movement control have not previously been compared between adolescent athletes and non-athletes.

The aims of this study were to evaluate the inter-rater reliability of the musculoskeletal examination and to examine the posture, movement control and mobility of adolescent athletes and non-athletes. We believe that a combination of static, transitional and dynamic tests with both quantitative and qualitative measurements and evaluations is the most feasible way to examine the function of the musculoskeletal system of an individual.

METHODS

This multi-institutional and multidisciplinary study was a part of the Finnish Health Promoting Sports Club (FHPSC) study and used a cross-sectional design. The study was conducted by the University of Jyväskylä in conjunction with six national Centres of Excellence in Sports and Exercise Medicine and the UKK-institute. All youth participating in the study were aged 14–17 years and represented both genders. A clinical health examination was performed, and the health behaviour and health status of youth participating in sports clubs was compared with their non-participating peers[11]; these groups are referred to as athletes and non-athletes in this article.

Data collection

A total of 240 youth sports clubs from 10 most popular sports disciplines in Finland were targeted to produce a nationally representative sample of the most popular team and individual youth sports. Sports that have their main competition season in the winter were basketball, cross-country skiing, floorball, ice hockey and skating. Summer sports were soccer, gymnastics, orienteering, swimming, and track and field. Of the invited sports clubs, 154 agreed to participate in the study.

The data collection started by surveys from January to May 2013 for winter sports and from August to December 2013 for summer sports. Comparison data for non-athletes were collected via schools (ninth grades) similarly in two stages within the same time frame. Complementary data, including athletes and non-athletes, were compiled

Table 1 Musculoskeletal tests in the Finnish Health Promoting Sports Club study

Test	Scoring
Posture	
Shoulder posture	Protrusion of one or both shoulders by inspection from the side scoliometer reading at acromioclavicular joint level.
Forward bend	Scoliometer reading from the level of sacrum, iliac crest and lower scapula.
Iliac crest height	Presence of asymmetry by palpation and inspection from the front.
Mobility	
Shoulder mobility	Dowel on raised straight arms, second dowel fits between head and arms. Highest score—with ease. Middle score—with mild resistance. Lowest score—compensates with cervical protrusion.
Modified Thomas test[46]	Presence of marked iliopsoas tightness on one or both sides.
Navicular drop[29]	≥10 mm on either or both sides, side difference ≥2 mm.
Beighton and Horan joint mobility index[47]	Generalised joint laxity ≥4 points.*[22]
Movement control	
30 s plank[48]	Ability to remain in correct position for 30 s.
Deep squat[49]	Highest score—lumbar spine remains in neutral zone and heels on the floor, dowel on raised straight arms. Middle score—lumbar spine control not assessed, heels remain on floor, hands behind neck. Lowest score—heels lifted from floor, hands behind neck.
Trendelenburg test[50]	20 cm stance, positive Trendelenburg sign—pelvis tilts toward raised leg.
One-leg stance[39]	20 cm stance, normal performance—lateral movement <13 cm, side difference ≤2 cm.
Vertical drop jump[51]	First and second landing assessed,[52] rating: good–reduced–poor control.[53]

*Ability to put hands flat on the floor with knees straight, elbow and knee hyper extension >10°, ability to bend thumb onto the front of forearm, ability to bend little finger up at 90° to the back of hand.

in spring 2014. The clinical examination data were mainly collected between August 2013 and April 2014.

Musculoskeletal examinations

The protocol for assessing the inter-rater reliability consisted of two separate visits. A physical examination including the musculoskeletal examination was followed by a second visit in which the musculoskeletal examination was repeated for selected subjects.

To assess the differences between athletes and non-athletes, 576 clinical examinations were performed, out of which 399 were for athletes and 177 for non-athletes (261 boys and 315 girls).[11] The participation percentage of those asked to take part in the health examination was 37% for athletes and 34% for non-athletes. The examinations were carried out in the six national Centres of Excellence in Sports and Exercise Medicine located in different regions of Finland (Helsinki, Tampere, Turku, Jyväskylä, Kuopio and Oulu).

Sixty youth (the first 10 athletes from each of the six centres) were invited for the repeated examination. Forty-one re-examinations were completed by another sports and exercise medicine physician for 30 athletes and 11 non-athletes (20 boys and 21 girls). These were completed within 2 weeks from the first visit. In all, there were 12 physicians completing the examinations and re-examinations.

Table 2 Inter-rater repeatability for posture and mobility tests in the Finnish Health Promoting Sports Club study

Test	Agreement (%)	κ values
Shoulder posture		
Shoulder protrusion on one or both sides	68	0.63
Scoliometer reading ≥3° at AC-joint level (yes/no)	83	0.56
Forward bend		
Scoliometer reading ≥3° at back	73	0.58
Scoliometer reading ≥7° at back	81	0.09
Asymmetry in iliac crest height	97	0.93
Shoulder mobility	68	0.42
Good	76	0.49
Satisfactory	81	0.22
Poor	81	0.47
Modified Thomas test		
Marked iliopsoas tightness on one side	93	0.36
Marked iliopsoas tightness on both sides	90	0.66
Navicular drop		
Side-to-side difference ≥2 mm	66	0.30
≥10 mm	71	0.15
Generalised joint laxity	81	0.47

During the first visit, height and weight were recorded. This was followed by a physical examination including a normal clinical investigation and also several previously well-documented static and dynamic posture, movement control and musculoskeletal balance tests (table 1). A scoliometer (OSI-scoliometer Orthopedic Systems) was used to measure height asymmetry at acromioclavicular joint level and angle of trunk rotation.

Outcomes

The main outcomes were the inter-rater reliability and the results of the musculoskeletal examination. The thresholds of acceptable reliability were defined at coefficient values (κ ≥0.4) corresponding to moderate reliability as sufficient for observing human movement for screening purposes.[8] Kappa 0.41–0.60 indicates moderate agreement, 0.61–0.80 substantial agreement and 0.81–1 almost perfect agreement.[12] The interpretation of κ also depends on the sample size.[13] The results of the Trendelenburg test are not presented as there was a misunderstanding in how to record the results of the test.

Statistical method

Means were calculated for continuous variables. Dichotomous variables are shown as percentages of athletes and non-athletes separately for girls and boys. Comparisons were performed by using generalised linear mixed models. Two-level data structure was constructed, the subjects being level 1, and the Centre of Excellence in Sports and Exercise Medicine being level 2. Basically, the two-level modelling allows for the clustering of subjects' values within the centre in which they were tested. When comparing athletes and non-athletes, there are two options to fit to a given data set with two-level data structure: one data structure allowing the possible clustering of subjects' values and the other ignoring it. Additionally, for comparison between boys and girls the modelling allows for the difference between genders to possibly vary among clubs and school classes.

ORs are reported with 95% CIs. All statistical analyses were two-sided, and a p values of <0.05 was considered significant. When testing inter-rater repeatability, the percentage agreement and Cohen's κ value were calculated. The assumption of normal distribution was confirmed by visual inspection for each continuous variable. IBM SPSS (V.24.0) was used to carry out all analyses.

RESULTS

Characteristics of the participants

Athletes were taller than non-athletes and more often had normal body mass index (BMI). Girls who were athletes reached menarche at an older age than non-athletes (online supplementary file 1).

Inter-rater repeatability of the musculoskeletal tests

Posture and mobility

The inter-rater repeatability for evaluating iliac crest height asymmetry was almost perfect (κ 0.93), and the

Table 3 Posture tests among athletes and non-athletes in the Finnish Health Promoting Sports Club study

Test	Boys (n=261) Athletes (n=198)	Boys Non-athletes (n=63)	Boys OR (95% CI)	Girls (n=315) Athletes (n=201)	Girls Non-athletes (n=114)	Girls OR (95% CI)	Total (n=576) Athletes (n=399)	Total Non-athletes (n=177)	Total OR (95% CI)
Shoulder posture									
One shoulder protruded (%)	7.6	1.6	7.29 (0.90 to 59.30)	8.5	5.3	1.94 (0.69 to 5.46)	**8.0**	**4.0**	**2.81 (1.16 to 6.81)**
Both shoulders protruded (%)	32.3	28.6	1.13 (0.58 to 2.20)	21.4	14.9	1.33 (0.69 to 2.57)	26.8	19.8	1.34 (0.85 to 2.12)
Scoliometer reading ≥3° at AC- joint level (%)	16.7	20.6	0.76 (0.37 to 1.57)	13.9	12.3	1.15 (0.58 to 2.29)	15.3	15.3	1.00 (0.61 to 1.64)
Forward bend									
Scoliometer reading ≥3° at back (%)	41.4	49.2	0.73 (0.41 to 1.30)	41.8	41.2	1.23 (0.75 to 2.02)	41.6	44.1	0.97 (−0.67 to 1.40)
Scoliometer reading ≥7° at back (%)	4.0	6.3	0.74 (0.23 to 2.34)	5.0	4.4	1.10 (0.40 to 2.93)	4.5	5.1	0.93 (0.44 to 1.96)
Asymmetry in iliac crest height (%)	**14.9**	**31.1**	**0.43 (0.21 to 0.89)**	14.1	9.3	1.68 (0.74 to 3.82)	14.5	17.2	0.90 (0.53 to 1.53)

Statistically significant results are indicated in bold.
Comparisons were performed by using generalised linear mixed models, the centre of sports medicine in which the examination was completed being level 2 in the analysis.

inter-rater repeatability for shoulder protrusion was substantial (κ 0.63). The following posture tests had moderate inter-rater agreement: scoliometer reading of ≥3° at acromioclavicular-joint level (κ 0.56), scoliometer reading of ≥3° at back (0.58). The percentage of agreement for scoliosis ≥7° at back was 81% (κ 0.09) (table 2).

