Musculoskeletal Extremity Injuries in School-aged Children

with special focus on overuse injuries, seasonal variation and body composition

An investigation based on an observational prospective school based cohort study
The Childhood Health, Activity and Motor Performance School Study Denmark

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Odense 2014

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Contents

Preface

This thesis was conducted at the Faculty of Health Sciences, Centre of Research in Childhood Health, Research Unit of Exercise Epidemiology, Department of Sport Science and Clinical Biomechanics, University of Southern Denmark, in the period 2008 – 2013.

This PhD thesis presents results obtained from The Childhood Health, Activity and Motor Performance School Study, Denmark – The CHAMPS Study-DK. In 2007 the city council of the municipality of Svendborg, Denmark, decided to create sports schools with the intention to improve physical health of children (the Svendborg Project). The CHAMPS Study-DK was made responsible for the scientific evaluation of this project. The study is ongoing since August 2008 and has the overall aim to investigate the effect of additional physical education in a school based curriculum on children's health. The studies of this thesis have focus on musculoskeletal extremity injuries in children during 2.5 years from 2008 to 2011. The author of this thesis contributed full time to the data collection for the entire study period.

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Funding

The studies of which the thesis comprises, was supported by grants from The IMK Foundation, The Nordea Foundation, The TrygFond Foundation - all private, non-profit organizations, who supports research in health prevention and treatment and TEAM Denmark, the elite sport organisation in Denmark, that provided the grant for the SMS-track system.

List of studies

This thesis is based on the following four studies, which will be referred to by their roman numerals in the text:

I. Jespersen E, Holst R, Franz C, Rexen CT, Klakk H, Wedderkopp N. **Overuse and traumatic extremity injuries in school children surveyed with weekly text messages over 2.5 years.** Scand J Med Sci Sports (2013) (Epub ahead of print)

II. Jespersen E, Rexen CT, Franz C, Møller NC, Froberg K, Wedderkopp N. **Musculoskeletal extremity injuries in a cohort of school children aged 6-12: A 2.5 year prospective study.**
Accepted for Scand J Med Sci Sports

III. Jespersen E, Holst R, Franz C, Rexen CT, Wedderkopp N. **Seasonal variation in musculoskeletal extremity injuries in school children aged 6-12 followed over 2.5 year.** BMJ Open (2014) (Epub ahead of print)

IV. Jespersen E, Verhagen E, Holst R, Klakk H, Heidemann M, Rexen CT, Franz C, Wedderkopp N. **Total body fat percentage and body mass index and the association with lower extremity injuries in children: a 2.5-year longitudinal study.** British Journal of Sports Medicine (2013) (Epub ahead of print)

Thesis at a glance

Study	Objectives & participants	Methods	Conclusions
|I	To report the incidence, prevalence and duration of traumatic and overuse injuries. To estimate the odds of injury types when looking at sports participation in school and leisure time as a risk factor, adjusting for gender, age, previous injuries, and seasonal variation. 1259 children (661 girls, 598 boys). Baseline mean age: 8.4 (5.4 - 11.6)	SMS-track (automated text messaging) reports on: • Musculoskeletal pain • Leisure time sports participation Telephone consultation identifying injuries and a clinical examination diagnosing injuries	Close to twice as many overuse as traumatic extremity injuries were registered, with 2.5 times more overuse than traumatic injuries in lower extremities. A reverse pattern was found for upper extremities, with 3.1 times more traumatic than overuse injuries. Grade level, school type, leisure time sport, and seasonal variation were associated with the risk of sustaining lower extremity injuries. Only grade level was associated with upper extremity injuries.
II	To describe the epidemiology of diagnosed musculoskeletal extremity injuries and to estimate the injury incidence rates in relation to different settings, different body regions and injury types. 1259 children (661 girls, 598 boys). Baseline mean age: 8.4 (5.4 - 11.6)	SMS-track (automated text messaging) reports on: • Musculoskeletal pain • Leisure time sports participation • Sports Telephone consultation identifying injuries and a clinical examination diagnosing injuries Accelerometer	A total of 1229 injuries were presented with apophyses and soft tissue injuries being the most common overuse injuries in lower and upper extremity. Ligament sprains were the most common traumatic injury. Injury rates of traumatic injuries were found to be highest for injuries sustained in sports and lowest for injuries sustained in physical education lessons. The shoulder/upper arm and the heel were the most common region of overuse injury in upper and lower extremity. The hand/wrist and the ankle were the most common regions of traumatic injury.
III	To determine the seasonal variation in extremity injuries in children. 1259 children (661 girls, 598 boys). Baseline mean age: 8.4 (5.4 - 11.6)	SMS-track (automated text messaging) reports on musculoskeletal pain. Telephone consultation identifying injuries and a clinical examination diagnosing injuries.	There are clear seasonal differences in the occurrence of musculoskeletal extremity injuries among children with almost twice as high injury incidence and prevalence estimates during autumn, summer and spring compared to winter.
IV	To examine two different measures of overweight, BMI and TBF%, as risk factors for lower extremity injuries in a school-based cohort, while considering potential confounding effects of gender, age, fitness levels and exposure times in physical education and leisure time sports participation. 632 children (321 girls, 311 boys) Baseline mean age: 9.6(7.7 - 12.0)	SMS-track (automated text messaging) reports on musculoskeletal pain and leisure time sports participation Telephone consultation identifying injuries and a clinical examination diagnosing injuries DXA scan providing body fat percentage BMI Aerobic fitness	The risk of lower extremity injuries increased in overweight children. When comparing two different measures of overweight, a body composition of proportional high levels of %BF is a higher risk factor, than overweight as measured by BMI. This suggests that a high proportion of adiposity explains injury risk better than being heavy for reasons that could also include a high proportion of lean muscle mass.

Description of contributions

	Study design	Data collection	Data analysis	Manuscript writing	Manuscript revision
Study I	EJ, NW	EJ, CF, CTR, HK, NW	EJ, RH, NW	EJ	EJ, RH, CF, CTR, HK, NW
Study IV	EJ, NW	EJ, CF, CTR, NCM, NW	EJ	EJ	EJ, CF, CTR, NCM, KF, NW
Study III	EJ, RH, NW	EJ, CF, CTR, NW	EJ, RH, NW	EJ, NW	EJ, RH, CF, CTR, CY-L, NW
Study II	EJ, EV, NW	EJ, HK, ML, CF, CTR, NW	EJ, EV, RH, NW	EJ	EJ, EV, RH, HK, MH, CF, CTR, NW

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NW	Niels Wedderkopp
RH	René Holst

Introduction

Why is it important to focus on musculoskeletal health in children?

Participation in physical activities promotes health in children. It has been shown that regular physical activity is associated with numerous physical health benefits, improved cognitive function, mental well-being, higher self-esteem and social skills in children [1-4]. A drawback of physical activity is the risk of related musculoskeletal injuries, both in adults and children. Injuries sustained during physical activity have been established as a leading cause of paediatric injuries in western countries [5-7]. Physical activity-related injuries in children constitute a significant public health burden, leading to high direct and indirect costs for both children and parents [8]. Injuries may cause short-term disability, absence from school and sport, loss of enthusiasm for participating in physical activities, and long-term consequences such as osteoarthritis resulting in pain and a decrease in physical activity [9-12]. A lowering of the physical activity level could have serious personal and public health implications, such as increased risk of cardiovascular disease and type II diabetes [13]. Thus from both an individual and a public health point of view it is important to prevent injuries.

Physical activity-related injury problems in general populations of children

A majority of published studies in the area of physical activity-related injuries in children have presented selected study populations and selected injury types, due to extracting data from selected settings (i.e. emergency departments, specific sports) or selected clinical conditions (i.e. ankle-ligament sprains, anterior cruciate ligament ruptures). Although all studies are informative it would seem that only part of the total injury problem is revealed, and that the less severe injuries and overuse injuries are under-represented. Previously pointed out as the “tip-of-the-iceberg” phenomenon by Dutch and Norwegian injury research groups [14-17].

A few descriptive epidemiology studies have looked into the general injury incidence in children and adolescents. The National Centre for Health Statistics conducted a large household survey in the US population and found that annually an estimated 7 million Americans received medical attention for sports and recreation related injuries (25.9 injury episodes per 1000 persons). The highest average annual medically attended sports and recreation injury episode rates were found in children aged 5-14 years (59.3 per 1000 persons) [6]. A Canadian survey of sport participation and sport injury high school students, aged 14-19, reported 65.7 injuries per 100 adolescents per year. When accounting for only those injuries that required medical attention the rate was 40.2 injuries per 100 adolescents per year [18]. The Childhood Injury Prevention Study followed a sample of 774 randomly selected Australian school children aged 4 to 12 years over 12 months. The overall injury incidence represented a 12-month physical activity-related injury incidence of 53.2 per 100 children. Child-based injury rates were calculated both in and out of the school setting, thus school injuries accounted for 10.8 injuries per 100 children per year, while non-school injuries accounted for 42.6 injuries per 100 children per year. The study also presented exposure rates based on time-at-risk for non-school injuries, namely 5.9 per 10.000 hours of exposure for injuries sustained outside school hours [19]. The Dutch iPlay-study, an injury prevention school study, was carried out in a cluster-randomised sample of 996 children aged 10-12 years followed over 12 months. The overall injury incidence rate was 0.48 per 1.000 hours of exposure, with leisure time physical activities having the lowest injury rate (0.39), followed subsequently by physical education lessons (0.50) and sport (0.66) [20].

Injury definitions and impact on the study outcomes

The above-mentioned surveys/ studies were carried out in population-based settings, but still reporting mostly severe and traumatic injuries due to the choice of injury definitions. Physical activity-related injuries are commonly defined by one of three possible criteria: the criteria of all physical complaints regardless of their consequences ('any physical complaint' definition), the criteria of needing medical care seeking ('medical attention' definition) or by the criteria of being unable to fully participate in normal activities ('time-loss' definition) [21].

It has been commonly acknowledged that different injury definitions identify different types of injuries in terms of injuries being severe or less severe and/or if they are traumatic or have a more gradual onset as overuse injuries [15 16, 22]. Traumatic injuries are those resulting from a single, specific, and identifiable event whereas overuse injuries are caused by repeated micro trauma without a single, identifiable event responsible for the injury [21].

The 'time-loss' injury definition has been questioned in the context of measuring overuse injuries as symptoms often have a vague and gradual onset, generating pain, but not necessarily causing time-loss from physical activities. This was illustrated in a study using beach volleyball as an example of how different injury definitions and recording methods led to different conclusions regarding the rate and severity of overuse injuries [16]. Beach volleyball is a technical sport with minimal contact between opposing players and few traumatic injuries [23], but a nature that calls for overuse injuries due to a lot of repetitive over-head and jumping activities. Bahr (2006) showed that using a traditional cohort study approach, the time-loss definition suggested that injury risk was very low, but using a survey of past and present pain problems in the shoulder, knees and low back demonstrated that overuse injuries were indeed prevalent [16]. The study was used to provide recommendations for a standardized methodology to quantify overuse injuries in sports and points out the advantage of frequent and prospective measurements, using sensitive scoring instruments to measure pain symptoms and define injuries by other means than time lost from sport or the need for medical attention [16].

The choice of an injury definition that embraces any physical complaint serve as a fine-meshed method for the recording of all symptom-giving injuries, independent of whether these injuries requires medical care or causes time loss from school and physical activities. Reporting of all injuries causing physical complaints seem relevant in the case of the young, growing and playing child. Musculoskeletal pain in children can be disabling and is not in all cases a self-limiting phenomenon [11, 24, 25]. Musculoskeletal pain and disability in adults are a major problem in modern society, and there has been an increasing amount of studies showing patterns of tracking of back pain from childhood into adulthood [26-28]. Only few studies have looked at extremity pain as a predictor and found associations between self-reported extremity pain and later extremity pain disorders. These studies were limited to a retrospective study design possibly inducing recall bias or cohort studies still awaiting long-term follow-up [24, 29, 30]. Results from these studies describe symptoms according to body area, frequency and duration, but leave causes uncertain. When Bishop and colleagues (2012) asked parents, what they thought was the cause of their child's extremity pain, a large number chose to state that the reason was unknown and the most often cited cause of extremity pain was referred to as growing pains [29].

Though it seems that musculoskeletal pain complaints should not be ignored in children through the years of growth, the injury definition 'any physical complaint' will yield a high rate of non-specific conditions if generated by self-report by child or parents and not by clinical assessments. Clinically diagnosed injuries give detailed information on the kind of tissue damage that is causing the physical complaints. Furthermore it gives an understanding of injury mechanism in terms of tissue damage being a result of a traumatic event or a result of accumulated micro-traumatic stress over time. An insight into the magnitude and nature of childhood musculoskeletal injuries allows for better planning and tailoring of preventive and treatment strategies.

Aetiology of physical activity-related injuries

An efficient preventive approach of musculoskeletal injuries in children also requires an insight in the circumstances in which they arise. The understanding of injury aetiology is another step to reduce physical-activity related injuries. Meeuwisse and colleagues (2007) developed a dynamic and cyclical model for injury causation, illustrating that injuries are not just the result of one specific inciting event but a complex interaction between intrinsic and extrinsic risk factors leading to the event that incites injury (figure 1) [31]. Risk factors are not considered stable, but may change through preceding cycles of participation and circumstances, for example a cohort of athletes will have a changing risk factor profile during a season. The recursive nature of the model also illustrates the cause of overuse injuries as it is not one single, identifiable event, but multiple exposures to the same risk factors that causes maladaptation and eventually tissue damage resulting in an overuse injury [21].

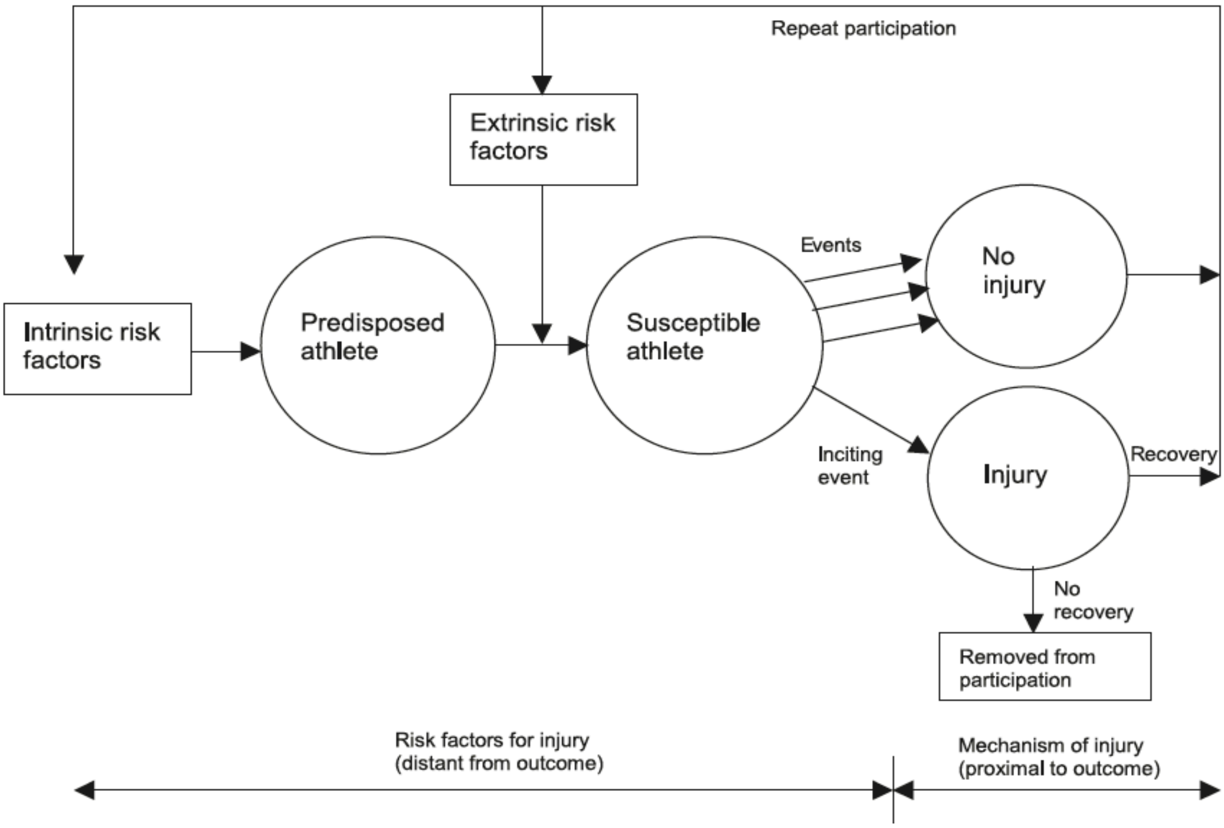


Figure 1. A dynamic, recursive model of aetiology in sport injury by Meeuwisse et al, 2007 [31]

Risk factors for injuries are factors that increase the potential risk for injury and can be divided into two categories: Intrinsic risk factors related to the individual (e.g. age, gender, previous injury, strength, fitness etc.) and extrinsic risk factors not related to the individual (e.g. time of season, playing surface, equipment, sport played, rules, etc.) [32]. Another consideration is whether risk factors are modifiable and can be altered by injury prevention strategies to reduce injury rates. Non-modifiable risk factors (e.g. gender, age, time of season) may affect the relationship between modifiable risk factors and injury and assists in defining high-risk groups [32].

Injury risk factors are a common set of factors that influence injury risk in all age groups, but in some fields they might have different influence in children /adolescents than later in adulthood and some factors are unique to the growing individual.

Intrinsic risk factors in children

Skeletal growth and musculoskeletal concerns

In the years of growth skeleton tissue develops from cartilage to bone tissue during processes of ossification occurring in several stages for different bones and continuing into the mid-20s [33]. The growing zones of the long bones include the physis and the epiphysis, and are sites vulnerable to musculoskeletal pain and injuries, commonly described as physeal injuries or growth plate injuries [34, 35].

Two types of epiphyses are found in the extremities: traction epiphyses and pressure epiphyses [34]. Traction epiphyses (or apophyses) are located at the site of attachment of major muscle tendons to bone (e.g. the attachment of the quadriceps muscle to the apophyses of the tibial tubercle). The apophyses contribute to bone shape, but not to the longitudinal growth. Consequently overuse apophyseal conditions, such as Osgood-Schlatter, Sinding-Larsen and Sever's are not generally associated with disruption of longitudinal bone growth, but may be a source of pain, discomfort and time lost from physical activities. Pressure epiphyses are situated at the end of long bones and are subjected to compressive forces (e.g. the epiphyses of distal femur and proximal tibia). In contrast with traction growth plates, injury to pressure epiphyses, such as physeal fractures may result in growth disturbance [34].

A decrease in bone strength appears to occur in the 2 to 3 years before peak height velocity in girls and boys (girls on average 12 y, boys on average 14 y) [33, 36]. It has been proposed that the time of rapid skeletal growth can temporarily increase muscle-tendon tightness and inflexibility because muscle development is thought to lag behind bone development [37]. However there is no evidence of this in the literature and one study found that adolescent growth were not associated with changes in flexibility [38].

To sum up, injuries that occur with similar mechanisms might result in different pathological conditions in children compared to adults. The immature skeleton is the weak link during growth, whereas soft tissue injuries (e.g. muscle strains, ligament sprains) are more prevalent in adults. One example is that while repeated contraction of the quadriceps muscle, typically from running -, jumping - and kicking sports, might result in pain at the apophyses of the tibial tubercle in children, the same mechanism might manifest as pain in the patellar tendon in adults [39].

Gender

Previous studies have found evidence that males are generally at higher risk of injury in child and adolescent sport (OR = 1.16 to 2,4) [32]. Possible explanations have included that boys are more likely to participate in vigorous exercise and sport, have a higher risk-taking attitude and have a larger body mass leading to greater forces generated on contact [32, 40]. Still, exceptions where girls are more at risk are easily found in sport specific studies (e.g. basketball, cross-country running, gymnastics, soccer and handball) or specific clinical conditions (e.g. knee injuries, especially anterior cruciate ligament ruptures) [41-44]. Many explanations have been given why girls suffer more serious knee injuries than boys, including anatomical variation, hormonal influences and neuromuscular factors [41, 42].

In heterogenic, more population-based cohorts, opposite results have been shown. Spinks and colleagues investigated 744 Australian school children aged 4-12 years and found that boys were injured at a higher rate than girls (62.9 vs. 41.5 injuries per 100 children per year) [19]. In contrast a Dutch school study, investigating 996 children aged 10-12 years, found that girls were at higher risk than boys (0.59 vs. 0.36 per 1000 hours of exposure) [20].

The possibility of gender differences in injury risk ‘crossing over’ between the ages 12 to 14, presumably due to the growth spurt appearing earlier in girls, has been suggested [20, 45]. A Danish study in 4619 children aged 6-17, treated in an emergency department, investigated age- and gender-specific incidence rates of sports injuries. They found girls had peak incidence rates at the age of 13 and boys at the age of 14, after which injury risk was observed to be substantially higher in boys [45].

Age

Risk of injuries generally increases with age across most studies when looking at specific sports [32, 41] even though some studies have shown the reverse or not found any association between age and injury [42]. Possible explanations are increasing hours of participating in sport, higher levels of competition and adolescents generating more force on contact than younger children, given that they are faster, heavier and stronger [32, 41].

Children of the same chronologic age may vary considerably in biologic maturity status, and individual differences in maturity status influence measures of growth and performance during childhood [33]. It has been speculated that early- and late-maturing children are at different injury risks. Findings from studies on the relationship between biologic maturity and injuries in sport are ambiguous and lack information on individual variation in exposure time, leaving the possibility that results are more an expression of time participating in sport than maturity [41].

Body composition

Body composition, defined as the relationship between bone tissue, lean muscle and fat mass, has received some attention as a potentially modifiable risk factor on sport injury risk [32, 41]. Major changes in body composition occur during childhood and especially in adolescence when gender differences are established [33].

There has been a focus on the particular association between overweight and injuries [46]. The importance is emphasized as overweight and obesity are affecting an increasing proportion of children globally [47]. Hence the paradox is, that while physical activity is associated with numerous health benefits, including reducing the levels of overweight and obesity[13], overweight might at the same time cause a rise in injury rates as the prevalence of overweight and obesity increases.

Overweight youth are generally considered as being at increased risk of sustaining lower extremity injuries in sports, due to a corresponding increase in the forces that bones, ligaments, tendons and muscular structures must endure [42, 46, 48]. However findings in studies about the association between body composition and injuries are inconclusive, and choices of measures of body composition have been different, such as height and weight, lean muscle mass, body fat content and most commonly body mass index (BMI) [42].

Overweight and obesity should be defined as excess body fat. The most widely used measurement to define obesity is BMI. It is an indicator of overweight and obesity from a population perspective, but has limitations on an individual level and is only a proxy measurement of body fat [49]. Not all individuals with excess weight are fat, because muscle mass and other non-fat tissues may contribute to the increase in weight [33]. Especially in athletes, the association between BMI and body fat has shown to be lower than in non-athlete controls [50-53].

In view of this, the common use of BMI as a criterion measurement may be an issue when it involves physically active children. A high BMI might in that case be an expression of a high proportion of lean muscle mass, rather than overweight or 'unhealthy' weight. Generally, caution should be taken when using BMI in growing individuals with changing relationship between body proportions (e.g. increased stature relative to weight) [33]. Body fat percentage is a measure of adiposity and in the area of sports it has proven to be a more precise measure for classification of overweight [51-54].

Previous injury

Evidence is provided in the literature that previous injuries combined with inadequate rehabilitation are risk factors for re-injury of the same type and location in adults, especially in the ankle [42, 55, 56]. A previous injury may lead to an increased risk of sustaining future injury, possibly due to persistent symptoms and underlying physiologic deficiencies (i.e. muscular weakness and imbalance, low endurance, impairment of ligaments, proprioception and fear of re-injury) [42, 57].

Few studies have addressed the problem in a childhood population. In a Dutch school cohort study, 38% of injuries were considered re-injuries, but criteria for classifying injuries as re-injuries were not stated [58]. When using the criteria of same body part, injury type, nature of onset and a history of injury the previous year a study in young (mean age: 12.6) female gymnasts showed a percentage of re-injuries of 32.7% [59]. It seems that re-injuries are an existing problem in childhood, but whether previous injuries leads to increased risk of sustaining a new injury has to our knowledge not been demonstrated in a child population.

Extrinsic risk factors in children

Time-at-risk

The time participating in physical activities, whether in physical education lessons, different sports or in unorganized physical activities in leisure time, is the time at risk of physical activity-related injuries.

Injury risk can be expressed as the number of new injuries that occur in a defined population during a specific period of time; i.e. injury incidence rates [60]. The most common approach to calculate incidence rates in the sports injury literature is to report the number of incident injuries divided by the total time at risk and is usually multiplied by a value expressing the chosen period of observation (e.g. 1000 hours) [61]. Other units of time-at-risk are 'athlete exposures', defined as one athlete participating in one practice or game where there is the possibility of sustaining an athletic injury and 'element-exposures', defined as one athlete participating in one element of activity (e.g. pitches, plays, bike trips) [61]. Finally, an incidence rate expressing the number of injuries divided by the total number of individuals and usually multiplied by a chosen number of individuals (e.g. 100) has served as an indicator of clinical resource use and therefore named a clinical incidence, but is not considered a valid estimator of risk nor a true rate as it does not take exposure time into account [60].

Using the 'time-exposure' accounts for the potential variance in exposure of individuals to risk of injury and makes comparison between studies possible if the same units of time-at-risk are used (e.g. minutes, hours) [61]. However, some authors have pointed out that a time-based exposure measure is meaningless in sports with constant interruptions (e.g. American football) leaving players inactive during significant proportions of game time [62] or in activities where it is more the specific elements (e.g. number of bicycle rides) that associates with risk of injury than the time [63].

Seasonal variation

Different times of the year invite different types and intensities of physical activities and different types of physical activities engender different types of injuries [64-68]. A review of the literature reveals that very little information is available on the injury pattern in children over the calendar year. Only data on more serious injuries from emergency room treatments and hospitalized children are available and show an indication of seasonal pattern to the incidence and type of injuries [65-68]. Literature on the seasonal injury pattern among children in the general population, which would be necessary in order to obtain proper incidence and prevalence data including also less serious injuries and overuse injuries, was not found. A Dutch school cohort study used a correction factor to account for seasonal effects on physical activity participation throughout the follow-up period (12 months) [20]. It seems reasonable that a proper survey of a possible variation in incidents of injuries across seasons necessitate frequent injury recording.

Injury incidence and prevalence

Basic epidemiology applied to sports and other physical activity-related injuries presents incidence as the number of new injuries that occur over a specific period of time, whereas the prevalence of injury is the proportion of athletes who have an existing injury at any given point in time [60]. Traditionally, the main focus has been on issues related to estimating injury incidence in sports injury research [60], but prevalence measures have been found more appropriate in the area of valid recording of overuse injuries [16]. The proportion of individuals affected by an overuse problem at any given time will capture the magnitude and severity of overuse injuries better, as symptoms might persist for several seasons and may exist before the injury recording has started. Thus the latter might not be registered as an incident injury, even though it is very long lasting and performance limiting [16]. Duration of injury affects the prevalence, but needs prospective and serial measurements of symptoms to get valid information on the severity of injury in terms of duration [22]. In the case of the growing child, the registration of injury incidence, injury prevalence and duration of injury are all important information. To date, however, there has been a lack of studies reporting childhood injury prevalence and duration of injuries, and there have been limited studies on childhood injury incidence and associated risk factors in general populations.

This thesis is based on information gathered in a large cohort of Danish schoolchildren aged 6 to 12 followed closely with mobile phone text messaging data on symptoms indicative of musculoskeletal injuries, with real time data on injuries diagnosed by clinicians and level and type of physical activity. This provided an opportunity to obtain estimates of the incidence, prevalence and duration of physical activity-related, musculoskeletal injuries occurring during a period of 2.5 years in a population-based sample of children. The thesis also looks into the above-described risk factors and the association with injury risk in children.

Aim and objectives of the thesis

Aim

To investigate the patterns of musculoskeletal extremity injuries in school children.

Objectives

1. To report the incidence, prevalence and duration of traumatic and overuse injuries in a cohort of school children using weekly assessments for 2.5 years and to estimate the odds of injury types when looking at sports participation in school and leisure time as a risk factor, adjusting for gender, age, previous injuries, and seasonal variation (study I).
2. To report diagnosis of all musculoskeletal extremity injuries and injury incidence rates in a cohort of school children aged 6-12 followed during 2.5 years (study II).
3. To examine the seasonal variation in extremity injuries in children (study III).
4. To examine two different measures of overweight, BMI and %BF, as risk factors for lower extremity injuries in a school-based cohort, while considering potential confounding effects of gender, age, fitness levels and exposure times in physical education and leisure time sports participation (study IV).

Methods

Setting

The studies in this thesis are all based on data from the Childhood Health, Activity, and Motor Performance School Study Denmark (CHAMPS Study–DK) August 2008 to July 2011 [69]. This investigation is a large prospective controlled school-based study in Denmark using the design of a natural experiment [70] to evaluate the effect of increased physical education on childhood health in general. Six schools were assigned to become sport schools with six physical education lessons per week and four normal schools served as control with two physical education lessons per week. The project is extensively described elsewhere (Wedderkopp et al., 2012).