The interrater repeatability was substantial for marked iliopsoas tightness on both sides (κ 0.66). The following mobility tests had moderate interrater repeatability: shoulder mobility test (κ 0.42), Beighton and Horan mobility index (κ 0.47), and heels lifted from floor in the deep squat test (κ 0.55) (tables 2 and 3). The Kappa value for the navicular drop test was <0.4 and percentage of agreement <80 % (table 2).

Movement control

The deep squat test as a whole had substantial inter-rater repeatability (κ 0.66), and the repeatability was best for receiving the highest score (κ 0.81). The vertical drop jump test as a whole had moderate inter-rater repeatability (κ 0.45), and the repeatability was substantial for poor control (κ 0.66). The one-leg stance test had moderate inter-rater repeatability (κ 0.48–0.60). A κ value of ≥0.4 was not obtained in the 30 s plank test; however, the percentage of agreement was >80 (table 4).

Musculoskeletal tests between athletes and non-athletes

Posture

Having one shoulder protruded (8.0% vs 4.0%, OR 2.81, 95% CI 1.16 to 6.81) was more common in athletes than non-athletes. Having iliac crests at different levels was less common in boys who were athletes (14.9% vs 31.1%) (OR 0.43, 95% CI 0.21 to 0.89) (table 3).

Mobility

Poor shoulder mobility was less common in boys who were athletes compared with non-athletes (30.3% vs 46.0%, OR 0.54, 95% CI 0.29 to 0.99) (table 5). Limited

Table 4 Inter-rater repeatability for movement control tests in the Finnish Health Promoting Sports Club study

Test	Agreement (%)	κ values
30 s plank	85	0.32
Deep squat	81	0.66
Highest score	93	0.81
Middle score	81	0.60
Lowest score	88	0.55
Trendelenburg sign positive	63	–0.13
One-leg stance		
>2 cm side-to-side difference	83	0.48
≥13 cm	83	0.60
Vertical drop jump	61	0.45
Good control	71	0.35
Impaired control	71	0.41
Poor control	90	0.66

Table 5 Mobility tests among athletes and non-athletes in the Finnish Health Promoting Sports Club study

Test	Boys (n=261)			Girls (n=315)			Total (n=576)		
	Athletes (n=198)	Non-athletes (n=63)	OR* (95% CI)	Athletes (n=201)	Non-athletes (n=114)	OR* (95% CI)	Athletes (n=399)	Non-athletes (n=177)	OR* (95% CI)
Shoulder mobility									
Good (%)	42.4	33.3	1.31 (0.70 to 2.45)	64.2	62.3	1.07 (0.63 to 1.81)	53.6	52.0	0.97 (0.66 to 1.43)
Satisfactory (%)	25.8	20.6	1.37 (0.68 to 2.76)	17.9	14.0	1.17 (0.61 to 2.36)	21.8	16.6	1.39 (0.86 to 2.24)
Poor (%)	**30.3**	**46.0**	**0.54 (0.29 to 0.99)**	16.9	23.7	0.78 (0.42 to 1.43)	23.6	31.6	0.75 (0.50 to 1.14)
Modified Thomas test									
Marked iliopsoas tightness on one side (%)	5.6	1.6	1.77 (0.42 to 7.41)	5.0	3.5	1.23 (0.44 to 3.44)	5.3	2.8	1.40 (0.62 to 3.19)
Marked iliopsoas tightness on both sides (%)	27.3	23.8	1.14 (0.55 to 2.37)	12.4	13.2	0.87 (0.41 to 1.84)	19.8	16.9	1.24 (0.75 to 2.05)
Generalised Joint laxity (%)	11.6	11.1	0.97 (0.37 to 2.57)	45.7	40.7	1.51 (0.91 to 2.51)	28.7	30.1	0.99 (0.66 to 1.50)

Statistically significant results are indicated in bold.
*Comparisons were performed by using generalised linear mixed models (GLMM), the centre of sports medicine in which the examination was completed being level two in the analysis.

ankle mobility in the deep squat test was less common in athletes than non-athletes; 21.8% of athletes compared with 37.3% of non-athletes were not able to perform the deep squat test with heels remaining on the floor (OR 0.48, 95% CI 0.32 to 0.71) (table 6).

Movement control

Athletes had better core muscle control with 86.3% being able to remain in the correct plank position for 30 s compared with 68.6% of non-athletes (OR 2.70, 95% CI 1.67 to 4.36). In the deep squat test, good lumbar spine control was maintained similarly in both groups (by 35.8% of athletes and 38.4% of non-athletes). Out of athletes, 41.6% and 22.6% of non-athletes were able to perform the deep squat test with heels remaining on the floor when lumbar spine control was not assessed (OR 2.52, 95% CI 1.65 to 3.86) (table 6).

In the one-leg stance test, girls who were athletes showed better lateral control of the trunk, 7.5% had lateral movement of <13 cm compared with 13.2% of non-athlete girls (OR 0.38, 95% CI 0.15 to 0.94). Good knee control was more common in athletes than non-athletes (45.9% vs 31.6% respectively, OR 1.99, 95% CI 1.29 to 3.06). Twelve per cent of athletes had poor knee control in the two-legged vertical drop jump test compared with 26% of non-athletes (OR 0.36, 95% CI 0.22 to 0.58) (table 6).

DISCUSSION

This study showed that 10 of the 11 musculoskeletal screening tests had at least moderate inter-rater reliability. These tests are reliable for trained physicians to evaluate the posture, mobility and movement control of adolescents as a part of a PHE.

This study also showed that athletes more often had normal BMI, better shoulder and ankle mobility, and better knee control in the vertical drop jump test compared with non-athletes. Core muscle control was better in athletes than non-athletes as was lateral control of the trunk in the one-leg stance test for girls. We found no difference between athletes and non-athletes in the deep squat test. Shortfalls in mobility, posture and movement control were common in both athletes and non-athletes. These deficits, such as shoulder protrusion, marked iliopsoas tightness and poor lumbar spine control, are speculated to be associated with sedentary behaviour, monotonous training, or both.

The strengths of this study were that the adolescents formed a representative sample from different regions of Finland and the sports club sample comprised the 10 most popular sports in Finland. Summer and winter sports and individual and team sports were equally represented.[14] The number of athletes in the study was greater than the amount of non-athletes because we wanted to include participants of the most popular sports in Finland, and include both summer and winter sports and individual and team sports. In general, it is unlikely that subjects developed their skills in the tests or underwent posture changes due to growth during the 2-week

Table 6 Movement control tests among athletes and non-athletes in the Finnish Health Promoting Sports Club study