This thesis is not an evaluation of the effect of increased physical education, but an investigation of musculoskeletal injuries in children taking exposure to physical activities, seasonal variation, body composition and other explaining factors into consideration.

Participants

All boys and girls from pre-school to fourth grade in ten public schools participating in the CHAMPS Study-DK also agreed to participate in the registration of musculoskeletal pain and injuries. The overall participation rate was 697 (90%) for the sport schools and 521 (71%) for the normal schools. The study was kept open, with the opportunity for new children to enter. Due to the novel data collection method of automated mobile phone text messaging (SMS-track), the ten schools were included gradually over eight months in order to allow for a phasing-in process.

Collection of injury data

SMS-track – surveying musculoskeletal problems using mobile phone text messaging

The method

The underlying theory to mobile phone short message service (SMS) surveying has been described by Schiffman[71] as an Ecological Momentary Assessment, a method well suited to assess how events change over time and across contexts in subjects' natural environments. Ecological Momentary Assessment was introduced in 1994 as a method to avoid memory lapse and recall bias, by repeated assessments using technologies ranging from diaries, telephone interviews, palm-top computers and lately SMS. The aim is to get real world information in real time about a subject's current state, thus maximizing validity of data as opposed to data collected retrospectively [71].

Using SMS in research is still a novel method, but has so far proven that it is possible to collect accurate data of fluctuating conditions by obtaining detailed information on changes over time [72, 73]. Moreover the method has shown to be an inexpensive, feasible and user-friendly method for collecting data, with high compliance rates [72-76].

Studies on validity and reliability are still needed, but in one study construct validity was moderate to strong when comparing weekly responses on low back pain with the initial pain score and two self-rated health measures collected during and after completion of the study [77]. In another study a comparison between real time data captured by SMS and retrospective telephone interview showed low agreement between 1-year recall and weekly reports, whereas 1-week and 1-month agreement was high [75]. In this study the SMS-Track reporting where validated against verbal reporting. The sensitivity for the SMS-track data was 0.98, specificity 0.87, positive predictive value 0.94 and the negative predictive value 0.95, indicating high validity of data [78].

The technology

SMS-Track is a web-based program (Software-as-a-Service) that enables use of text messages as a means to perform surveys. The service has been used within research projects with a focus on frequent monitoring and iterative data gathering, which has transformed the service to contain a series of industry best practices within SMS surveying. The technology enables data from a large number of respondents to be gathered at frequent intervals and yield real time information through two-way messaging. Data from the text message can be viewed instantly, making it possible to identify non-responders and recognize misunderstandings. The data are automatically transferred to an electronic data file which is readily available for download in various formats, making import to statistical programs possible [79].

SMS-track as a method in this study

Data on musculoskeletal complaints were collected weekly during 2.5 school years using SMS-track. Collection of data was suspended during the six weeks of summer holiday and one week of Christmas holiday.

Parents were used as informants on behalf of the child, as self-reported data from young children may be inaccurate [80, 81]. Every Sunday, text messages were automatically sent to the parent's mobile phone asking the following question:

> "Has [NAME OF CHILD] during the last week had any pain in:
> 1. Neck, back or low back
> 2. Shoulder, arm or hand
> 3. Hip, leg or foot
> 4. No my child has not had any pain."

The parents were asked to type the relevant number in a return text message.

If parents forgot to answer, reminders were sent twice with an interval of 48 hours. If parents did not answer at all, or answered in text or other invalid ways, research assistants contacted them by telephone to clarify facts. If there was no contact, the answer was coded as a missing value. All the answers were stored directly in a database, thus making it possible for researchers to extract information instantly.

The answers served to investigate the fluctuations in musculoskeletal symptoms and duration of pain over time, but was at the same time a weekly screening, leading to the identification of new incidences of musculoskeletal related injuries. The procedure was to identify all new reports on musculoskeletal pain by listing the parents, who had answered 1, 2 or 3, giving the information that the child had experienced pain and in which anatomical region (back, upper extremity or lower extremity). Further information on the origin, nature and course of pain, was captured by clinicians contacting the parents by telephone.

Telephone consultation

Two physiotherapists and two chiropractors were responsible for the follow-up of children reporting pain. Every Monday they telephoned parents whose children had musculoskeletal problems in the past week. During the telephone consultation a standardised questionnaire was completed. This collected information about whether the pain had a traumatic, a more gradual or an unknown cause, if it occurred during PE-lessons, in sport or leisure time physical activities and the specific anatomic location. The nature of pain was not defined in the instructions to parents, leaving the broadest possible interpretation open to the parents, when they had to decide what to report. The possibility of parents reporting burns, cuts etc. was present, but only musculoskeletal symptoms were registered for later analysis. If the pain was non-musculoskeletal, had disappeared or was well explained by an earlier medical history, there would be no more intervention before next pain reporting (if any). If the pain was still present and unexplained, a clinical examination was scheduled.

Clinical examination

Physiotherapists, chiropractors and a medical practitioner were responsible for the clinical examination and diagnosing of injuries within the next fortnight at the respective schools of the child in need of examination. A standard medical record was performed and a standardised questionnaire was also completed for research use.

If necessary, the child was referred for examination at a sports medicine clinic and seen by the research leader, who is an orthopaedic surgeon, leader of the sports medicine clinic and professor in clinical biomechanics. If needed, the child would be referred for para-clinical examination procedures, such as x-ray, ultrasound or MRI-scans.

Information on children being seen or treated elsewhere (e.g. emergency department, GP) during the study period was collected concurrently to get a complete data collection on injuries.

An injury was not registered as a new injury if the condition was determined to be an exacerbation of a non-recovered index injury.

Classification of injuries

Injuries were diagnosed using the International Classification of Diseases (ICD-10) [82]. Furthermore injuries were classified according to injury causation; whether they were traumatic or overuse injuries. Injuries were classified into these two categories by looking at diagnosis and medical records, where the injury mechanisms were documented.

Overuse injuries are complex to describe when looking for the context in which they occur in a general, non-sports specific, cohort. The tissue damage is a result of repetitive demands over the course of time and probably an accumulation of different types of physical activities across different settings. Thus only the traumatic injuries were categorized and presented according to whether they happened during physical education lessons, sports, or during leisure time physical activities.

Explaining risk factors

Injury rates - exposure time

Injury rates, where exposure time is taken into consideration, are useful when comparing risks of injury between groups. In this study exposure data were collected in three different settings of being physically active; physical education lessons, organised leisure time sports and leisure time physical activity.

School – physical education lessons

Weekly amount of physical education lessons was 4.5 hours for sport schools and 1.5 hours for normal schools, corresponding to three and one double lesson per week respectively. Children at sport and normal schools were therefore assigned three and one physical activity exposure unit per week respectively. The recording of non-attendance was attempted, but finally omitted as teaching records were not consistent.

Sports

The weekly amount of organised leisure time sport was assessed using SMS-track. Every Sunday, text messages were automatically sent to each parent's mobile phone as a second question after the "pain question", asking the following:

> "How many times did [NAME OF CHILD] participate in sports in leisure time the previous week?"

The parents were instructed to type the relevant number between 0 and 8. The answers 0 to 7 represented the unique number of times engaging in sports, whereas 8 stood for 'more than 7 times'. If the answer was different from zero, meaning that the child had participated in organized sport during the previous week, a third question asking about the type of sport was automatically sent:

> " Which type of sports?"

The parents had 10 answer options: 1. Soccer, 2. Handball, 3. Basketball, 4. Volleyball, 5. Rhythmic gymnastics, 6. Tumbling gymnastics, 7. Swimming, 8. Horse-riding, 9. Dancing, 10. Other sports. The parents were instructed to type the relevant number(s).

For feasibility reasons, the parents were asked to report how many times their child had participated in leisure time sport and not the exact amount of minutes/hours. Therefore the injury rates were expressed in the form of injuries per 1000 physical activity units, instead of injuries per 1000 hours. The time spent in different sports per training or per match typically varies from 30 minutes (i.e. swim training) to 90 minutes (i.e. soccer and handball training) for Danish children aged 6 to 12.

Leisure time physical activity

There were no weekly measures of the amount of physical activity besides organised sport and PE lessons, hereafter named leisure time physical activity. Instead data from accelerometer measurements was used to estimate the amount of exposure in terms of leisure time physical activity. Accelerometer assessments were performed from November 2009 to January 2010, when the children attended 1st - 5th grade, using an Actigraph GT3X accelerometer (Pensacola, Florida, USA), designed to monitor human activity. The children were instructed to wear the device from the time they woke up in the morning until bedtime in order to capture the entire amount of physical activity for each day. The only exception was to remove the monitor when showering or swimming in order to prevent damage to the device. The children were asked to wear the accelerometers for 7 full consecutive days, thus potentially including all weekdays and a full weekend. After the measurement period the accelerometers were recollected and data downloaded to a computer.

A customized software program (Propero, version 1.0.18, University of Southern Denmark, Odense, Denmark) was used to process the accelerometer data using information on physical activity for every 10 seconds. In order to distinguish between true intervals of inactivity and "false intervals of inactivity" recorded when the monitor had been taken off, consecutive strings of zeros of 30 minutes or longer were interpreted as "accelerometer non-worn". Activity data were included for further analyses if the child had accumulated a minimum of 10 hours of activity per day for at least four days. Cut-off points for four activity intensity levels; sedentary, light, moderate, vigorous, were used according to Evenson et al [83].

For estimates of exposure time in relation to leisure time injuries, calculations of time spent in moderate and vigorous activity were chosen, as this activity type was regarded as the "risk of injury activity". For study II data were used on sample-level, meaning that a mean estimate of the total number of exposure units was extracted. An exposure unit was arbitrarily chosen to equal 60 minutes of moderate and vigorous activity. Exposure time for the amount of physical activity outside organised sport and physical education lessons is thus the number of exposure units in physical education and organised sports subtracted from the total number of exposure units as estimated from accelerometer measurements.

Body composition measures

Total Body Fat Percentage (TBF%)

Total body fat percentage (TBF%) was measured by Dual Energy X ray Absorptiometry (DXA), (GE Lunar Prodigy, GE Medical Systems, Madison, WI), ENCORE software (version 12.3, Prodigy; Lunar Corp, Madison, WI). The procedure took place at Hans Christian Andersen Children's Hospital, Odense, Denmark. Children were instructed to lie still on the scanner table in a supine position wearing underwear, a thin T-shirt, stockings and a blanket for the duration of the DXA scan. The typical scan duration was 5 min, depending on child's height. If quality was not acceptable a new scan was performed. All scans were performed and analysed by two different operators only and analysed by one. The DXA machine was calibrated daily, following standardized procedures.

TBF% was calculated for each participant from the equation: [(FM (g) x 100)/ Total body weight (g)]. Cut-offs to classify children as normal-weight or overweight was defined using the cardiovascular health- and gender-related TBF% standards according to Williams et al. Cut-off for overweight boys was ≥ 25 TBF% and similar cut-off for girls was ≥ 30 TBF% [84].

Body Mass Index (BMI)

Weight was measured to the nearest 0.1 kg on an electronic scale, (Tanita BWB-800S, Tanita Corporation, Tokyo, Japan). Height was measured to the nearest 0.5 cm using a portable stadiometer, (SECA 214, Seca Corporation, Hanover, MD). Both anthropometrics were conducted without shoes.

Body Mass Index (BMI) was calculated as [weight (kg)/height2 (m)]. BMI classifications for normal-weight, overweight and obese were defined using age- and sex specific cut-offs as recommended by the International Obesity Taskforce recommendations [85]. Dichotomized categories were made for weight classes normal-weight or overweight/obese (hereon referred to as overweight) for easier comparison with the dichotomous variable of normal-weight vs. overweight as described above for TBF%.

Aerobic fitness

Aerobic fitness was used to explain associations between the risk of lower leg injuries and overweight in study IV. Aerobic fitness was assessed by the Andersen test. This is a 10 minutes intermittent running test to estimate maximal oxygen uptake and indicate aerobic fitness [86]. The test was carried out indoors on 20-m running lanes marked by cones. Children were urged to run as quickly as possible for 15 seconds, then stopped for the next 15 seconds and repeating this pattern for 10 minutes. The total distance measured in meters was the test result. This field test was tested and described thoroughly for the age group of our cohort in a study by Ahler et al.[87], thus validity was $r^2 = 0.85$ compared to VO_2 treadmill test and reliability was $r^2 = 0.86$ test/retest.

Ethics

The study was approved by the Ethics Committee for the region of Southern Denmark before the start of the project (ID S20080047), and registration in the Danish Data Protection Agency was made, as stipulated by the law J.nr. 2008-41-2240. No person referable data are available in the main data set. Written informed consent was obtained from the child's parent. All participation was voluntary with the option to withdraw from parts of, or the entire project, at any time. Prior to every clinical examination, an additional verbal agreement was obtained from both child and parent to allow the recording of information on the injury. All clinical examinations were conducted with respect to every child's personal integrity.

Ethical considerations were applied in relation to the fact that children being examined often experienced some level of pain and functional limitations. Clinicians gave advice as a natural implication of the duty to alleviate symptoms, and referred to specialists and further examinations as needed.

Data analysis

The collection of data on injury incidence and prevalence and risk factors every week for 2.5 years in a school setting provides a multitude of observations. The challenge is to correctly analyse and exploit data and at the same time make clinical sense. Some considerations were common, some concerned the outcome variables and some the explaining variables – all are presented in the following paragraphs.

Common considerations

Start-up-phase

When looking at injury incidences across weeks, there were suggestions of a larger diversity and lack of stability in the first period, approximately first four weeks, of sending out mobile phone text messages (figure 1 in appendences). Weeks relative to each school inclusion was used, thus week one is the first week for all ten schools even though the inclusion of schools to participate in SMS-track was gradual. The purpose was to distinguish if the higher rates of incidence were a phenomenon connected to a start-up-phase as also empirical experience would suggest.

To investigate if the difference between the start-up-phase and the rest of the period was influencing the estimates from other explanatory effects, a binomial variable was generated, indicating if this was start-up-phase or not, and used as an explanatory variable in a logistic regression model. Analysis showed this to be significant in all cases, indicating that we could expect the estimates to be affected by the diversity of the two periods. We looked at estimates in analysis with, and without, the first four weeks relative to each school and found results to be different. Consequently observations from the first four weeks relative to each school were excluded for modelling of the final analysis, as the high levels of injury incidences in the start-up-phase were considered to be unrepresentative and a possible effect of injuries accumulated over time and not yet seen by other clinicians.

Missing

Repeated data collection inevitably implies missing data. SMS-track data presented with four kinds of missing: 1. Parents replied, but in a non-valid manner, 2. Parents replied, but with an empty SMS, 3. Parents received SMS, but did not answer, 4. Parents never received SMS because of wrong or changed mobile numbers. Missing values because of practicalities concerning wrong or changed mobile numbers were dropped for analyses. Potential patterns for the missing values were addressed by a logistic regression analysis, controlling for gender, age, school type, and leisure time sports effects.

Outcome variables

Analysis of injury incidence data

Observed incidence

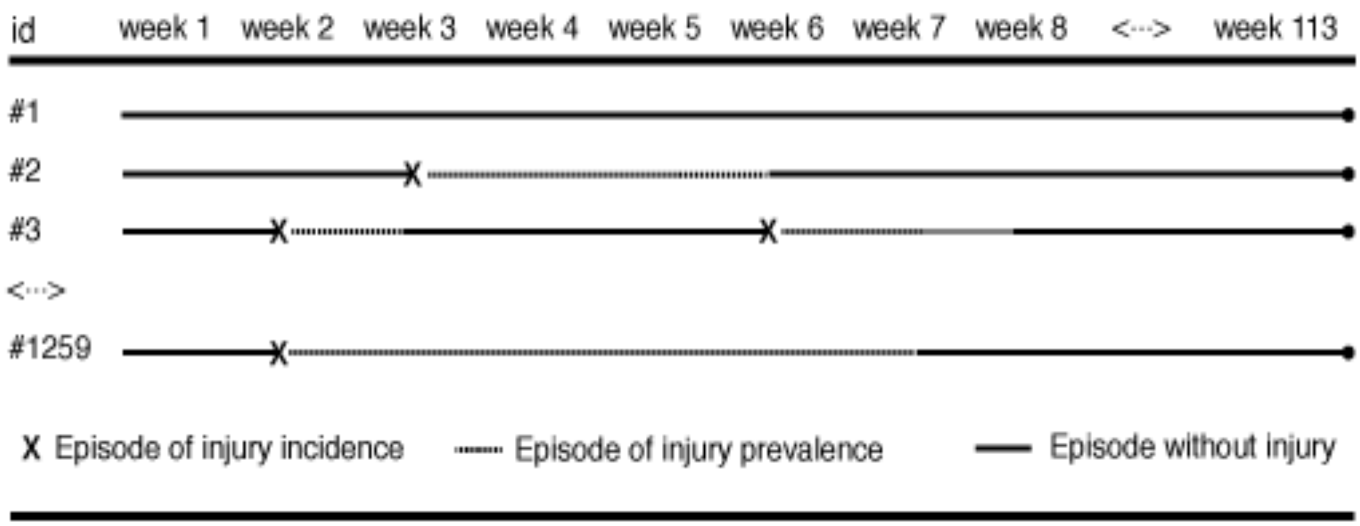
Unadjusted numbers of new incidences of injury were presented in different ways depending on the objective in the study. In study I, the results were presented as a weekly mean incidence with standard deviations for all individuals across all participating weeks shown for musculoskeletal pain and injuries in lower- and upper extremity, reporting overuse- and traumatic injury respectively (table 1). In study II, number of injuries was presented for all individuals according to diagnosis and body region (all injury types) and to different settings (only traumatic injuries) (table 1-4, study II). In study III, injury numbers and mean incidence rates (±SD) are presented by the four seasons for lower- and upper extremity (table 2; study III). In study IV number of lower extremity injuries are presented by gender (table 1, study IV).

Modelled incidence

Analyses on associations between possible explaining risk factors and injury incidence were carried out, but initially some general considerations for using injury incidence as outcome variable are explained.

Figure 2 gives a simplistic overview of the three events of main interest for regression analyses: The child sustaining an injury (episode of incidence), the child being in a state of injury (episode of prevalence) and the child being in a state without injury (episode without injury). The incidence models were based only on the data from the episodes without injury, as a child carries no information on the risk of injury when being in a state of injury. Consequently, an episode without injury was considered a risk episode.

Figure 2: Simple illustration of the observations of interest; the episodes of injury incidence, episodes of injury prevalence and episodes without injury.



Modelling the risk of injury incidence was done within the frame of logistic regressions with a binary outcome of interest: the absence or presence of extremity injury. In study I, looking at the risk of overuse - and traumatic injury incidence, the model was adjusted to handle three outcomes; absence of injury, presence of overuse injury and presence of traumatic injury. This was done using a multinomial logistic regression model, adequately taking the competing risk between the three types of events that could occur every week into consideration [88].

Analysis of injury prevalence data

Observed prevalence

Unadjusted injury prevalence was presented in different ways depending on objective in the study. In study I, the results were presented as a weekly mean prevalence with standard deviations for all individuals across all participating weeks shown for musculoskeletal pain and injuries in lower- and upper extremity, reporting overuse- and traumatic injury respectively (table 1). In study III, mean prevalence rates (±SD) were presented by the four seasons for lower- and upper extremity and extremity injuries combined (table 2, study III).

Modelled prevalence

The prevalence models (study III) were based on data from episodes of being without injury as well as episodes of being injured (figure 2). That is, a child was considered in risk of prevalence regardless of whether they were in a state with or without injury the week before. Modelling the risk of injury prevalence was done within the frame of logistic regressions with a binary outcome of interest: the absence or presence of pain being prevalent in relation to injury.

Analysis of injury duration

With prevalence data being available, it was possible to report mean injury duration (±SD) in terms of number of weeks with injury being prevalent for musculoskeletal pain and injuries in lower- and upper extremity, reporting overuse- and traumatic injury respectively (table 2, study I).

Explaining variables

Time-at-risk

Incidence rates using physical activity as exposure

Numbers of new incidences of injury, adjusted for the variations in time of being physically active were presented in different ways on either individual level or group level, depending on the objective in the study.

In study I, the calculation of injury incidence rates accounted for the total sum of exposure in injured children expressed in 1000 physical activity units. These comprised the physical education and sport exposures presented by grade and by injury type (overuse and traumatic) in mean incidence rates ±95%CI (table 1, study 1). In study IV, the total sum of physical education and sport exposures in injured children expressed in 1000 physical activity units, was likewise used to calculate incidence rates, this time by gender and in groups of children being normal weight or overweight (table 2, study IV). In study II, the calculation of injury incidence rates (IR) accounted for the total sum of exposure across all children expressed in 1000 physical activity units. These comprised the physical education, the sports and the leisure time PA exposures.

To sum up, study I and IV uses the individual data on injury numbers and exposure time in injured children, whereas study II injury rates are the sum of injuries across all individuals divided by the sum of exposure across all individuals.

Physical activity as an explaining covariate in regression models

While incidence rates calculated as the number of injuries divided by the number of exposures is a very common method of getting information on associations between injury risk and exposure time [22], other explaining risk factors were not taken into account. In order to examine the concurrent effect of all possible confounders explaining the injury risk, physical activity was included as an explaining covariate in multiple regression models. This was done in different ways, depending on the objective in the study.

In study I, the amount of physical education were accounted for by including school type as a covariate, i.e. the effect of being a child on a sport school (six physical education lessons per week) with children at normal schools (two physical education lessons per week) as reference. Sports participation was likewise included as an explaining covariate. The study looked at the weekly risk of sustaining overuse and traumatic extremity injury and the challenge was to capture a relevant period of sports participation, possibly influencing the risk of a new injury. Physiologically, there was no obvious cut point, as traumatic injuries could be sustained the first time a child participates, whereas overuse injuries typically would be a result of repetitive demands over the course of weeks or months.

An arbitrary timeframe of 8 weeks was chosen for the analyses, giving highest weight to the most immediate weeks before an incidence of injury when a child participated in sport. While study I was explorative in nature, outlining all covariates that could elucidate aetiology in overuse and traumatic extremity injury risk, the focal point of interest in study IV, was the exposure-outcome association between overweight and lower extremity injuries. Time-at-risk was adjusted for by a covariate expressing the mean physical education and sports participation per child and a covariate accounting for aerobic fitness as a proxy of how physically active children were.

Gender, age and previous injury

The selection of potential confounder effects for the analysis chosen a priori included gender, age, and previous injuries. These are commonly acknowledged modifying factors [32, 41].

Gender was used as an explaining covariate in study I, III and IV. Age was used as an explaining covariate in study I, III and IV. Grade level (0-6) was used as a proxy of age. The Danish 'grade 0' would correspond to pre-school and the age of 6 years, grade 1=7 years, grade 2=8 years, grade 3=9 years, grade 4=10 years, grade 5=11 years, grade 6=12 years. The same cohort of children was followed for 2.5 years, starting with them being pre-school to 4th grade pupils and ending with them being 2nd to 6th grade pupils. This explains the larger proportion of pupils in some grades in analysis.

Previous injury is a commonly acknowledged risk factor for sustaining new incidence of injury [32, 42]. From an analytic point of view the question is when to categorize a previous injury as an injury that could possibly influence the risk of a new injury. Consideration needs to be given to capture an aetiologically relevant time period, looking back from the time of injury, rather than forward from the beginning of the registration period. Timeframes for tissue recovery and rehabilitation (e.g. regaining muscular strength and balance, proprioception, aerobic fitness) are different and vary from weeks to months [89].

For study I a timeframe of 8 weeks was arbitrarily chosen for the analyses. Previous leg injury during the last 8 weeks was included as a covariate, when looking at the risk of new incidence of leg injury and likewise previous arm injury was included, when looking at risk of arm injury. It was considered clinically relevant to give most importance to the weeks just before the new incidence of injury by a Gaussian weighting.

Seasonal Variation

For an observational study, which is exploratory in nature, it is often not possible to completely specify all possible confounders of the exposure-outcome associations a priori [90]. Explorative plots of the observed injury incidence and prevalence for all injuries over the period of the study indicated an annual pattern, peaking during the autumn and spring seasons, and reaching a minimum injury incidence and prevalence during wintertime. Seasonal variation was therefore also included as a potential explaining covariate.

For study I, a dichotomous variable was included, indicating whether it was a high-risk period or a low risk period. In study III, the specific objective was to determine the seasonal pattern in extremity injuries. This was done by a harmonic regression model where the annual variation was accounted for by sine and cosine terms with periods of 52 weeks, representing the mathematical best fit of the data [91].

Prevalence history

To date, no studies have reported childhood injury prevalence using weekly information stating if the child is in a state of prevalence or no-prevalence. This gave reason for new hypotheses and explorative ways to address these by looking at crude data. Logically, it could be hypothesised that the risk of injury being prevalent would be higher if injury was prevalent the week before and vice versa.

Explorative plots, using the lorelogram were chosen to give information on a possible serial dependence between consecutive weeks in episodes of injury. A lorelogram is a plausible working correlation matrix used as a visual tool to illustrate the association between repeated measurements on the same individual. Different risks are expressed in terms of log odds ratios for 2x2 tables formed by the presence or absence of pain being prevalent on weeks separated by given distances/lags in time: lag1=the distance of one week, lag2=the distance of two weeks, etc. The value of zero implies independence, whereas values above zero imply positive associations [92 93].

Looking at prevalence data on leg pain as an example in the present study, the hypothesis about a serial dependency is confirmed (figure 2 in appendences). There are some main features to this plot. At lag 1, the log odds ratios are very high (3.8 => odds ratio=44.7), indicating that weeks with leg pain tend to follow each other. The lorelogram then decays very quickly for about 10 weeks, possibly reflecting the injury episode effect (duration of injury). After that the mean is stable at a level considerably above 0 (log(OR) approximately 1.5 => odds ratio=4.5). This long-term association is thought to occur as a result of heterogeneity between children, essentially a frailty effect: some children are prone to have frequent episodes of injury and some children are prone to have few episodes of injuries or none [93]. Summing up, serial dependency between weeks of injury being prevalent was obvious, leading to the necessity of allowing for this explaining effect in prevalence models.

The risk of injury prevalence were modelled in study III and the serial correlation between consecutive weeks in episodes of injury were accounted for by a covariate expressing if pain was prevalent the week before and also expressing the current duration of injury episode. This was considered of clinical relevance as the 1st week of injury being prevalent might associate differently to risk compared to for example the 7th week of injury being prevalent, as also indicated by explorative plots (figure 2 in appendences). The prevalence models in study III also accounted for the different risks when being in an episode of injury prevalence and when being in an episode without injury.

Overweight as exposure

In study IV, the risk of getting injured according to baseline BMI and TBF% was explored. Furthermore the potential effect of children changing body composition through the 2.5 years of injury monitoring was evaluated by separate regression analyses for BMI and TBF% using a variable with “no change”, “change to elevated BMI/TBF%” and “change to normal BMI/TBF% values” as categories.

Concerns about children being underweight were addressed, as injury patterns could possibly be different in this group [50, 94]. For this reason the prevalence of underweight was determined in the baseline population, using recommended cut-offs [95 96]. An initial analysis excluding the group of underweight children did not change estimates of risk of injury or the estimated effect of other covariates. Underweight children were therefore not considered different from normal weight children regarding the risk of injury and thus categorized as normal weight children for analysis.

A multilevel mixed-effects Poisson regression was used to estimate incidence rate ratios (IRR) with BMI and TBF% as primary risk factors. BMI and TBF% were used as dichotomized variables (0=normal values, 1=elevated values) in separate regression analyses. For identification of groups of potential clinical interest, the four combinations of normal and elevated BMI with normal and elevated TBF% were likewise tested in a regression analysis, with normal BMI and normal TBF% being the reference group.

Finally BMI and TBF% were tested as continuous variables and used for illustrating the adjusted risk of lower extremity injuries in relation to the two measures of body composition.

Analysis of clustered data

Observations in a school study are clustered, assuming that observations in one cluster tend to be more similar to each other than in another cluster in the same sample [90]. In the present study three levels of clustering were defined; schools, classes and children, acknowledging a hierarchical structure allowing for potential variation between schools, between classes within schools and between children within classes. Thus, each level in this structure added to the random variation in the data and therefore the choice of using random effect models was made. The sources of variation (e.g. different environments, teacher’s enthusiasm, atmosphere) in themselves were not of interest and were therefore deemed to be random effects in multilevel models.

Statistical software:

All data from SMS-track and data on diagnosed injuries were analysed using STATA 12.1, StataCorp, College Station, Texas, USA. Stata statistical software is a complete, integrated statistical software package that provides data management, data analysis and graphics. For study III the statistical software program; R 2.15.197, was also used.

Main results

This section consists of three parts. First, the data on descriptive and analytic injury epidemiology is presented (Study I & II). In this part the overall picture of musculoskeletal extremity injuries in a sample of school children aged 6-12 followed during 2.5 years is shown. Second, the seasonal variation in injuries is described (Study III). Finally, overweight as an independent predictor of lower extremity injuries is presented (Study IV).

Study I and II

There was a gradual inclusion of schools, starting with 231 children from three schools, including one school per month thereafter, and ending eight months later with children from all ten schools being included. Thus all the schools participated from the start of the 2009-2010 school year. In total 1259 children took part during the study period. The range of participation time was 1-113 weeks with an average of 90.2 weeks. Dropouts were due to children moving away from the municipality or changing to a non-project school, but were counterbalanced by new children moving to project schools. Fifteen children dropped out for other reasons, the main one being that answering SMS questions every week was too bothersome. An average weekly response rate of 96.2% was recorded during the study period of 113 weeks of parents answering text messages concerning musculoskeletal pain. A total number of 109.245 observations were recorded and 4.297 (3.8%) were missing. Analysis of missing data did not show any patterns when looking at gender, age, school type, and leisure time sports.