	Boys (n=261)			Girls (n=315)			Total (n=576)		
Test	**Athletes (n=198)**	**Non-athletes (n=63)**	**OR* (95% CI)**	**Athletes (n=201)**	**Non-athletes (n=114)**	**OR* (95% CI)**	**Athletes (n=399)**	**Non-athletes (n=177)**	**OR* (95% CI)**
Able to perform 30 s plank (%)	**85.1**	**66.7**	**2.84 (1.36 to 5.93)**	**87.4**	**69.6**	**2.60 (1.36 to 4.95)**	**86.3**	**68.6**	**2.70 (1.67–4.36)**
Deep squat									
Highest score (%)	36.4	39.7	0.87 (0.47–1.61)	35.3	37.7	0.91 (0.53–1.56)	35.8	38.4	0.87 (0.58–1.29)
Middle score (%)	**42.9**	**25.4**	**2.42 (1.24–4.73)**	**40.3**	**21.1**	**2.39 (1.36–4.20)**	**41.6**	**22.6**	**2.52 (1.65–3.86)**
Lowest score (%)	**20.7**	**34.9**	**0.46 (0.24–0.88)**	**22.9**	**38.6**	**0.49 (0.30–0.83)**	**21.8**	**37.3**	**0.48 (0.32–0.71)**
One-leg stance									
>2 cm side-to-side difference (%)	12.6	7.9	1.68 (0.60–4.70)	10.0	11.4	0.89 (0.43–1.84)	11.3	10.2	1.16 (0.66–2.06)
≥13 cm on one side (%)	5.6	0.0	NA	5.5	3.5	1.62 (0.49–5.41)	5.5	2.3	2.38 (0.79–7.17)
≥13 cm on both sides (%)	6.6	3.2	1.38 (0.28–6.84)	**7.5**	**13.2**	**0.38 (0.15–0.94)**	7.0	9.6	0.53 (0.26–1.09)
Vertical drop jump									
Good control (%)	53.0	46.0	1.17 (0.84–3.37)	**38.8**	**23.7**	**1.99 (1.11–3.56)**	**45.9**	**31.6**	**1.99 (1.29–3.06)**
Impaired control (%)	40.4	36.5	1.09 (0.55–2.16)	41.8	43.9	1.02 (0.63–1.65)	41.1	41.2	1.07 (0.73–1.58)
Poor control (%)	**5.6**	**15.9**	**0.28 (0.11–0.73)**	**18.4**	**31.6**	**0.47 (0.27–0.83)**	**12.0**	**26.0**	**0.36 (0.22–0.58)**

Statistically significant results are indicated in bold.
*Comparisons were performed by using generalised linear mixed models (GLMM), the centre of sports medicine in which the examination was completed being level two in the analysis.

period of time between the musculoskeletal examination and the re-examination. However, it is possible that the subject had day-to-day variation in alertness and this may have affected the performance. Further, performing a movement in an office setting may not reflect actual movement patterns during training or competition. The office setting is, however, valuable in adding awareness of these factors. There is evidence that programmes aimed at improving core muscle control and neuromuscular function are effective in reducing the risk of low back pain and acute injuries in young athletes and conscripts.[15 16]

The tests or subtests that did not reach moderate inter-rater reliability (κ ≥0.4) were such in which one finding was significantly less prevalent than the other. For example, scoliosis of 7° or more or marked iliopsoas tightness on one side only was present in approximately 5% of the subjects. However, in these tests the percentage of agreement reached >80%. Thus we did not consider this to affect the repeatability of the Thomas test or forward bend test as a whole. Also, the 30 s plank test did not reach moderate repeatability based on the κ value; however, the percentage of agreement was 85%. In the re-examination, only 7% were not able to complete this test which may explain the low κ value for this test together with the small sample size (n=41). The navicular drop test was not found to have acceptable repeatability, thus we do not recommend using this test in a musculoskeletal examination.

More than 90% of the male subjects had reached puberty, and the girls who were athletes had reached menarche at an older age. In a previous study among adolescents aged 8–14 years, the FMS scores were found to be higher after puberty than before or during it. This suggests that after puberty there is an increase in muscular strength, proprioception and coordination. No significant differences in asymmetries were found across pubertal groups.[17]

Clinical findings

Protrusion of the shoulders is a common posture finding in adolescents.[18] In our study, having one shoulder protruded was more common in athletes than non-athletes and may be explained by sport specific postures and muscle tightness as well as training habits. Smart phone usage time may also have an effect on shoulder posture.[19]

Differences in iliac crest height may be due to leg length discrepancy, bony asymmetry in pelvic bones or muscle imbalance. Leg length discrepancy, which may lead to asymmetric gait and posture changes with compensatory imbalances in muscle strength and flexibility, may be predictive of stress fractures in select populations.[20] Leg length discrepancy can be reliably assessed using radiologic techniques,[21] but radiographs are not used in general screening.

Generalised joint laxity (GJL) has been suggested to be positively associated with physical activity in girls.[22] However, in this study we did not find a difference between athlete and non-athlete girls in the prevalence of GJL. In previous studies, GJL has been associated with a higher injury incidence in male and female athletes.[23 24] There is also a possible link between generalised joint hypermobility and developing joint pain in adolescence.[25]

In our study, we assessed core muscle function, knee joint alignment in the vertical drop jump and navicular drop. Poor core muscle control may be associated with anterior pelvic tilt and internal rotation of the femur along with valgus alignment of the knee and foot.[26 27] Tight iliopsoas and rectus femoris muscles may also be associated with anterior pelvic tilt; however, this may not apply to findings during running.[28] It is important to consider the entire lower extremity posture rather than single-alignment characteristics since it has been found that navicular drop and quadriceps angle have independent and interactive effects on neuromuscular responses to a weightbearing, rotational perturbation.[29] Furthermore, the impaired ability to maintain dynamic joint stability has been found to contribute to the development of exertional medial tibial pain in women.[30]

Knee joint malalignment is associated with increased loading of the joints, ligaments and tendons.[31] Previous studies have shown that excessive knee valgus[31] and stiff landings[32] during the vertical drop jump (VDJ) test are associated with increased risk of ACL injury in young female athletes. Furthermore, ACL injuries are more common among female athletes than their male counterparts[33] and that girls display an increase in valgus alignment during puberty.[34] Patellofemoral knee pain is more often experienced by females than males and is highly prevalent in all age groups.[35] Knee valgus displacement in a vertical drop jump test has been shown to predict patellofemoral pain in adolescent females.[36]

The prevalence of adolescent back pain increases with age,[37] and low back and pelvic pain have been found to be a common type of overuse injury in young athletes.[38] Patients with reduced control of active movements may form an important subgroup in patients with non-specific low back pain[39] and maintaining good lumbar spine position can also help reduce and prevent low back pain.[15 40 41] We found that <40% of adolescents were able to perform the deep squat while maintaining good lumbar spine control and heels on the floor, and there was no difference between athletes and non-athletes. In a previous study comparing college-aged athletes and non-athletes, the female athletes scored higher in the deep squat test compared with non-athletes, whereas no difference was observed in men.[9]

From the one-leg stance position, the lateral shift of the pelvis relative to the trunk can be measured with moderate reliability in adults.[39 42] In our study, we found that non-athlete girls more frequently had poor lateral control of the pelvis than athletes, and that there was no difference between athletes and non-athletes in asymmetric lateral control of the pelvis. Furthermore, nearly one-fifth of the adolescents in both groups had a side difference on ≥2 cm or lateral shift ≥13 cm on both sides indicating asymmetric or poor lateral control of the pelvis.

Although a number of markers in musculoskeletal screening tests are associated with an increased risk of sports injury, there is yet no final evidence to support screening of athletes' injury risk. In sports injury prevention studies, one challenge is to find the cut point at which athletes are determined to be at a higher risk.[43] An important goal of the PHE is to evaluate risk factors for developing acute and overuse injuries and musculoskeletal pain and to address those before the onset of problems. Importantly, risk factors also include later maturity, higher BMI and previous injury.[44 45]

CONCLUSIONS

When using the level of at least moderate inter-rater reliability as a criterion, trained physicians may use musculoskeletal tests to assess adolescents' posture, mobility and movement control in a PHE.

The posture tests we recommend are shoulder posture, scoliosis in forward bend and iliac crest height asymmetry. For testing mobility, we recommend the shoulder mobility test, Thomas test and the Beighton and Horan mobility index. Finally, for testing movement control, we recommend the deep squat test, the one-legged stance test, the vertical drop jump test and the 30 s plank test.

Future studies are needed to see how the findings in these musculoskeletal tests and their different cut points predict and are associated with musculoskeletal symptoms and injury risk. Test properties need to be validated in different populations using appropriate statistical methods.

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PUBLICATION IV

Hemoglobin, iron status and lung function of adolescents participating in organized sports in the Finnish Health Promoting Sports Club (FHPSC) Study.

Toivo K, Kannus P, Kokko S, Alanko L, Heinonen OJ, Korpelainen R, Savonen K, Selänne H, Vasankari T, Kannas L, Kujala UM, Villberg J, Parkkari J

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Haemoglobin, iron status and lung function of adolescents participating in organised sports in the Finnish Health Promoting Sports Club Study

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ABSTRACT

Objectives To compare laboratory test results and lung function of adolescent organised sports participants (SP) with non-participants (NP).

Methods In this cross-sectional study, laboratory tests (haemoglobin, iron status), and flow-volume spirometry were performed on SP youths (199 boys, 203 girls) and their NP peers (62 boys, 114 girls) aged 14–17.