Some children experienced more than one injury; the range was from zero injuries and up to nine episodes of lower extremity injuries and up to three episodes of upper extremity injuries. On average the children participated 1.5 times per week (range 0 to 7.2) in leisure time sport. Third and fourth grade had a significantly higher mean sports participation in leisure time, compared to pre-school, first and second grade.

Musculoskeletal extremity injuries – the general picture

In the participating 1259 children a total of 1229 injuries were registered, of these 180 were upper extremity injuries and 1049 were lower extremity injuries.

The overall weekly injury incidence and prevalence rates were 1.2% and 4.6% respectively with a mean duration of 4.9 weeks and an incidence rate of 1.59 injuries per 1000 physical activity units. The number of injuries, the weekly incidence, prevalence and duration of injuries and incidence rate of injuries per physical activity units are shown in table 1.

Looking at injury types, 794 were overuse injuries and 435 were traumatic injuries. The ratio of overuse lower extremity injury to traumatic lower extremity injury was 2.5:1. The reverse applied for upper extremity injuries, with the corresponding ratio being 1:3.1.

Injury incidence rate according to body region and injury type, using the total amount of physical activity exposures (774362 units) during 2.5 years, was 1.03 per 1000 physical activity units (95% CI 0.95 to 1.10) for overuse injuries in total and 0.56 per 1000 physical activity units (95% CI 0.51 to 0.61) for traumatic injuries in total.

Injury rates of traumatic injuries and the setting in which they occur was highest for injuries sustained in sports; 1.57 per 1000 sport exposure units (95% CI 1.3 to 1.8), followed by injuries sustained in leisure time PA; 0.57 per 1000 leisure time PA exposure units (95% CI 0.5 to 0.6) and lowest for injuries sustained in PE; 0.14 per 1000 PE exposure units (95% CI 0.1 to 0.2).

Injury rates of traumatic injuries and the specific sports in which they occur was highest for injuries sustained in basketball; 4.61 per 1000 basketball exposure units (95% CI 0.92 to 8.3), but injury numbers were only 6 with a total number of physical activity exposures being 1301. In handball, the total number of physical activity exposures was 16822 and incidence rate was 2.9 per 1000 handball exposure units (95% CI 2.1 to 3.7). In soccer, the total number of physical activity exposures was 25982 and incidence rate was 2.3 per 1000 soccer exposure units (95% CI 1.7 to 2.9). Finally, for the non-ballgame sport having the highest incidence rate, tumbling gymnastics had an incidence rate of 2.4 per 1000 tumbling gymnastics exposure units (95% CI 1.2 to 3.5).

Upper extremity injuries

For upper extremity injuries the overall weekly incidence and prevalence rates were 0.2% and 0.5% respectively with a mean duration of 3.8 weeks and an incidence rate of 0.2 injuries per 1000 physical activity exposures (table 1). The body region most commonly injured was the hand and wrist (n=66) followed by shoulder/upper arm, fingers and elbow/underarm in declining order (table 4, study II).

Overuse injuries in upper extremity

For upper extremity overuse injuries the overall weekly incidence and prevalence rates were 0.04% and 0.2% respectively with a mean duration of 5.2 weeks and an incidence rate of 0.06 injuries per 1000 physical activity exposures (table 1).

A total number of 44 overuse injuries were diagnosed in upper extremities, with soft tissue injuries being the most common (n=31). Shoulder and upper arm was the most common region of overuse injury: n=26, IR=0.03 per 1000 physical activity units (95% CI 0.02 to 0.05).

Traumatic injuries in upper extremity

For upper extremity traumatic injuries the overall weekly incidence and prevalence rates were 0.1% and 0.3% respectively, with a mean duration of 3.3 weeks and an incidence rate of 0.18 injuries per 1000 physical activity exposures (table 1).

For traumatic injuries a number of 136 upper injuries were diagnosed, with ligament sprains being the most common (n=71). The hand and wrist was the most common region of traumatic injury: n=60, IR=0.08 per 1000 physical activity units (95% CI 0.06 to 0.10).

Injury rates of traumatic upper extremity injuries and the setting in which they occur was highest for injuries sustained in sports; 0.48 per 1000 sport exposure units (95% CI 0.4 to 0.6), followed by injuries sustained in leisure time PA; 0.19 per 1000 leisure time PA exposure units (95% CI 0.1 to 0.2) and lowest for injuries sustained in PE; 0.04 per 1000 PE exposure units (95% CI 0.01 to 0.06).

Injury rates of traumatic upper extremity injuries and the specific sports in which they occur was highest for injuries sustained in basketball; 1.54 per 1000 basketball exposure units (95% CI 0.00 to 3.4), but injury numbers were only 2 with a total number of physical activity exposures being 1301. In handball, the total number of physical activity exposures was 16822 and incidence rate was 1.07 per 1000 handball exposure units (95% CI 0.6 to 1.6). In soccer, the total number of physical activity exposures was 25982 and incidence rate was 0.4 per 1000 soccer exposure units (95% CI 0.2 to 0.6). Tumbling gymnastics presented with an incidence rate of 1.08 per 1000 tumbling gymnastics exposure units (95% CI 0.4 to 1.8).

Lower extremity injuries

For upper extremity injuries the overall weekly incidence and prevalence rates were 1.0% and 4.1% respectively, with a mean duration of 5.0 weeks and an incidence rate of 1.35 injuries per 1000 physical activity exposures (table 1). The body region most commonly injured was the knee (n=311) followed by heel, ankle, foot, thigh, achilles and hip in declining order (table 4, study II).

Overuse injuries in lower extremity

For lower extremity overuse injuries the overall weekly incidence and prevalence rates were 0.7% and 3.2% respectively with a mean duration of 5.3 weeks and an incidence rate of 0.97 injuries per 1000 physical activity exposures (table 1).

A total number of 750 overuse injuries were diagnosed in lower extremities. Apophysitis injuries at the growth plates of the heel (n=274) or the knee (n=189) were the most commonly diagnosed injuries. The heel was the most common region of overuse injury: n=275, IR=0.36 per 1000 physical activity units (95% CI 0.31 to 0.40).

Traumatic injuries in lower extremity

For lower extremity traumatic injuries the overall weekly incidence and prevalence rates were 0.3% and 1.1% respectively, with a mean duration of 4.8 weeks and an incidence rate of 0.39 injuries per 1000 physical activity exposures (table 1).

For traumatic injuries a number of 299 lower extremity injuries were diagnosed, with ligament sprains being the most common (n=178). The ankle was the most common region of traumatic injury: n=136, IR=0.18 per 1000 physical activity units (95% CI 0.15 to 0.21).

Injury rates of traumatic lower extremity injuries, and the setting in which they occur, was highest for injuries sustained in sports; 1.09 per 1000 sport exposure units (95% CI 0.9 to 1.3), followed by injuries sustained in leisure time PA; 0.38 per 1000 leisure time PA exposure units (95% CI 0.3 to 0.4) and lowest for injuries sustained in PE; 0.10 per 1000 PE exposure units (95% CI 0.06 to 0.14).

Injury rates of traumatic upper extremity injuries and the specific sports in which they occur was highest for injuries sustained in basketball; 3.07 per 1000 basketball exposure units (95% CI 0.1 to 6.1), but injury numbers were only 4 with a total number of physical activity exposures being 1301. In handball, the total number of physical activity exposures was 16822 and incidence rate was 1.84 per 1000 handball exposure units (95% CI 1.2 to 2.5). In soccer, the total number of physical activity exposures was 25982 and incidence rate was 1.92 per 1000 soccer exposure units (95% CI 1.4 to 2.5). Tumbling gymnastics presented with an incidence rate of 1.32 per 1000 tumbling gymnastics exposure units (95% CI 0.5 to 2.1).

Table 1: Musculoskeletal injuries presented in numbers, weekly mean incidence, prevalence and duration in weeks and incidence rates for total group of 1259 participants during 2.5 years of weekly registration.

	Numbers	Weekly mean incidence in percentage (±SD)	Weekly mean prevalence in percentage (±SD)	Mean duration in weeks (±SD)	Incidence rates per 1000 physical activity exposures (95% CI)
Upper extremity					
Injury	180	0.2 (±4.0)	0.5 (±7.2)	3.8 (±8.3)	0.23 (0.20 to 0.27)
Overuse injury	44	0.04 (±2.0)	0.2 (±4.9)	5.2 (±13.6)	0.06 (0.04 to 0.07)
Traumatic injury	136	0.1 (±3.5)	0.3 (±5.8)	3.3 (±4.6)	0.18 (0.15 to 0.21)
Lower extremity					
Injury	1049	1.0 (±9.7)	4.1 (±19.9)	5.0 (±7.1)	1.35 (1.27 to 1.44)
Overuse injury	750	0.7 (±8.2)	3.2 (±17.7)	5.3 (±7.7)	0.97 (0.90 to 1.04)
Traumatic injury	299	0.3 (±5.2)	1.1 (±10.4)	4.8 (±7.2)	0.39 (0.34 to 0.43)
Extremity combined					
Injury	1229	1.1 (±10.5)	4.6 (±21.0)	4.9 (±7.4)	1.59 (1.50 to 1.68)
Overuse injury	794	0.7 (±8.4)	3.5 (±18.3)	5.3 (±8.4)	1.03 (0.95 to 1.10)
Traumatic injury	435	0.4 (±6.2)	1.4 (±11.8)	4.4 (±6.6)	0.56 (0.51 to 0.61)

Risk of overuse and traumatic extremity injuries adjusted for explaining factors

The adjusted injury risk analyses showed a significant association between age and injuries across both injury types on both lower extremity and upper extremity injuries, with odds increasing for each grade level for both types of injuries. With normal school as reference the children in sport schools increased the odds significantly by 60% for traumatic lower extremity injury. No other differences were found between normal and sport schools. Each additional time a child participated in leisure time sport, the odds for an overuse and a traumatic lower extremity injury increased by 20%. The odds of sustaining an overuse lower extremity injury increased significantly by 90% in high-risk season. Only age was associated with upper extremity injuries, with odds for traumatic and overuse upper extremity injuries increasing by 20% and 60% respectively for each step in grade level (table 3, study I).

Study III

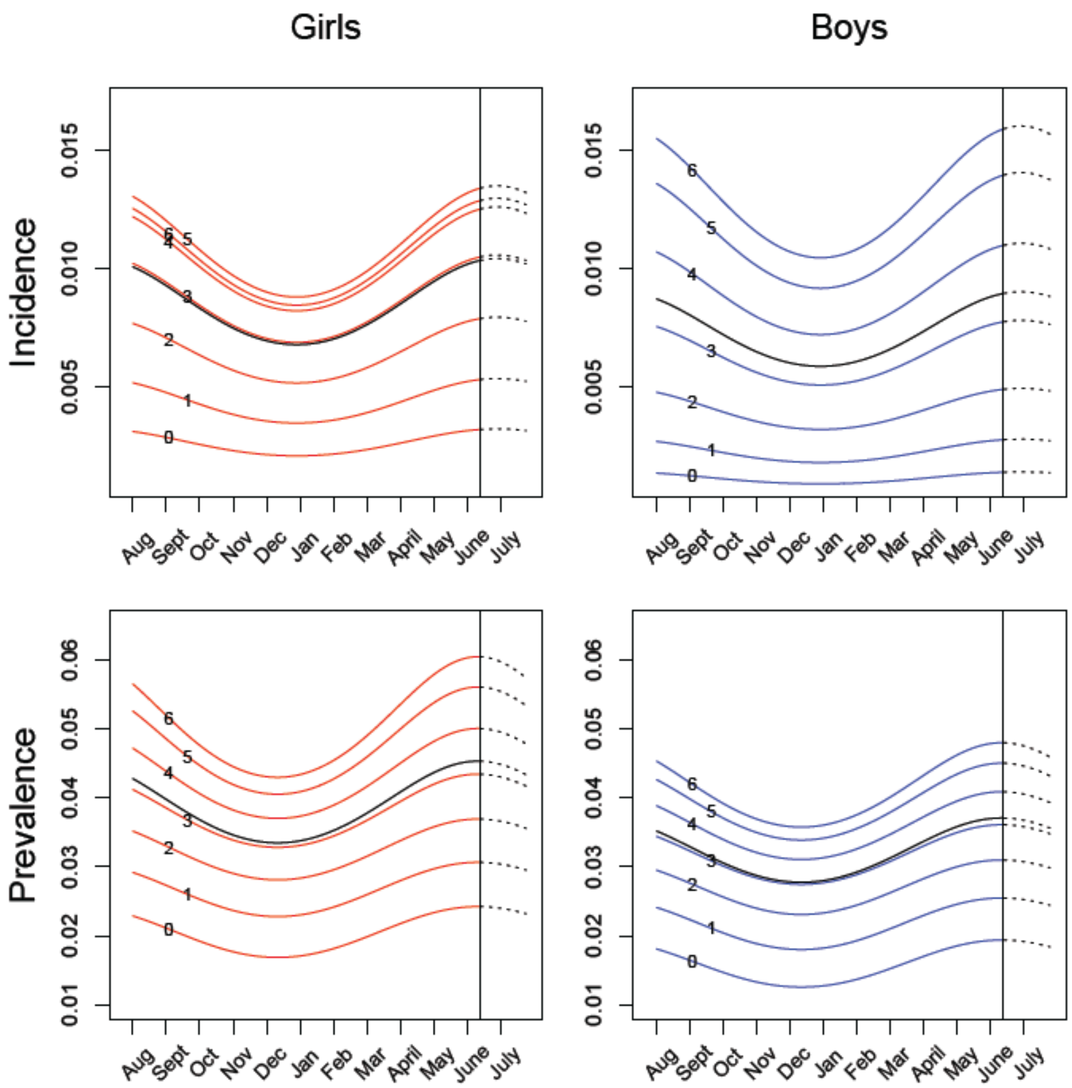
There was a clear seasonal variation in the observed incidences of extremity injuries. The highest injury incidence and prevalence rates for extremity injuries were observed for autumn; 1.3% and 5.1% respectively and for spring; 1.2% and 5.0% respectively, whereas they decreased to 0.8% and 3.6% in winter (table 2, study III)

The adjusted analysis showed a significant seasonal variation for extremity injuries on both incidence and prevalence. Other significant effects on the incidences were gender and grade, with different effects of grade for the two genders. The prevalence rates of extremity injuries showed significant effects of gender, class, the current duration of the injury and a state effect reflecting the difference between the risk- and the prevalence-states (table 3, study III).