Results Haemoglobin concentration <120/130 g/L was found in 5.8% of SP and 5.1% NP (OR 1.20, 95% CI 0.54 to 2.68). Ferritin concentration below 15 µg/L was found in 22.7% of both SP and NP girls. Among boys ferritin <30 µg/L was found in 26.5% of SP and 30.2% of NP (OR 0.76, 95% CI 0.40 to 1.47). Among SP iron supplement use was reported by 3.5% of girls and 1.5% of boys. In flow-volume spirometry with bronchodilation test, 7.0% of SP and 6.4% of NP had asthma-like findings (OR 1.17, 95% CI 0.54 to 2.54); those using asthma medication, that is, 9.8% of SP and 5.2% of NP were excluded from the analysis.

Conclusions Screening for iron deficiency is recommended for symptomatic persons and persons engaging in sports. Lung function testing is recommended for symptomatic persons and persons participating in sports in which asthma is more prevalent.

What are the new findings

- Twenty-three per cent of 14–17-year-old girls in both groups had ferritin levels below 15 suggesting iron store depletion.
- Among boys, 27% of sports participants and 30% of non-participants had ferritin concentration below 30.
- Iron deficiency was undertreated. Supplemental iron use was reported by 3.5% of girls and 1.5% of boys participating in sports and by none of the non-participants.
- Bronchial hyper-responsiveness may be an undertreated condition among adolescents. Among those who did not use asthma medication, a bronchodilator response consistent with asthma was found in 7% of sports participants and in 6.4% of non-participants.

INTRODUCTION

Prevention of injury and illness is the cornerstone of sports medicine.[1] Haemoglobin concentration is positively associated with maximal oxygen uptake which is an important determinant of an athlete's performance potential, especially in endurance sports. Depleted iron stores are known to reduce haemoglobin mass.[2] Studies have revealed low iron storage levels in up to 50% of adolescent females, and iron-deficiency anaemia in 5–10%, with anaemia being no more common among athletes than non-athletes.[3 4] The effect of iron supplementation on exercise performance in athletes with iron deficiency varies between studies.[5]

Asthma is a chronic respiratory disorder often coexisting with atopy, allergies and chronic rhinosinusitis.[6 7] It is an inflammatory disease, causing difficulty in breathing and leading to increased energy expenditure.[8] Twenty per cent of young Finnish adults report a history of allergies and/or atopy and 5% report physician-diagnosed asthma.[9] Adults typically suffer 2–3 upper respiratory infections yearly,[10] and athletes more often than others.[11] The focus of this descriptive study is on clinical laboratory findings among adolescent sports participant (SP) with an emphasis on anaemia, iron deficiency and asthma detection.

METHODS

This cross-sectional study was a part of the Finnish Health Promoting Sports Club study conducted by the University of Jyväskylä together with six national Centres of

Excellence in Sports and Exercise Medicine located in different regions of Finland, as well as the UKK-institute.[12] A total of 240 youth sports clubs active in the country's 10 most popular sports were targeted, with the goal to produce a representative sample of the most popular individual and team youth sports. Both summer and winter sports were included.[12] The data were collected over 14 months. Non-participant (NP) were recruited from schools (9th grade). The 578 adolescents were aged 14–17 (402 SP, 50% females and 179 NP, 64% females). All completed a medical history questionnaire at home with their parents.[12] The questionnaire was reviewed at the beginning of a health examination by a sports and exercise medicine specialist.[12]

Venous blood samples were taken after a ≥10-hour fast and haemoglobin was determined with a standard automatic haematology analyser. Serum was separated by standard procedures and stored at −75°C for future analysis. Anaemia was defined as Hb <120 g/L for all females and males under 15 years, the threshold for males ≥15 years was <130 g/L as recommended by the WHO. Blood chemistry, serum ferritin and transferrin receptor analyses were carried out on a Cobas 8000 modular analyser (Roche Diagnostics) in an SFS-EN ISO 15 189:2013 accredited laboratory. Subjects with C-reactiveprotein levels indicating inflammation, that is, >5 mg/L were excluded from the ferritin analyses. Additionally, subjects taking iron supplements who had normal ferritin levels (>30 µg/L) were excluded from ferritin and transferrin receptor analyses. Ferritin concentrations were obtained from 561 subjects, and transferrin receptor concentrations from 567 subjects. Two ferritin concentrations were used to indicate iron deficiency <15 µg/L and <30 µg/L.[13 14] A lower ferritin threshold to indicate iron deficiency is commonly used for females. The laboratory-specific reference range for serum transferrin receptor was 2.2–5.0 mg/L for males and 1.9–4.4 mg/L for females.

Height and weight were measured and recorded. Flow-volume spirometry was measured according to American Thoracic Society/European Respiratory Society guidelines[15] using a Medikro Pro 909 Spirometer (Kuopio, Finland). Finnish reference values for children were used.[16] Salbutamol 0.4 µg was used for the bronchodilation test. Subjects reporting asthma medication use (n=48) were excluded from the analysis as well as those, whose results were deemed unreliable due to technical shortcomings (n=63). Additionally, 21 subjects had poor quality results after the bronchodilator administration, and these were also excluded. An asthma diagnosis was not an exclusion criterion if the person was not using asthma medication regularly. The number of spirometry tests included in the analysis was 515. The criteria for baseline obstruction were FEV% z-score <−1.65 and for new asthma diagnosis FEV1(forced expiratory volume in 1 second) or FVC (forced vital capacity) +12% in the bronchodilation test.[17]

Statistical methods

Dichotomous variables are shown as numbers and percentages of participants and NP, separately for boys and girls and in total. Differences between the groups were assessed using generalised linear-mixed models. A two-tier data structure was constructed, the subject being level 1, and the Centre of Excellence in Sports and Exercise Medicine being level 2. For continuous variables, either normal distribution or gamma distribution was used depending on the normality of the outcome variable. For dichotomous variables, binomial distribution was used to obtain ORs. Coefficients and ORs are reported with 95% CIs. IBM SPSS (v.26.0) was used to carry out all analyses.

RESULTS

Basic characteristics

SP were slightly taller than NP 171 cm vs 169 cm (coefficient 0.01, 95% CI 0.05 to 0.02) (table 1). Online supple mental table 1 shows the sports participated in by each sex.

Haemoglobin and iron status

Haemoglobin <120/130 was present in 5.8% of SP and in 5.1% of NP (OR 1.20, 95% CI 0.54 to 2.68). Ferritin concentrations <15 µg/L was found in 22.7% of both SP and NP girls. Ferritin <30 µg/L was found in 26.5% of SP boys and 30.2% for NP boys (OR 0.76 , 95% CI 0.40 to 1.47). The use of an iron supplement was rare in all groups (table 2).

Allergies and asthma

Recurrent skin rash was less common in SP than NP (15.1% vs 23.6%, OR 0.63, 95% CI 0.40 to 0.99). SP tended to use asthma medication more frequently NP (9.8% vs 5.2%), the difference was not statistically significant (OR 1.74, 95% CI 0.86 to 3.53). In baseline spirometry, a low FEV% suggestive of pulmonary obstruction was found in 16.5% of SP and 15.3% of NP. A significant bronchodilator response was observed in 7% of SP and 6.4% of NP (OR 1.17, 95% CI 0.54 to 2.54), those using asthma medication were excluded from the analysis. Girls who reported dyspnoea during exercise were more likely to have a significant bronchodilator response in flow-volume spirometry (OR 3.17, 95% CI 1.12 to 9.02). When looking at boys and girls together this finding was not statistically significant (OR 2.05, 95% CI 0.80 to 5.27). None of the 13 boys who reported dyspnoea during exercise had a significant bronchodilator response (table 3).