The model based estimates of the incidence rates reached a maximum of 1.0% (girls) and 0.9% (boys) in week 29 (mid July) and a minimum of 0.7% (girls) and 0.6% (boys) in week 3 (mid January). The corresponding estimates for the prevalence rates reached a maximum of 4.5% (girls) and 3.7% (boys) in week 26 (late June) and a minimum of 3.4% (girls) and 2.8% (boys) in week 1 (early January).

Fitted curves illustrate the seasonal variation for the injury incidence and prevalence for extremity injuries by gender and age with grade level (0-6) as a proxy of age (figure 3). Corresponding results can be found in figures 2 and 3, study III, but now showing patterns separately for upper and lower extremity injuries.

Figure 3 Fitted curves for seasonal variation for extremity injury incidence and prevalence, showing curves in regard to gender and grade level (0-6) as a proxy of age. The thick, solid line illustrates the mean curve. The dotted lines illustrate the period of 6 weeks of extrapolated data.



Study IV

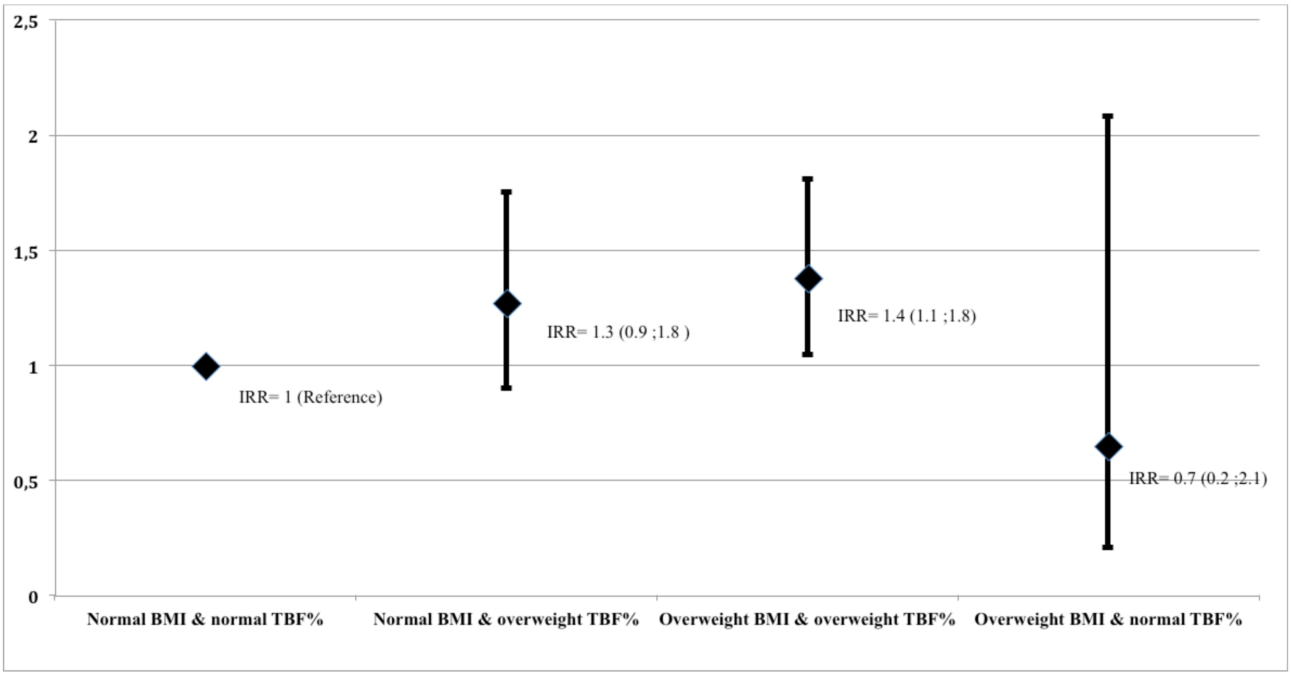
A total of 632 children, aged 7.7–12 years at baseline, participated at both baseline and follow-up DXA scan and in the registration of musculoskeletal injuries. Mean baseline BMI was 16.6 (± SD 2.1) and TBF% was 20.1% (± SD 8.0). A total number of 673 lower extremity injuries were diagnosed during the 2.5 years of follow-up. Mean weekly sport exposures units in PE and leisure time sport were 3.9 (± SD 1.3) and fitness level at baseline had a mean of 930.8 m (± SD101.9).

Injury rates per 1000 physical activity exposures showed a trend, albeit not significant, towards higher risk for children being overweight, whether defined by BMI or by TBF%. Injury rates, 95% CI and gender differences are described in Table 2, study IV.

The adjusted incidence-rate ratio (IRR) estimates suggested that children being overweight were generally at higher risk of sustaining lower leg injuries, by BMI: 1.28 (95% CI 0.98 to 1.66) and by TBF% 1.34 (95% CI 1.07 to 1.68), the latter being statistically significant.

Looking at the four combined groups of body composition, children with both elevated BMI and TBF% showed the highest risk of sustaining lower leg injuries: 1.38 (95% CI 1.05 to 1.81) relative to children having a normal BMI and a normal TBF% (figure 4).

Figure 4: Incidence-rate ratio estimates (95% CI) by four groups of body compositions, adjusted for age, gender, physical education/leisure time sport and fitness level.



The possible effect of children changing body composition during the 2.5 years of injury monitoring was also accounted for in the adjusted analysis, but did not explain the risk of lower extremity injuries, nor did it influence the estimated effects of other covariates.

Gender and age did not influence the risk, whereas the time participating in PE and leisure time sport and fitness level explained some of the lower extremity injury risk. The risk of injury significantly increased for each additional time a child participated in PE and leisure time sport from zero to 6.5 weekly exposure units. For the 18 children with a mean of more than 6.5 exposures a week, risk decreased again. A positive linear relationship was found between risk of lower extremity injuries and aerobic fitness.

The adjusted risk of lower extremity injuries in relation to the two measures of body composition measured on a continuous scale, are illustrated for girls and boys. A positive linear relationship was found between risk of lower extremity injuries and the continuous values of TBF% and BMI across the full range (figure 2, study IV).

Discussion

The main findings of this thesis is a fundamental understanding of injury epidemiology in school children aged 6 to 12 by describing incidence and prevalence of musculoskeletal extremity injuries and associated risk factors, thus giving new insight to injury aetiology. The following discussion will take the previously mentioned specific objectives of this thesis, including methodological considerations as the starting point.

Overuse injuries and traumatic injuries (Study I & II)

These studies are to our knowledge the first to report risk of overuse and traumatic extremity injuries by numbers, incidence, prevalence, duration and the association with physical activity, gender, age, previous injuries, and seasonal variation in a prospective cohort study of school children.

Clinical findings

Clinical findings were done using SMS-track to capture all symptoms indicative of musculoskeletal problems and having clinicians assigned to diagnose injuries, supplemented by data on injuries diagnosed in other clinical settings, prospectively during 2.5 school years.

A number of 1229 injuries were diagnosed; with close to twice as many overuse injuries (794) as traumatic injuries (435). The incidence and prevalence rates of overuse injuries were 0.7% and 3.2% respectively and the incidence and prevalence rates of traumatic injuries were 0.3% and 1.1% respectively. The average duration, measured as weeks with pain symptoms, was 4.4 weeks for traumatic injuries and 5.3 weeks for overuse injuries.

Approximately two decades ago authors started to think of overuse injuries as a new genre of paediatric sports injury and saw this as a consequence of the advent of regimented and repetitive sports training [98, 99]. Since then, there has been a concern with the issue of overuse injuries in children speculating that early specialization, increased intensity of training and competition in sport at younger ages, maybe on multiple teams simultaneously, and often year-round, could be a cause for an increased number of overuse injuries [100, 101]. Concerns have been raised that the consequences of overuse injury might be more serious to children and adolescents because the growing tissues are particularly vulnerable to stress [102, 103]. It has been suggested that approximately half of all sports-related injuries are in fact caused by overuse [104, 105]. Still actual epidemiologic investigations are scarce in the area of childhood overuse injuries. One British study from 1996 presented the results from a three-year retrospective survey of injuries to children and adolescents (5-17 years of age) treated at a sports injuries clinic. Out of a total of 394 injuries, 49.5% were characterised as being chronic and affecting mostly articular cartilage, epiphyseal and apophyseal growth plates [106]. In a group of 469 male and female elite figure skaters (13 to 20 years of age) 44.1% (a total of 469 injuries) reported overuse symptoms in a retrospective questionnaire survey [107].

The share of overuse injuries were 64.6% in the present study. The somewhat higher percentage may be explained by the fine-meshed method of frequent and prospective collection of injury data, capturing also overuse injuries. In the above-mentioned studies, percentages might be lower as injuries seen at a sports clinic might only be 'tip of the iceberg' and less severe overuse injuries might have been forgotten in retrospective questionnaires.

Diagnosis concerning traumatic injuries such as ligament strains, fractures, contusions and strains accounted for the largest part of the total number of upper extremity injuries. From studies in emergency departments, the same patterns of sprains, contusions, fractures and strains being the most frequent traumatic injury in children are seen [45, 108].

For lower extremity injuries a reverse pattern was found, as overuse injuries were by far the most common injury, with a notable high number of apophysitis injuries located at the heel or knee being diagnosed. Thus diagnosis as Sever's lesion, Sinding-Larsen and Osgood-Schlatter, accounted for 44% of all lower extremity injuries. These are injuries expected in this age group, where skeletal growth zones are still immature, yet the epidemiology of these injuries in prepubertal children have seldom been reported in school-based cohorts, which have focused mainly on traumatic injuries [20, 109]. These studies have included injuries that demanded first aid treatment, professional health treatment and/or time lost from PA and/or school. The 'time-loss' injury definition does not capture all overuse injuries [16] and the 'medical attention' injury definition overlooks less severe injuries [15].

We suggest that the benefit from the present studies is a broader insight into musculoskeletal physical activity-related injuries in children, including also less severe injuries and overuse injuries, by using a close and frequent method of monitoring musculoskeletal symptoms and with clinicians assigned to diagnose the injuries prospectively. It could be argued that the epidemiology of less severe injuries and overuse injuries has little relevance as they are less costly than severe injuries in terms of needing medical care or losing time from school and PA. Still it is noteworthy that even in the less severe injuries, pain is a present symptom that affects the child and might predict future pain [11, 24]. The duration of musculoskeletal pain in relation to overuse injuries was measured in a previous study on the same cohort and showed mean durations of 5.3 and 5.2 weeks for lower and upper extremity overuse injuries respectively [110]. Reporting of all injuries causing physical complaints is therefore advocated in the case of the young, growing and playing child.

Injury rates

Injury incidence rates were presented in relation to injury type, different body regions and different settings comprising physical education lessons, organized sports and leisure time PA.

In study I the reported injury rates were the sum of injuries across all injured children divided by the sum of exposure time in terms of physical education classes and organized sport across all injured children. This resulted in an incidence rate of 3.01 per 1000 units of physical activity for overuse injuries and 2.99 per 1000 units of physical activity for traumatic injuries. The lack of information on non-organized physical activity in leisure time was a limitation to this study.

In study II, the reporting of injury rates were strengthened with the inclusion of accelerometer measurements of leisure time physical activity. Thus injury rates are the sum of injuries across all participating children divided by the sum of exposure across all participating children, including exposure time from leisure time. This resulted in an incidence rate of 1.03 per 1000 units of physical activity for overuse injuries and 0.56 per 1000 units of physically activity for traumatic injuries.

While all information is important, the latter results are more comparable to existing studies, where injury incidence rates are collected at group level, including data from all children in a team [41, 111] or in a school cohort [19, 20] and including the total time of exposure across the relevant settings of being physical active.

A study on a Dutch school cohort of 10-12 year old children reported an traumatic injury incidence rate of 0.48 per 1000 hours of physical activity [20]. This finding corresponds to the incidence rate of

0.56 per 1000 units of physical activity for traumatic injuries in the present cohort, even though it should be noticed that exposure time were based on units of participation instead of hours. Exposure time based on exact hours instead of units of participation would have been more accurate to account for the variance in time-at-risk and has been the preferred measure of incidence rates in sports injury research studies [41, 111]. Still it has been argued that the content of e.g. a training/match session or a leisure time activity, just as much as the length of time is associated with injury risk [62, 63].

Another difference between the two studies was that data on leisure time physical were collected by accelerometers in the present study compared to parental reports in baseline and one year follow-up questionnaires in the Dutch study. Both methods are subject to uncertainty as extrapolated estimates from one week of accelerometer measurements might not reflect the child's activity level in general, as well as parental reports twice in 12 months might have resulted in a slight overestimation, as suggested by the authors [20]. Direct comparison between studies is hampered by differences in the aforementioned injury definition and in particular the injury data collection methods.

Looking at traumatic injuries, the injury incidence rate was highest in sport settings, with ball games and a high impact sport (tumbling gymnastics) being the most risky sports. Leisure time physical activity were less risky, but still with a higher injury incidence rate than physical education. It could be argued that in addition to being supervised by teachers, physical education lessons have a more pedagogic aim and are less competitive than most sports, thus resulting in the lowest injury IR for the three different types of setting.

In general, most injuries were sustained in the lower extremities (85%), of which the knee, heel and ankle accounted for 30%, 26% and 14% respectively. It is well established that injuries in weight bearing extremities are predominant, and of those, knee and ankle injuries present the majority [61]. The diagnosing of overuse injuries in the present study has added the heel to a body part commonly injured in this age group.

The reported incidence rate of 1.03 per 1000 units of physical activity for overuse injuries is a novel finding in the area of childhood musculoskeletal physical activity-related injuries.

Injury risk and explaining factors

Risk of injuries consistently increases with age across most studies when looking at specific sports (Caine et al., 2008; Emery, 2003). This pattern was reproduced in this cohort of children with a broad diversity in choice of sports, amount of participation, competitive levels etc. This suggests increasing age as a robust risk factor and though not modifiable, age should be considered when targeting groups of children and adolescents for injury prevention.

Previous studies have found evidence that males are generally at higher risk of injury in child and adolescent sport (Caine et al., 2008; Emery, 2003). We found no association between gender and overuse and traumatic injuries. This may be explained by the heterogeneity of the cohort and because it was not selected by any specific clinical condition or sports. Furthermore, it could be speculated that gender differences in injury patterns are more pronounced after puberty, because of the developmental differences in physique.

Previous injuries have shown to be one of the most consistent risk factors for sustaining new injuries, with relative risks ranging from 2.88 to 9.41 (Emery, 2003). These findings are from studies of adults where a previous injury has been defined as an incidence that has caused time lost from sport or the need of medical attention (Caine et al., 2008; Emery, 2003). This motivated the adjustment for previous injuries, but it appeared to have no influence on the risk of sustaining a new injury. Possible explanations could be that the chosen time period of two month was to short in the present study, the recovery of damaged tissue and rehabilitation might go beyond this. It could also be speculated that most children are not marked by potential implications of inadequate rehabilitation after an injury to the same extent as adults.