DISCUSSION

Iron deficiency was a common finding in both groups. However, iron supplement use was reported by only 3.5% of SP girls and 1.5% of SP boys. NP reported no

Table 1 Basic characteristics

	Boys (n=261)			Girls (n=317)			Total (n=578)		
	Sports participants (n=199)	Non-participants (n=62)	Coefficient (95% CI)	Sports participants (n=203)	Non-participants (n=114)	Coefficient (95% CI)	Sports participants (n=402)	Non-participants (n=176)	Coefficient (95% CI)
Age, mean	15.7	15.7	−0.02 (−0.17–0.12)	15.6	15.6	−0.03 (−0.15–0.09)	15.6	15.6	0.00 (−0.09–0.09)
Weight, kg, mean	64.5	62.5	0.03 (−0.01–0.08)	58.3	59.8	−0.03 (−0.06–0.01)	61.4	60.8	0.01 (−0.02–0.04)
Height, cm, mean	**176**	**174**	**0.01 (0.001–0.02)**	167	166	0.00 (−0.01–0.01)	**171**	**169**	**0.01 (0.05–0.02)**
BMI, mean	20.8	20.6	0.01 (−0.03–0.05)	20.9	21.7	−0.04 (−0.06–0.01)	20.9	21.3	−0.02 (−0.04–0.00)

Statistically significant results are indicated in bold.

use of iron supplements. The serum ferritin concentrations used to define iron deficiency vary between studies, frequently falling within the 15–30 µg/L range.[4 13 14 18] Iron deficiency in athletes is thought to be caused by reduced dietary iron and increased requirements associated with exercise.[19] Iron deficiency is more common in females than males across studies as well as in our study[18 20] and it is known that the onset and duration of menstruation affect iron status.[21] The roles of several minerals and trace elements in improving athletic performance have been studied, with iron and magnesium having the strongest quality evidence.[5]

The use of allergy medication has previously been found to be more common in athletes than non-athletes, but no difference between the groups was found in this study.[22] It was found that only half of the athletes who reported allergic rhinitis reported using allergy medication within the past year.[22] Among those who did not use asthma medication, a bronchodilator response consistent with asthma was found in 7% of SP and 6.4% of NP. We found no statistically significant difference in use of asthma medication between SP and NP, although other studies show that asthma is more prevalent among endurance athletes, especially those exposed to cold and dry air, and in swimmers.[23]

The strengths of this study were that both summer and winter sports and individual and team sports were equally represented.[24] The prevalence of the various health conditions and problems was similar to those found in other studies indicating that the study sample represented typical adolescents. Our study also contained certain limitations. First, the questionnaire in the study was based on self-reported data, which is a potential issue for recall bias. However, sports and exercise medicine physicians reviewed all the questions with the study subjects, which should improve the accuracy of the collected data. Second, since the drop-out rate from sports participation is high in adolescence it is likely that a proportion of the NP's had just recently withdrawn from sports club activities thus blurring the difference between SP and NP. It should also be conceded that regarding SP as a single homogenous group ignores the difference in the frequency and intensity of PA between individuals and between different sports.

Health is an important determinant of sports performance and to maximise the amount of healthy training days, medical conditions should be identified and managed adequately. Iron deficiency is common and undertreated among adolescents and screening is recommended for symptomatic persons and persons engaging in sports. Lung function testing is recommended for persons with a family history of bronchial hyper-responsiveness, asthma-like symptoms and persons participating in sports in which asthma is more prevalent.

Table 2 Clinical laboratory data and iron supplement use

Number of missing results in brackets	Boys (n=261) Participants (n=199)	Boys Non-participants (n=62)	Boys Coefficient/ OR (95% CI)	Girls (n=317) Participants (n=203)	Girls Non-participants (n=114)	Girls Coefficient/ OR (95% CI)	Total (n=578) Participants (n=402)	Total Non-participants (n=176)	Total Coefficient/ OR (95% CI)
Haemoglobin, mean (6)	147	149	−0.01 (−0.03–0.004)	132	132	−0.00 (−0.02–0.01)	140	138	0.01 (−0.01–0.02)
Hb <120/130	7 (3.5)	1 (1.6)	1.34 (0.31–5.79)	16 (8.1)	8 (7.1)	1.19 (0.49–2.92)	23 (5.8)	9 (5.1)	1.20 (0.54–2.68)
Ferritin, mean, (17)	47	44	0.08 (−0.07–0.24)	31	32	−0.03 (−0.19–0.13)	39	36	0.08 (−0.04–0.19)
Ferritin <30, n, (%)	49 (26.5)	19 (30.2)	0.76 (0.40–1.47)	117 (60.3)	62 (56.4)	1.15 (0.71–1.86)	166 (43.8)	81 (46.8)	0.86 (0.60–1.23)
Ferritin <15, n, (%)	9 (4.9)	5 (7.9)	0.67 (0.23–1.99)	44 (22.7)	25 (22.7)	1.02 (0.58–1.79)	53 (14)	30 (17.3)	0.77 (0.47–1.27)
Transferrin receptor, mean (11)	3.28	3.18	0.03 (−0.04–0.10)	3.14	3.09	0.01 (−0.08–0.11)	3.35	3.30	0.01 (−0.05–0.08)
Elevated transferrin receptor, n, (%)	7 (3.7)	1 (1.6)	1.37 (0.32–5.97)	29 (14.9)	11 (10.0)	1.52 (0.73–3.18)	36 (9.4)	12 (6.9)	1.30 (0.67–2.51)
Use of iron supplement (%), (5)	3 (1.5)	0	1.30 (0.24–6.97)	7 (3.5)	0	1.75 (0.49–6.28)	10 (2.5)	0	1.56 (0.56–4.34)

Table 3 Allergies and asthma

Number of missing results in brackets	Boys (n=261)			Girls (n=317)			Total (n=578)		
	Sports participants (n=199)	Non-participants (n=62)	OR (95% CI)	Participants (n=203)	Non-participants (n=114)	OR (95% CI)	Participants (n=402)	Non-participants (n=176)	OR (95% CI)
Asthma in family, n, (%), (15)	83 (43.2)	30 (50.0)	0.76 (0.43–1.37)	99 (49.7)	66 (58.9)	0.69 (0.43–1.10)	182 (46.5)	96 (55.8)	0.72 (0.50–1.03)
Regular use of allergy medication*, n, (%), (5)	42 (21.3)	13 (21.3)	0.99 (0.49–2.00)	39 (19.3)	15 (13.3)	1.51 (0.78–2.92)	81 (20.3)	28 (16.1)	1.26 (0.78–2.05)
Regular use of asthma medication, n, (%), (5)	16 (8.1)	4 (6.6)	1.20 (0.40–3.58)	23 (11.4)	5 (4.4)	2.65 (0.97–7.27)	39 (9.8)	9 (5.2)	1.74 (0.86–3.53)
Recurrent respiratory tract infections†, n, (%), (9)	63 (32.1)	21 (35.0)	0.88 (0.48–1.62)	80 (40.0)	42 (37.2)	1.13 (0.70–1.82)	143 (36.1)	63 (36.4)	1.03 (0.71–1.50)
Recurrent skin rash, n, (%), (7)	21 (10.7)	10 (16.4)	0.60 (0.26–1.36)	39 (19.4)	31 (27.4)	0.64 (0.37–1.11)	**60 (15.1)**	**41 (23.6)**	**0.63 (0.40–0.99)**
Dyspnoea during exertion, n, (%) (19)	18 (8.4)	9 (14.8)	0.62 (0.26–1.46)	45 (23.1)	21 (18.8)	1.30 (0.73–2.33)	63 (16.3)	30 (17.3)	1.04 (0.64–1.69)
Pulmonary obstruction (FEV% z-score <−1.65, n, (%), (63)	33 (18.9)	13 (22.8)	0.75 (0.36–1.56)	25(14.1)	12 (11.3)	1.29 (0.62–2.71)	58 (16.5)	25 (15.3)	1.07 (0.64–1.78)
Significant bronchodilator response (FEV1 or FVC ≥+12%, (84)	13 (7.6)	3 (5.6)	1.43 (0.38–5.41)	11 (6.4)	7 (6.9)	0.95 (0.37–2.43)	24 (7.0)	10 (6.4)	1.17 (0.54–2.54)

*Antihistamine in the spring, for example, nasal corticosteroid if used together with antihistamine, allergy eye medication, medication for hyposensitisation.
†Common cold, sore throat, rhinitis, bronchitis more than three times per year.
Statistically significant results are indicated in bold.

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Competing interests None declared.

Patient consent for publication The adolescents and their guardians provided written consent to participate in the study, and the adolescents were told that they could retract their consent at a later date.

Ethics approval The study conforms to the declaration of Helsinki. A positive statement from the Ethics Committee of healthcare District of Central Finland was received (record number 23U/2012). Before the start of this study, we requested permission from all the sports clubs to take part. This permission was granted freely.

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Data availability statement The data may not be shared because permission was not requested from the participants or their parents.

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PUBLICATION V

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Resting Electrocardiogram and Blood Pressure in Young Endurance and Nonendurance Athletes and Nonathletes

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Context: Much information is available on electrocardiogram (ECG) and blood pressure (BP) changes in senior athletes. However, corresponding data on adolescent athletes are scarce.

Objective: To study the differences in resting ECG and BP values among adolescent endurance athletes, nonendurance athletes, and nonathletes.

Design: Cross-sectional study.

Setting: A total of 154 youth sports clubs in Finland and 100 secondary schools for comparison data.

Patients or Other Participants: We recruited young athletes (n = 410) aged 14 to 16 years in 10 popular sport disciplines, including winter and summer as well as team and individual sports, and categorized them as endurance or nonendurance sports. Comparison data for age-matched, non–sports club participants (n = 164) were collected via secondary schools.

Main Outcome Measure(s): Resting ECG, including heart rate, PR interval, QRS duration, QRS axis, QRS amplitude, T axis, and QT interval as well as systolic and diastolic BPs.

Results: No differences in any ECG variable of interest were found between the endurance and nonendurance athletes. The PR interval was longer in endurance athletes than in nonathletes ($P = .05$). The QRS amplitude ($P = .03$) was higher among nonendurance athletes than among nonathletes. Diastolic BP was lower among endurance ($P = .002$) and nonendurance ($P = .02$) athletes than among nonathletes. Endurance athletes (odds ratio [OR] = 2.85; 95% CI = 1.81, 4.50) and nonendurance athletes (OR = 2.19; 95% CI = 1.43, 3.35) were more likely to have sinus bradycardia than were nonathletes. Nonendurance athletes were more likely to have elevated systolic BP than were endurance athletes (OR = 1.70; 95% CI = 1.07, 2.72) and nonathletes (OR = 1.73; 95% CI = 1.04, 2.87).

Conclusions: Young athletes had similar ECG and BP findings independent of their sports. Physiological adaptations including sinus bradycardia, higher QRS amplitude, and lower diastolic BP, which are commonly seen in adult athletes, were also present in adolescent athletes.

Key Words: adolescent athletes, cardiovascular health, heart electric activity, sports clubs

Key Points

- Young athletes exhibited similar electrocardiographic findings independent of their sports.
- Nonendurance athletes were more likely to have elevated systolic blood pressure (BP) than endurance athletes, but diastolic BP and pulse pressure levels were similar independent of sport.
- Physiological adaptations such as sinus bradycardia, higher QRS amplitude, and lower diastolic BP, which reflect commonly found ECG and BP patterns in adult athletes, were already present in adolescent athletes.

Regular exercise in athletes causes adaptive structural and functional changes in the heart. These consist principally of pronounced cardiac vagal tone and increased cardiac dimensions, which are reflected on the surface 12-lead electrocardiogram (ECG) in the form of sinus bradycardia, left ventricular hypertrophy (LVH), and depolarization and repolarization changes, along with other common electrical changes, especially in the anterior leads.[1,2] However, few researchers have assessed training-induced ECG changes in adolescent athletes. In a study of

1710 highly trained athletes aged 14 to 18 years, the PR interval, QRS, and corrected QT duration were more prolonged in athletes than in nonathletes.[3] Furthermore, in the same study, the Sokolow-Lyon voltage criterion for LVH and sinus bradycardia were more common in athletes.[3] Similarly, a higher prevalence of LVH by voltage criteria and a lower resting heart rate (HR) were observed in 13- to 19-year-old elite tennis players than in nonathletes.[4]

Regular exercise is also associated with reduced blood pressure (BP) in the general population[5]; however, elevated BP is one of the most frequent cardiovascular abnormalities in athletic populations.[6] Highly trained young athletes may have spurious systolic hypertension characterized by elevated brachial systolic BP and pulse pressure (PP) but normal diastolic BP. This is a nonpathologic finding resulting from increased cardiac stroke volume combined with highly elastic arteries and low peripheral vascular resistance. None of 1710 highly trained 14- to 18-year-old athletes had a systolic BP >120 mm Hg or a diastolic BP >80 mm Hg.[3] Additionally, highly trained 13- to 19-year-old players had lower systolic and diastolic BP readings than did control participants.[4]

Whereas information on ECG and BP changes in senior athletes is extensive, data on ECG and BP differences in adolescent athletes are lacking. Our aim was to define ECG and BP differences in adolescent endurance and nonendurance athletes and nonathletic, age-matched control participants.

METHODS

Between August 2013 and April 2014, 410 athletes and 164 nonathletes aged 14 to 16 years underwent cardiac evaluation as part of the multicenter Finnish Health Promoting Sports Club study. The study concept and design have been previously reported in detail.[7] The evaluation comprised a validated health questionnaire[8] on training activity and the presence of cardiac symptoms as well as a cardiovascular evaluation including a resting 12-lead ECG and BP measurements. Ethical approval was received from the Ethics Committee of the Health Care District of Central Finland. Written informed consent was obtained from a parent or guardian and the participant.

Athletes

A total of 240 youth sports clubs in the 10 most popular Finnish sports disciplines were targeted to produce a nationally representative sample of the most popular team and individual youth sports. Sports with their main competition season in the winter were basketball, cross-country skiing, floorball, ice hockey, and skating. Summer sports were gymnastics, orienteering, soccer, swimming, and track and field. Of the invited sports clubs, 154 agreed to participate in the study. We categorized cross-country skiing, orienteering, soccer, and swimming as endurance sports (n = 169) and other disciplines as nonendurance sports (n = 241).

Sampling of the athletes who were members of the sports clubs was tailored separately to team and individual sports and presented some differences between winter and summer sports, depending on the timing of data collection. Our aim was to collect winter and summer sports data during competition periods. Certain questions were related to the ongoing season, and thus, the specific goal was to time data collection after the midpoint of the competition period. Unfortunately, this was not always possible, and in those situations, we collected additional data just after the competition period.

The targeted athletes were 15 years old (9th graders). The athletes were randomly sampled from a list of eligible participants (based on age) on a given team. For individual sports, the athletes were similarly randomly sampled from a list of all eligible participants. Every third participant from the list was picked. If the number of athletes was small (more typical in the individual sports than in the team sports), it was possible that almost every athlete was invited. Initially, we aimed for 5 boys and 5 girls per club. This target was reduced to 3 per sex in the individual sports clubs because of the insufficient number of eligible athletes in some clubs.

Based on responses ascertained from the health questionnaire, none of the athletes had prior symptoms suggestive of underlying cardiac disease, and none were taking any medications relevant to the current study.

Nonathletes

Comparison data for the non–sports club participant control group were collected via secondary schools (9th graders) in the same approximate timeframe followed for the athletes. The schools were stratified according to (1) size (large versus small) and (2) location (city versus countryside). Initially, the aim was to convenience sample 10 schools over the strata in each of the 6 districts of the sports medicine centers. However, because of an insufficient number of small or countryside-based schools willing to participate in certain districts, we could not achieve the goal of 60 schools. In each school, non–sports club control individuals from 1 randomly selected class of 9th graders were asked to participate in the cardiac evaluation.

The nonathletes were healthy asymptomatic adolescents who were age matched with athletes based on school class. Like the athletes, none of the nonathletes had prior symptoms suggestive of underlying cardiac disease, and none were taking any relevant medications.

The 12-Lead ECG

A standard 12-lead resting ECG was recorded from each participant after a 5-minute rest during quiet respiration in a supine position. The electrodes were placed carefully to ensure consistency in the precordial lead locations, and ECGs were recorded at a paper speed of 25 mm/s with a 10-mm/mV gain. Seven quantitative ECG measurements that are believed to be correlates of HR, conduction, left ventricular mass, and repolarization were extracted for each participant: HR, PR interval, QRS duration and axis, sum of S wave amplitude in lead V1 and the maximum R wave in lead V5 or V6, T axis, and QT interval.[9] Amplitudes were recorded to the nearest 100th of a millivolt and times to the nearest millisecond.[9] The HR, QRS and T axis, QRS duration, and PR and QT intervals were analyzed digitally using each ECG recorder's software. The S wave in V1 and the R wave in V5 and V6 were measured using a millimeter ruler. The digital ECG measures were reviewed independently by a different physician in each sports medicine center, and manual measurements were taken using calipers and a ruler on demand.

Sinus bradycardia was defined as HR <60 beats per minute. *Prolonged and short PR intervals* were defined as a PR interval >200 milliseconds or <120 milliseconds, respectively. The QRS complex was considered abnormally widened if >120 milliseconds. *Left and right QRS axis deviations* were defined as a QRS axis more negative than 0° or more positive than +110°, respectively. Left and right T-axis deviations were defined as a T axis more negative than –15° or more positive than +105°, respectively. The QT interval was corrected for HR (QTc) using the Bazett formula. The QTc interval was considered abnormally prolonged if longer than 460 milliseconds. *Left ventricular hypertrophy* was identified using the Sokolow-Lyon voltage amplitude criterion: sum of the S wave in V1 and the higher of the R waves in V5 or V6 >3.5 mV.

Resting BP

Resting BP was measured in the left arm with the participant in a seated position after a 5-minute rest.[10] The measurement was performed with a similar validated, cuff-style oscillometric (automated) device (model M6W; Omron Healthcare, Inc) in each sports and exercise center. A correct-sized brachial cuff was placed with the lower edge about 2 to 3 cm above the elbow crease.[10] The device recorded the oscillations of pressure in a cuff during gradual deflation, and systolic and diastolic BP were estimated indirectly according to an empirically derived algorithm.[10] Two independent consecutive measurements were taken at intervals of 1 minute. If there was a >10 mm Hg difference in systolic or diastolic BP between the first and second measurements, a third reading was obtained after 1 minute. The PP was calculated as the difference between the systolic and diastolic BP.[11] *Elevated BP* was defined as ≥120 mm Hg or ≥80 mm Hg for systolic and diastolic BP, respectively.