In study I, the risk of sustaining overuse lower extremity injuries almost doubled in high-risk periods of season (autumn and spring). Previous studies have suggested that the different levels of physical activity partly explain the variation in number of injuries across seasons (Tucker & Gilliland 2007). The proposition of seasonal variation being a proxy measurement for levels of sport participation were ruled out, as there were no indications of collinearity. Other potential extrinsic risk factors include weather conditions, training surface/field conditions, time of season in relation to level of physical fitness etc., which might explain the difference in risk.

Seasonal variation in injury risk (Study III)

This is the first prospective study presenting a seasonal variation in musculoskeletal extremity injuries in a cohort of school children followed closely during 2.5 years. The weekly data showed a 46% increase in injury incidence and a 32% increase in injury prevalence during summer compared to winter for extremity injuries.

There seem to be no studies on the overall incidence and prevalence of injury of the extremities in the general population. However, a few studies have looked at children hospitalized or treated in emergency rooms [66-68]. The present results are in accordance with Foltran et al. (2012) who looked at all serious paediatric injuries in an Italian region [68] and found a clear seasonal variation in serious injuries, with distinct peaks in prevalence of hospitalization of seriously injured children in the summer, and a low prevalence during the winter. Graham et al. (2005) also demonstrated this in a Scottish population of children with injuries needing emergency treatment [66]. The very large retrospective study of Loder et al. (2011) was also in agreement with the present results [67].

Proposed explanations of the variation in number of injuries across seasons vary across a broad spectrum of potential extrinsic risk factors, including weather and playing surface [112-114], venue being indoor or outdoor [58, 115], and time of season [116]. It also appears that the levels of physical activity vary with weather and season, hereby influencing the time-at-risk [64]. Thus, several mechanisms can be at play, e.g. the high injury incidence and prevalence in the autumn could have resulted from children starting organised sports participation without appropriate preparation. The results from the study of Wareham et al suggest that the overall physical activity and the use of outdoor recreational activities might be a significant factor, as they found that children have a clear increased prevalence of wrist fractures in spring and summer [65]. A Dutch school cohort study used a correction factor of 0.8 in order to account for the seasonal effects on physical activity participation throughout a 12 month follow-up period [20]. Although arbitrarily chosen, the correctional factor was in line with the decrease in physical activities during winter found in a previous review study [64].

The model based estimates for seasonal variation showed a noticeable and surprising difference between the highest and lowest incidence and prevalence rates respectively. A pattern was observed of the lowest prevalence rate early January preceding the lowest incidence rate 3 weeks later. Likewise, a pattern of the highest prevalence rate in late June was followed by the highest incidence rate 3 weeks later. Logically, high incidence rates should precede high prevalence rates and likewise with low rates. Prevalence of injury is the proportion of individuals who have an existing injury at any given point in time and is logically affected by the duration of injury [22]. Injury durations vary [110], possibly reflecting different types of injuries and time for tissue to heal. It can be speculated that high prevalence rates at certain time points are the result of accumulated severe and long-lasting injuries and vice versa for low prevalence rates.

Looking at adjusted estimates in the present study, all age groups followed the same pattern of seasonal variation for musculoskeletal extremity injury incidence and prevalence, but with more pronounced seasonal differences with increasing age. Risk of injury incidence consistently increases with age across most studies when looking at specific sports [32, 41]. This pattern was reproduced in this cohort of children with a broad diversity in choice of sports, amount of participation, competitive levels etc. [110].

The same patterns of higher injury incidence and prevalence estimates during warmer seasons than during winter were shown for both genders. A United States study, analysing all paediatric emergency department visits during four years from seven selected activities (bicycles/tricycles, scooters, playground equipment, swimming/water activities, skiing/snowboarding, trampolines and skating activities), found different peaks for girls and boys (mean age 9.5 years). Girls had the highest number of emergency department visits in the spring and boys in the autumn. This is explained by the most common activity by gender peaking at the same time (girls=playground equipment activities, boys= cycling) [67]. The present study did not look at seasonal risk by specific activities, which might have disclosed gender differences.

In this school-based cohort approximately half the children attended sports schools having three times as many physical education lessons as the rest of the children. This study has not taken the amount of physical activity into account, but it could still be speculated that the circumstances surrounding children being pupils at sports schools influences the injury risk. It is possible that not only the amount of physical education lessons makes a difference, but also that the form and content of physical education have a more pedagogic aim and are less competitive than sports participation in leisure time, hereby influencing injury rates and the seasonal variation in injury risk.

Data collection was put on hold during the six weeks of summer holiday. The predicted times of peak incidence and prevalence fall within this period. However, it seems plausible to assume a consistent pattern all year round. Children being more physically active during the warmer season may likely explain high rates of injuries at this time of the year. More activities take place outdoor, possibly under less rigorous supervision, than during the winter indoor activities. In relation to injury prevention, attention should therefore be focused on outdoor activities and leisure time sport during this time of the year.

This study confirms the need to look into the dynamic and cyclic nature of risk factors and causation to understand injury aetiology. Risk factors are not stable, but may change through preceding cycles of exposure, circumstances and season as suggested by Meeuwisse and colleagues (2007) [31].

Overweight and the association to injury risk (Study IV)

This study is the first to evaluate and compare two different measures of overweight as risk factors for lower extremity injuries in a school-based cohort of children. The risk of lower extremity injuries was observed to increase in overweight children. Being overweight measured by TBF% or the combination of elevated TBF% and BMI were more predictive than being overweight measured by BMI. This suggests that a high proportion of adiposity is more predictive of lower extremity injuries, possibly due to a lower proportion of lean muscle mass.

In contrast, Kaplan *et al* [117] found that body weight was a more powerful injury risk factor than adiposity, with no differences in injury risk between linemen and non-linemen in American football. This was shown in a study comparing different measures of body composition (body fat, BMI, weight, height) to injury risk in a group of 98 high school players with 28 injuries registered by trainers. This was reproduced in another American football study reporting injury rates by body fat, weight, BMI and lean body mass in high school football linemen.[118] Whereas in army cadets, adiposity expressed as TBF% was a stronger predictor of the magnitude and type (overuse/traumatic) of musculoskeletal injuries than BMI [119]. Direct comparisons may not be relevant because of differences in techniques to measure TBF%, injury registration methods, size of studies, ages and sports specific vs. more heterogenic settings. Still, it is possible that in some sports, the effect of increased mechanical loading during weight bearing or collisions have a more pronounced effect than in other sports.

Injury patterns might also differ in relation to different injury types. Traumatic injuries provoked and/or aggravated by greater collision forces due to heavy weight could be argued to be independent of the muscle/fat distribution to a greater extent than overuse injuries, where the quality of tissue (e.g. muscle strength and endurance) is important. The effect of overweight in relation to different injury types (overuse/traumatic), different diagnoses, different anatomical regions and different sports still needs to be clarified.

In this study, injury risk increased with increased participation in PE and leisure time sport. This is in accordance with the common understanding of the need to consider exposure time when estimating injury risk. Surprisingly, children with high fitness levels had a higher risk of sustaining lower extremity injuries. This is in contrast to earlier beliefs where lower fitness levels have been associated with muscle fatigue and subsequent injury [120]. A possible explanation could be that children with high aerobic capacities are also the children with the largest amount of exposure time.

Cut-offs to classify children as normal-weight or overweight were defined using cardiovascular health related and gender specific TBF% standards[84] and age- and gender-specific centiles from pooled international dataset, linked to adult cut-offs for BMI classifications.[85] It can be questioned if these criteria have the same relevance in injury risk research, but they permit comparison across studies and contribute to a general evaluation of health risk among overweight children.
The presentation of data in Figure 2 (study IV), does not suggest any obvious cut-off for a significant increase in risk of lower extremity injuries in relation to overweight. Specific overweight cut-offs for being at increased injury risk might be less important in the context of injury prevention, especially on an individual level where a more comprehensive screening of body composition involving an expression of TBF% would be more relevant. While DXA scans are expensive and not feasible in most settings, a measurement method such as waist circumference is cheap and easy to obtain.[121] Further research is needed into the proposed underlying mechanisms for overweight children being at increased injury risk. Previous suggested mechanisms have been poor postural control – leading to problems with balance and coordination, poor physical fitness – associated with muscle fatigue and subsequent injury and low pre-participation physical activity levels – associated with impaired neuromuscular and motor learning.[46]

Methodological considerations

Quantifying overuse injuries

The data collection method, using weekly text messages to gain knowledge about children possibly having sustained an injury might explain the relatively high number of injuries and injury rates found in this study. It could be argued that the inclusion of overuse injuries contributes to the high figure.
Previous recommendations for a standardized methodology to quantify overuse injuries in sports have mentioned the advantage of frequent and prospective measurements, using sensitive scoring instruments to measure pain symptoms and define injuries by other means than time lost from sport or the need for medical attention [16]. This study followed a cohort of school children for 2.5 years with weekly recordings on incidence and prevalence of musculoskeletal pain and injuries and severity based on diagnosis and duration of pain. This method allowed for a wider perspective on the area concerning musculoskeletal extremity injuries in school children aged 6 to 12, including severe and less severe injuries, traumatic and overuse injuries.

It could be argued that it was because of the particular method of prospective, frequent and sensitive monitoring that injury numbers and rates were high. The possible issue of parents reporting events that would normally be ignored was dealt with by a telephone consultation as a first screen between trivial complaints and persisting symptoms in relation to injury. If the latter was the case, a clinical examination, and if needed para-clinical investigations and/or further examination by medical specialists, was carried out before an injury was finally defined. It was a strength to this study that parental reports on pain and injuries were validated through objective examinations by clinicians.

Asking for pain for a long time

Two concerns emerge when using frequent data collection for a long period; an ethical concern and a methodologically concern.

The ethical question was whether it was sound to repeatedly ask for a negative outcome, such as pain. A study of adult individuals with rheumatic pain, assessed several times a day at random intervals for a month, did not induce a depressed mood [122]. However, the impact on healthy children with mostly temporary and self-limiting symptoms is to our knowledge unknown. In the present study proxy parent reports were considered appropriate, and we hoped to avoid unnecessary child focus on negative symptoms and attention bias in this way.

The methodological concern was whether reports were valid. More specifically, did we get exact measures on both positive responses (no pain) and negative responses (pain)? All negative responses (pain in back, arm or leg) were validated by a telephone consultation, which would identify possible fault reports and clarify if pain symptoms were trivial or indicative of injury. To validate if positive responses were indeed positive, the SMS-Track reporting were compared against verbal reporting and indicated high validity of data [78]. Another concern in this longitudinal setting was if gradual attrition would arise during the long survey period. Looking at response rates a notable high rate was seen throughout the study period, with a mean of 96.2%, confirming the feasibility of the method also seen in other studies [72-76]. One crucial reason for high compliance was believed to be the mutual benefit of parents getting their children clinically examined if required and researchers getting answers.

Injury durations

Duration of pain symptoms in relation to a diagnosed injury was interpreted as equivalent to duration of injury in the present study. This is an open discussion point and depending on the definition of when injury is considered recovered. In sport specific settings, the definition has often

been that injury was fully recovered with the athlete's return to competition or training [123]. A clinical approach weighting pain symptoms is advocated in this heterogeneous cohort of school children to make results comparable on this parameter.
For ethical reasons, the clinical staff assigned to the study gave advice to children and parents on how to alleviate symptoms. This might have influenced prevalence, thus biasing the duration in the direction of shortening injury durations.

Injury incidence rates

A general limitation to the presented injury incidence rates is the use of sample-level exposure data done for feasibility reasons. Taking the point estimate for the incidence rate in the sample as the sum of injuries across all individuals divided by the sum of exposures across all individuals, is the method used in most injury research, but this assumes that there is a fixed overall injury rate that is the same for every individual, which is rarely the case [22]. Another weakness is that with a follow-up of 2.5 school years both incidences of injury and exposure time might have varied in a way that makes causal inferences more uncertain, i.e. a child might have had no injuries and a low level of sports participation one year and several injuries and a high level of sports participation the next year or the reverse. Finally the uncertainty by extrapolating estimates from one week of accelerometer measurements must be mentioned, i.e. the physical activity patterns shown across one week in the winter might not reflect the child's activity level in general.

Lacking 6 weeks of injury data

A general weakness to the data collection was the lack of information on injuries and level of physical activity during 6 weeks of children's summer holiday. This was done to avoid parental attrition and for practical reasons, as children away on holiday could not be clinically examined.
Data collection was also put on hold for one week of Christmas holiday. This was not considered a significant methodological problem, as an injury would still be reported at the end of the holiday, with a maximum of two weeks delay.

Re-injury or exacerbation

The fact that some children experienced more than one injury in the study period, could suggest that some injuries were recurrent. It was not the focus of this study to define if an injury was in fact a re-injury (i.e. injuries occurring at the same site after the index injury has fully recovered [123]). However, an injury was not registered if the condition was clinically determined to be an exacerbation of a non-recovered index injury, thus avoiding over-reporting of the number of new injuries.

Commonly, in the context of sports injuries, an index injury is regarded as closed when the athlete return to full training or competition [123]. Fuller *et al* problematize this as many athletes often return to training or competition before they are completely recovered and suggest that clinicians should make the distinction between re-injuries and exacerbation of index injury [123]. It was a strength to this study that a clinical judgement distinguished between injuries being a new incidence or an exacerbation of a non-recovered index injury.

Conclusions

By presenting incidence and prevalence of musculoskeletal extremity injuries and associated risk factors possibly explaining aetiology, this thesis brings forward new and important knowledge concerning injury epidemiology in school children aged 6 to 12.

The main findings in relation to objectives:

1. **Study I:** Close to twice as many overuse as traumatic extremity injuries were registered, with 2.5 times more overuse than traumatic injuries in lower extremities. A reverse pattern was found for upper extremities, with 3.1 times more traumatic than overuse injuries. Grade level, school type, leisure time sport, and seasonal variation were associated with the risk of sustaining lower extremity injuries. Only grade level was associated with upper extremity injuries.
2. **Study II:** A number of 1229 injuries were presented, with apophyses and soft tissue injuries being the most common overuse injuries in lower and upper extremity respectively. Ligament sprains were the most common traumatic extremity injury. Injury rates of traumatic injuries and the setting in which they occur were found to be highest for injuries sustained in sports, followed by injuries sustained in leisure time physical activity and lowest for injuries sustained in physical education lessons. The shoulder/upper arm and the heel was the most common body region of overuse injury in upper and lower extremity respectively. The hand/wrist and the ankle was the most common region of traumatic injury in upper and lower extremities respectively.