Statistical Analysis

Means and SDs were calculated for the continuous variables. Distribution of the dichotomous variables is shown as frequencies and percentages. Mean body surface area was calculated using the formula of Du Bois and Du Bois.[12]

Comparisons between endurance and nonendurance athletes, between endurance athletes and nonathletes, and between nonendurance athletes and nonathletes were performed using multilevel modeling (SPSS version 25; IBM Corp). Multilevel modeling was used to appropriately allow for correlated data due to (1) cluster sampling (clubs for athletes, classes for nonathletes) and (2) the different ECG recorders used in 6 sports medicine centers. A 3-level data structure was constructed: the participants were level 1, the clubs and classes were level 2, and the sports medicine centers were level 3. Given the many choices of models to fit to a given data set with a 3-level data structure, we used the Bayesian information criterion (BIC) as a measure of model adequacy. The BIC number penalizes the likelihood of the observed data based on the total number of parameters in a model, with a lower BIC indicating a better model with a better balance between complexity and good fit. We fitted several models for each continuous and dichotomous ECG variable as a dependent variable and decided in advance to choose the model with the lowest BIC as our final model for a particular variable. That is, we did not force the 3-level data structure to our model in cases when it did not improve the model fit but instead brought unnecessary complexity to the model. The final models chosen for each ECG and BP variable are shown in Supplemental Tables 1a and 1b (available online at 10.4085/1062-6050-0078.20.S1). The results of the final binary logistic models are presented as (ORs) and 95% CIs.

The assumption of normal distribution was confirmed by visual inspection for each continuous variable. All statistical analyses were 2 sided, and a P value < .05 was considered significant.

Table 1. Anthropometric Characteristics of Endurance and Nonendurance Athletes By Sport Discipline

		Mean ± SD		
Sport Discipline	No. (%)	Height, cm	Weight, kg	Body Surface Area, m^2
Endurance sports				
Cross-country skiing	38 (9.3)	169.1 ± 6.5	57.7 ± 8.3	1.66 ± 0.14
Soccer	50 (12.2)	170.9 ± 8.0	59.1 ± 8.5	1.69 ± 0.15
Orienteering	41 (10.0)	169.4 ± 7.3	58.4 ± 8.1	1.67 ± 0.13
Swimming	40 (9.8)	171.6 ± 5.9	64.4 ± 8.9	1.76 ± 0.14
Nonendurance sports				
Basketball	39 (9.5)	177.6 ± 8.5	67.5 ± 8.3	1.84 ± 0.15
Floorball	42 (10.2)	175.7 ± 7.0	64.0 ± 9.0	1.78 ± 0.15
Ice hockey	39 (9.5)	174.1 ± 6.1	65.1 ± 9.2	1.78 ± 0.14
Skating	34 (8.3)	165.1 ± 6.1	57.1 ± 7.2	1.62 ± 0.12
Gymnastics	45 (11.0)	165.4 ± 7.0	58.0 ± 8.8	1.63 ± 0.14
Track and field	42 (10.2)	171.9 ± 7.9	62.6 ± 8.2	1.74 ± 0.14

RESULTS

The athletes' mean age was 15.5 ± 0.6 years. They competed mostly at the national (52.6%) or regional (26.4%) level, and 51.5% were female. The mean amount of training per athlete was similar during the preparation and competitive periods: approximately 9.5 hours of training per week. The nonathletes' mean age was 15.5 ± 0.5 years, and 66.5% were females.

Height, weight, and body surface area of the endurance and nonendurance athletes according to sport discipline are shown in Table 1. Height did not differ between endurance and nonendurance athletes, but nonendurance athletes were on average 3.1 cm taller than nonathletes (95% CI = 1.3, 5.0; $P < .05$). Nonendurance athletes were on average 2.5 kg heavier than endurance athletes (95% CI = 0.3, 4.8; $P < .05$). The mean body surface area of nonendurance athletes (1.73 m^2) was larger ($P < .05$) than that of endurance athletes (1.69 m^2) and nonathletes (1.69 m^2; Table 1).

The ECG in Athletes and Nonathletes

Resting ECG characteristics of endurance athletes, nonendurance athletes, and nonathletes are presented in Table 2. Mean resting HR, PR interval, QRS duration, QRS axis, QRS amplitude, T axis, and corrected QT interval showed no difference between endurance and nonendurance athletes ($P > .05$). The resting HR of endurance ($P < .001$) and nonendurance ($P < .001$) athletes was lower than

Table 2. Resting Electrocardiogram Characteristics in Endurance Athletes, Nonendurance Athletes, and Nonathletes

Electrocardiogram Variable	Endurance Athletes (n = 169)	Nonendurance Athletes (n = 241)	Nonathletes (n = 164)
Continuous variables, mean ± SD			
Heart rate, beats/min	60.0 ± 8.9	61.0 ± 10.7	66.6 ± 12.1
PR interval, ms	150.6 ± 20.5	148.9 ± 22.4	146.2 ± 19.0
QRS duration, ms	91.4 ± 9.2	92.0 ± 10.2	89.4 ± 8.3
QRS axis, °	64.6 ± 32.4	65.0 ± 21.9	65.1 ± 26.6
T axis, °	35.7 ± 16.6	36.7 ± 14.8	38.2 ± 15.7
Corrected QT interval, ms	415.2 ± 25.6	413.4 ± 34.7	414.2 ± 23.7
QRS amplitude, mm	27.0 ± 8.3	27.2 ± 8.3	23.6 ± 7.1
Dichotomous variables, n (%)			
Sinus bradycardia	89 (52.7)	111 (46.1)	46 (28.0)
Prolonged PR interval	4 (2.4)	4 (1.7)	1 (0.6)
Widened QRS complex	0 (0.0)	1 (0.4)	0 (0.0)
Left QRS axis deviation	7 (4.1)	4 (1.7)	3 (1.8)
Right QRS axis deviation	2 (1.2)	1 (0.4)	0 (0.0)
Left T axis deviation	0 (0.0)	1 (0.4)	0 (0.0)
Prolonged corrected QT interval	9 (5.3)	17 (7.1)	4 (2.4)
Left ventricular hypertrophy	26 (15.4)	34 (14.1)	14 (8.5)
Short PR interval	2 (1.2)	17 (7.1)	9 (5.5)
Left anterior hemiblock	1 (0.6)	0 (0.0)	0 (0.0)
Left posterior hemiblock	1 (0.6)	1 (0.4)	0 (0.0)

that of nonathletes. The PR interval was longer in endurance athletes than in nonathletes ($P = .05$). The QRS amplitude was higher in nonendurance athletes ($P = .03$) but not in endurance athletes ($P = .06$) compared with nonathletes (Table 2).

Sinus bradycardia (OR = 0.77; 95% CI = 0.52, 1.14), LVH (OR = 0.94; 95% CI = 0.60, 1.48), short PR interval (OR = 1.33; 95% CI = 0.85, 2.10), prolonged PR interval (OR = 0.97; 95% CI = 0.61, 1.52), left QRS axis deviation (OR = 0.69; 95% CI = 0.27, 1.77), right QRS axis deviation (OR = 0.96; 95% CI = 0.61, 1.52), prolonged corrected QT interval (OR = 1.09; 95% CI = 0.69, 1.72), widened QRS complex (OR = 1.02; 95% CI = 0.65, 1.61), left T axis deviation (OR = 1.02; 95% CI = 0.65, 1.61), left anterior hemiblock (OR = 0.97; 95% CI = 0.62, 1.53), and left posterior hemiblock (OR = 0.99; 95% CI = 0.63, 1.56) were equally prevalent among endurance and nonendurance athletes. Endurance athletes (OR = 2.85; 95% CI = 1.81, 4.50) and nonendurance athletes (OR = 2.19; 95% CI = 1.43, 3.35) were more likely to have sinus bradycardia than were nonathletes (Table 2).

Interaction Analyses

We also studied the modifying effect of sex on the differences in ECG variables among study groups. We performed 3 different interaction analyses per variable to study whether sex modified the differences between endurance athletes and nonendurance athletes, endurance athletes and nonathletes, and nonendurance athletes and nonathletes. Sex modified the difference in resting HR between nonendurance athletes and nonathletes ($P = .04$). The mean difference in resting HR between nonendurance athletes and nonathletes was 7.5 ± 1.6 and 2.6 ± 1.6 beats per minute in males and females, respectively. Similarly, sex modified the difference in bradycardia between nonendurance athletes and nonathletes ($P = .03$). No other interactions were found. The ECG characteristics in boys and girls are presented in Supplemental Table 2.

Table 3. Resting Blood Pressure (BP) in Endurance Athletes, Nonendurance Athletes, and Nonathletes[a]

Variable	Endurance Athletes (n = 169)	Nonendurance Athletes (n = 241)	Nonathletes (n = 164)
Continuous, mean ± SD, mm Hg			
Systolic BP	114.3 ± 9.7	115.7 ± 10.6	113.5 ± 10.2
Diastolic BP	64.1 ± 7.1	64.8 ± 7.8	66.1 ± 7.8
Pulse pressure	47.4 ± 9.8	48.0 ± 10.0	44.9 ± 9.7
Dichotomous, n (%)			
Elevated systolic BP	42 (24.9)	87 (36.1)	41 (25.0)
Elevated diastolic BP	4 (2.4)	7 (2.9)	6 (3.7)

Athletes' and Nonathletes' BP

The resting BPs of endurance athletes, nonendurance athletes, and nonathletes are presented in Table 3. In endurance athletes, systolic BP varied from 88 to 145 mm Hg and diastolic BP from 45 to 82 mm Hg. Corresponding values in nonendurance athletes ranged from 82 to 145 mm Hg for systolic BP and from 43 to 86 mm Hg for diastolic BP. In nonathletes, systolic BP varied from 90 to 145 mm Hg and diastolic BP from 48 to 90 mm Hg. The PP varied from 11 to 77 mm Hg in endurance athletes, 21 to 84 mm Hg in nonendurance athletes, and 19 to 83 mm Hg in nonathletes.

Systolic BP, diastolic BP, and PP showed no differences between endurance and nonendurance athletes ($P > .05$; Table 3). Systolic BP was higher in nonendurance athletes than in nonathletes ($P = .04$). Diastolic BP in endurance ($P = .002$) and nonendurance ($P = .02$) athletes was lower than in nonathletes. The PP was higher in nonendurance athletes than in nonathletes ($P = .04$) but did not differ between endurance athletes and nonathletes ($P = .07$).

Nonendurance athletes were more likely to have elevated systolic BP than were endurance athletes (OR = 1.70; 95% CI = 1.07, 2.72) and nonathletes (OR = 1.73; 95% CI = 1.04, 2.87). The prevalence of elevated diastolic BP did not differ between groups (Table 3). Sex did not modify the difference in any of the BP variables (P values > .05).

DISCUSSION

Our results suggested that ECG findings in adolescent athletes were similar regardless of their sports. However, resting HR was lower in endurance and nonendurance athletes than in nonathletes, and both endurance and nonendurance athletes had sinus bradycardia more often than did nonathletes. Furthermore, nonendurance athletes had a higher QRS amplitude than did nonathletes. Endurance athletes had a longer PR interval than did nonathletes.

Adolescent nonendurance athletes were more likely to have elevated systolic BP than were endurance athletes and nonathletes. Diastolic BP was lower in both endurance and nonendurance athletes than in nonathletes. The PP was higher in nonendurance athletes than in nonathletes. In a recent review[13] of mostly young athletes, researchers reported lower systolic and diastolic BP in endurance-trained athletes than in strength-trained athletes. Although nonendurance athletes in our study did not represent solely strength-trained athletes, our findings are mainly in line with the review results. However, in contrast to our outcomes, BP did not differ between athletes and nonathletes. In the same review, the investigators[13] noted a trend toward higher BP in athletes training >10 hours per week than in those who trained less.

Our findings yield further information for professionals interpreting ECG and BP results in young athletes. Young athletes have displayed different ECG findings than nonathletes.[3,4] Changes in the athletes' ECGs typically reflected cardiac hypertrophy due to pressure and volume overload.[14]

According to current knowledge, these various findings are thought to result mainly from endurance-type training. However, our work suggested that in addition to endurance athletes, ECG changes may also be present in adolescents participating in sports other than endurance types. Although health care professionals should take into account each athlete's status, the nature of the sport discipline may be less important. Due to the observational nature of our investigation, we are not able to provide guidelines for classifying a particular ECG finding as either abnormal and requiring further evaluation or the basis for granting clearance for participation.

Electrocardiographic Findings

Resting HR did not differ between endurance and nonendurance athletes but was significantly lower in both groups than in nonathletes. This finding is consistent with previous assessments in young athletes.[14,15] We noted that sinus bradycardia was more prevalent in endurance and nonendurance athletes than in nonathletes. The most pronounced ECG features have usually been seen in endurance athletes, and therefore, bradycardia was expected in that group. However, nonendurance athletes also exhibited bradycardia. This was not surprising considering that some sport disciplines categorized as nonendurance sports include characteristics similar to those of endurance sports.

Up to half of male adult athletes exhibited the Sokolow-Lyon voltage criterion for LVH,[15,16] and LVH has been commonly seen in young athletes.[16–18] In our research, LVH was more prevalent in athletes than in nonathletes, but the difference was not statistically significant. However, nonendurance athletes had higher QRS amplitudes than nonathletes, and the association was borderline significant in endurance athletes and nonathletes. This suggests that adolescent athletes also experienced thickening of the left ventricular myocardium. Our finding that adolescent endurance athletes had longer PR intervals than nonathletes is consistent with previous results in adolescents[3,18,19] and prepubertal children.[19,20] We did not see differences in QRS duration or QT interval between athletes and nonathletes. The literature is inconsistent concerning QRS duration and QT interval: some researchers found differences[3,16,17] between athletes and nonathletes, whereas others did not.[17–20]

To our knowledge, we are the first to compare ECG findings between adolescent endurance athletes and nonendurance athletes, but ECG findings have been extensively studied in adult athletes. More than half of adult athletes demonstrated ECG changes such as sinus bradycardia, sinus arrhythmia, first-degree atrioventricular block, early repolarization, incomplete right bundle branch block, and voltage criteria for LVH.[2] Compared with adult athletes, young athletes more rarely presented with distinctly abnormal ECGs.[20,21] The ECG findings observed in adult athletes may reflect structural changes that developed as a result of long-term training; such prominent changes probably do not occur in adolescent athletes with fewer years of training.

Blood Pressure and Pulse Pressure Findings

Resting systolic and diastolic BP were mostly at a low-normal level in endurance and nonendurance athletes, which is consistent with previously studied young athletes.[13] However, children who reported more endurance-type physical activity displayed higher systolic BP and PP levels than sedentary children.[21,22] Especially intense physical activity correlated directly with systolic BP and PP in 2 investigations,[21,22] yet others found opposite results.[13]

A low prevalence of elevated BP among our participants is in line with descriptions[22,23] of a low (3%) prevalence of hypertension in young adults who were engaged in competitive sports. In the general population, elevated BP was observed in 11% of young adults,[23,24] largely related to family history and being overweight. The prognostic significance of high BP in athletes is still unclear,[13] although a high-normal level of resting BP was a predisposing factor for future hypertension in middle-aged men with an exaggerated increase in BP during exercise.[24,25]

As expected, average PP was normal in all study groups despite some high values. Although physical activity plays an important role in preventing a high PP, the dose-response relation between physical activity and BP in adolescents is unknown.[21,22] Within optimal BP values, PP remains between 40 and 45 mm Hg, showing good elasticity of large arteries in adults. The PP typically rises gradually due to stiffening of the large arteries during aging, which predicts the risk of coronary heart disease.[25,26]

Strengths and Limitations

The major strength of this study was our representative and relatively large sample from different regions of Finland, including the 10 most popular sport disciplines in Finland. We included more athletes than nonathletes because we wanted to assess participants in both summer and winter sports as well as individual and team sports. Further, we used multilevel modeling, which enabled clustered observations inside separate clubs for athletes and nonathletes, as well as the possibility of clustering in 6 separate sports medicine centers. The use of regular single-level regression techniques to address multilevel factors is subject to errors originating from violations of the regression assumptions, which may lead to poorly estimated results. Our robust classification of sport disciplines as endurance sports or nonendurance sports allowed us to compare ECG findings in adolescent athletes across different types of sports. However, our research addressed only 10 of the most popular sports for youth in Finland, and our results are not generalizable beyond these sports. Other limitations include the cross-sectional nature of this study, which prevented us from drawing any inferences about causality. In addition, our work was partly based on self-reported questionnaire data, so recall bias is possible; with retrospective designs, the participant's ability to remember and report information correctly is a potential concern.

In conclusion, young athletes mainly exhibited similar ECG findings and BP and PP levels independent of sport, but differences emerged when they were compared with nonathletes. Particular physiological adaptations, such as sinus bradycardia, higher QRS amplitude, and lower diastolic BP, which reflect common ECG and BP patterns in adult athletes, were already present in adolescent athletes.

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