3. **Study III:** There are clear seasonal differences in the occurrence of musculoskeletal extremity injuries among children with almost twice as high injury incidence and prevalence estimates during autumn, summer and spring compared to winter.

4. **Study IV:** The risk of lower extremity injuries increased in overweight children. When comparing two different measures of overweight, a body composition of proportional high levels of TBF% is a higher risk factor, than overweight as measured by BMI. This suggests that a high proportion of adiposity is more predictive of lower extremity injuries, possibly due to a lower proportion of lean muscle mass.

Perspectives

Future research

In the studies included in the present thesis we have addressed injury epidemiology in school children and associated risk factors possibly explaining aetiology. We have attempted to overcome methodological shortcomings in previous studies by using frequent and prospective measures. Nevertheless, limitations to the present study are still a concern and the following suggestions are given to future research.

To fully utilise the text messaging method of recurrent and frequent gathering of real time information, it is important to avoid gaps in data collection. Circumstances might necessitate that data collection is put on hold, but ways to compensate should be attempted. The obvious choice is to take advantage of the text messaging system and obtain the lost information retrospectively, e.g. after participants' holidays. This information will not have the same accuracy as weekly, prospective data, but still it will contribute to a more complete data collection.

Study III and IV investigated the particular association between injury risk and time of season and body composition respectively. While associations were found, further research into the underlying causation is still needed.

Injury severity in this study was presented only by the magnitude of diagnosed injuries and the related duration of pain. Other measures of severity might receive more attention on organisational levels, which can actual influence public health. Thus measures of e.g. days away from school, sports, parental costs and use of health services will be more compelling arguments and render possible economic evaluation. In advocating for increasing involvement of children in sports and physical recreation, it is important to be aware of the magnitude of the adverse health consequences that may be involved.

Policy implications

The understanding of injury epidemiology in children is fundamental to acknowledge that despite the many health benefits of physical activity, there are drawbacks in terms of related injuries. Emery *et al* (2006) developed a theoretical model (figure 5) that defines a responsibility hierarchy in preventing injuries in youth sport based on potential influence on different levels ranging from the child itself to policy-based strategies on governmental level [124]. The different levels will be taken as the starting point in placing the findings of this thesis into a broader perspective.

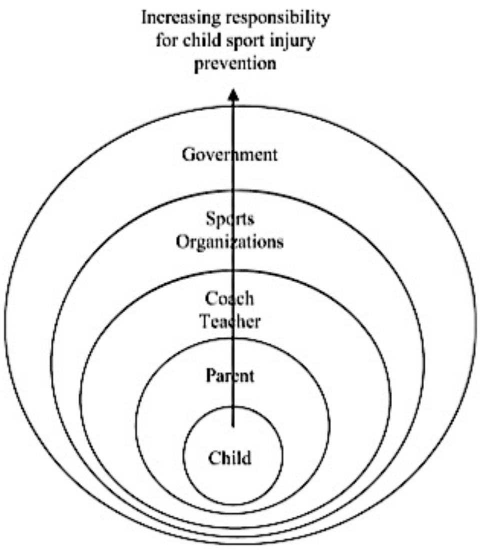


Figure 5 Responsibility hierarchy for child sport injury-prevention based on potential influence. Emery et al, 2006

The lowest level of responsibility has been assigned to the child because the extent of perceptual and cognitive development cannot be expected to adequately identify and recognize hazards in sports [124]. Our findings support this theory, as children in the case of overuse injuries, carry on being physical active in a way that aggravates symptoms. This can be caused by the individual lack of personal responsibility (e.g. not telling about overuse symptoms, not wearing appropriate shoes) or by externally imposed factors (e.g. content of physical education lessons and sports). Parents have a responsibility to support the child in avoiding risk behaviour e.g. ignoring pain, weight gain, but have no influence on the way that their children are trained and physically educated. Coaches and physical education teachers are strong moderators of behaviour and attitudes to sport, and their level of training skills and knowledge about the growing and physically active child is crucial. In relation to our findings on injury rates of traumatic injuries, risks were found to be highest for injuries sustained in sports and lowest for injuries sustained in physical education lessons. This suggests that appropriate interventions should target especially sport organisations and clubs as first choice for prevention of traumatic injuries, especially in ball game sports and high impact sports as tumbling gymnastics.

Overuse injuries is a result of repetitive demands over the course of time and probably an accumulation of different types of physical activities, which make it more complex to pinpoint settings for being most at risk. However, the findings of injuries being associated with time of season in relation to both traumatic and overuse injuries and across all settings, suggest preventive strategies before and during high-risk periods of children being physically active. Coaches and physical education teachers are in first-line to take this in charge, but sport organisations and teachers' colleges need to prioritise this in terms of education in age related training concepts and preparticipation sport-specific training.

Our results concerning overuse injuries and the risk factors involved, confirms the need for guidelines and recommendations on the prevention of overtraining, burnout and overuse injuries in children and adolescents as suggested by Brenner [100] and Valovich McLeod and colleagues [105]. The mentioned guidelines are primarily active strategies e.g. preparticipation physical screening, coach education, medical supervision, training and conditioning programs. The guidelines and recommendations address coaches, and health care professionals, but appropriate interventions on all responsible levels ranging from policy-based strategies to parents are important to prevent child sport injuries [124]. Emery *et al* suggest passive prevention strategies (e.g. legislation on bicycle helmets, bicycle paths, changing sport rules, optimizing surfaces, releasing binding for skiers) to be more effective than relying solely on active strategies and behaviour change [124]. Therefore Emery *et al* assign the highest level of responsibility to the governmental level to mandate policy-based strategies, ex safe playgrounds, money for maintenance of sports arenas (e.g., playing surfaces), safe roads with paths for cycles, legislation about helmet use for bicycling etc.

The findings in this thesis especially call for considering strategies to avoid overuse injuries. While the prevention and treatment of the severe 'time loss' and medical care needing traumatic injuries have been described to some extent [41, 125-129], a suitable approach towards less severe injuries and overuse injuries needs more attention. Efforts to keep the child physically active, but with consideration for the injury, are suggested to ensure continued fitness and social contact with the preferred activities, but further intervention research is needed to clarify best practice.

Summary in English

Background: Participation in physical activities promotes health in children, but a drawback is the risk of related injuries. Physical activity-related injuries have been established as a leading cause of paediatric injuries in western countries with high costs for children, parents and society. Previous studies have primarily presented severe and traumatic injuries; the "tip-of-the-iceberg" phenomenon. Information on the less severe injuries and overuse injuries is difficult to capture and quantify because symptoms might have a vague and gradual onset, their presence may not result in a measurable consequence and there has been a lack of valid and user-friendly methods for collecting this type of data. The common use of mobile phones now makes it possible to collect frequent data of self-reported symptoms indicative of musculoskeletal injuries for long periods in large cohorts.

Objectives: The objectives of this thesis were to investigate the patterns of musculoskeletal extremity injuries in a cohort of school children using weekly assessments for 2.5 years and to estimate the associations of possible risk factors such as exposure time, time of season and overweight measures.

Methods: To address these objectives, data from the Childhood Health, Activity, and Motor Performance School Study Denmark (CHAMPS Study–DK) August 2008 to July 2011 were used. In all, 1259 school children, aged 6-12, were surveyed each week with an automated mobile phone text message asking questions on the presence of any musculoskeletal problems. A telephone consultation served as a first screen between trivial complaints and persisting symptoms in relation to injury. If the latter was the case, clinicians assigned to the study examined the children and diagnosed injuries using the International Classification of Diseases (ICD-10). To get a complete recording of musculoskeletal extremity injuries in the sample, injuries diagnosed in other clinical settings (e.g. emergency departments) were collected in the same period. Physical activity was measured from text messaging and accelerometers.

Results: We found overall weekly rates of injury incidence and prevalence of 1.2% and 4.6% respectively. In the participating 1259 children a total of 1229 injuries were registered. Close to

twice as many overuse as traumatic extremity injuries were found, with 2.5 times more overuse than traumatic injuries in lower extremities. A reverse pattern was found for upper extremities, with 3.1 times more traumatic than overuse injuries. Grade level, school type, leisure time sport, and seasonal variation were associated with the risk of sustaining lower extremity injuries. Only grade level was associated with upper extremity injuries.

In general, most injuries were sustained in the lower extremities n=1049 (85%), with overuse injuries being by far the most common injury type with a notable high number of apophysitis injuries located at the heel or knee being diagnosed. Thus diagnosis as Sever's lesion, Sinding-Larsen and Osgood-Schlatter, accounted for 44% of all lower extremity injuries. A reverse pattern was found for upper extremity injuries (n=180) where traumatic injuries such as ligament strains, fractures, contusions and strains predominated.

The shoulder/upper arm and the heel was the most common body region of overuse injury in upper and lower extremity respectively. The hand/wrist and the ankle was the most common region of traumatic injury in upper and lower extremities respectively.

Injury rates of traumatic injuries and the setting in which they occur were found to be highest for injuries sustained in sports (1.57 per 1000 sport exposure units), followed by injuries sustained in leisure time physical activity (0.57 per 1000 leisure time PA exposure units) and lowest for injuries sustained in physical education lessons (0.14 per 1000 PE exposure units).

Seasonal variation in the patterns of injury incidence and prevalence was found with almost twice as high injury incidence and prevalence estimates during autumn, summer and spring compared to winter. Overweight by measures of BMI and total body fat percentage predicts lower extremity injuries suggesting that overweight children are at higher risk.

Conclusions and perspectives: This thesis has added an overall perspective to the area concerning musculoskeletal extremity injuries in school children aged 6 to 12, by using frequent and prospective measures to capture both traumatic and overuse injuries. Describing and analysing injury incidence and prevalence and associated risk factors possibly explaining aetiology, has broadened the understanding of injury epidemiology in children. The generic findings from this heterogenic cohort of school children especially call for considering strategies to avoid overuse injuries, suggestively on all responsible levels from children, parents, coaches, physical education teachers, sports health care professionals to policy-makers.

Summary in Danish

Baggrund: Fysisk aktivitet fremmer børns sundhed, men giver også en risiko for skader. Det er påvist at skader relateret til fysisk aktivitet er den største gruppe af skader blandt børn i vestlige lande medførende store omkostninger for både børn, forældre og samfund. Tidligere studier har fortrinsvist præsenteret alvorlige, traumatiske skader; det såkaldte "toppen af isbjerget" fænomen. Det har været vanskeligt at opfange og kvantificere mindre skader og overbelastningsskader af flere grunde: For det første er symptomerne ofte diskrete og gradvist indsættende, for det andet medfører de ikke nødvendigvis at der søges hjælp hos sundhedsprofessionelle eller at deltagelse i idrætsaktiviteter stoppes, for det tredje har der været en mangel på valide og brugervenlige metoder at indsamle denne slags viden med. Den almindelige udbredelse og brug af mobiltelefoner og sms beskeder har muliggjort opsamling af selvrapporterede symptomer, som en første screening for eventuelle skader. Metoden muliggør hyppige registreringer over lange perioder i store kohorter.

Formål: Formålet med denne afhandling var at undersøge forekomsten af skader i bevægeapparatet i ekstremiteter og at estimere sammenhænge mellem mulige risikofaktorer så som eksponeringstid, årstidsvariation og overvægt i en kohorte af skolebørn undersøgt ugentligt over 2.5 år

Metode: Data fra the Childhood Health, Activity, and Motor Performance School Study Denmark (CHAMPS Study–DK) fra perioden august 2008 til juli 2011 blev anvendt. I alt blev 1259 skolebørn i alderen 6 til 12 år fulgt gennem ugentlige tilbagemeldinger på automatiserede sms spørgsmål om bevægeapparats problemer. En telefonkonsultation blev anvendt til at skelne mellem trivielle klager og vedvarende symptomer i relation til mulig skade. I sidstnævnte tilfælde, blev børn undersøgt af klinikere tilknyttet studiet og diagnosticeret i forhold til ICD-10 (the International Classification of Diseases). Skader diagnosticeret i andre kliniske sammenhænge (f.eks. skadestue) blev indsamlet i samme periode for at opnå en komplet skadesregistrering i kohorten. Fysisk aktivitet blev målt via sms spørgsmål og accelerometer målinger.

Resultater: Samlet set blev der observeret en ugentlig skadesincidens og skadesprævalens på henholdsvis 1.2% og 4.6%. Blandt de 1259 børn, der deltog blev der registreret 1229 skader. Der var nærved dobbelt så mange overbelastningsskader som traumatiske. I underekstremiteter var der

2.5 gange flere overbelastningsskader end traumatiske skader. Det modsatte gjorde sig gældende for overekstremiteter, hvor der var 3.1 gange flere traumatiske skader end overbelastningsskader. I forhold til risikoen for at pådrage sig underekstremitetsskader, blev der fundet en sammenhæng med klassetrin, skoletype, mængden af sport og årstid. I forhold til risikoen for at pådrage sig overekstremitetsskader, blev der kun fundet en sammenhæng med klassetrin.

De fleste skader var underekstremitetsskader, i alt 1049 (85%), hvoraf overbelastningsskader i form af apofysit skader svarende til hæl og knæ var langt det mest almindeligt forekommende. Således tegnede diagnoser som Sever's lesion, Sinding-Larsen og Osgood-Schlatter sig for 44% af alle underekstremitetsskader. For overekstremitetsskader, i alt 180, var det hovedsageligt traumatiske skader så som forvridninger, frakturer, kontusioner og forstrækninger der blev registreret.

For overbelastningsskader var det hyppigst skadede område i overekstremiteter skulder og overarm, imens det for underekstremiteter var hælen, der var mest skadet. For traumatiske skader var det hyppigst skadede område i overekstremiteter håndled og hånd, imens det for underekstremiteter var anklen, der var mest skadet.

De højeste skadesincidens rater for traumatiske skader forekom til sport i fritiden (1.57 per 1000 enheder sport). De næsthøjeste forekom i uorganiserede aktiviteter i fritiden (0.57 per 1000 enheder fysisk aktivitet i fritiden), imens den laveste risiko forekom i skoleidrætstimerne (0.14 per 1000 enheder skoleidræt).

Der blev fundet årstidsvariation i skadesincidens og skadesprævalens med næsten dobbelt så stor skadesrisiko henover forår, sommer og efterår, sammenlignet med vinter. Overvægt defineret med henholdsvis BMI og den totale andel af fedt i kroppen prædikterer forekomsten af underekstremitetsskader, hvilket indikerer at overvægtige børn er i øget risiko.

Konklusion og perspektivering

Denne afhandling har tilføjet en bredere indsigt i bevægeapparatsskader i ekstremiteter i en kohorte af 6-12 årige skolebørn ved at anvende hyppige og prospektive data indsamlings metoder til at opfange såvel traumatiske skader som overbelastningsskader. Den epidemiologiske viden omkring børns skader er udvidet ved at beskrive og analysere skadesincidens og skadesprævalens og de associerede risikofaktorer der bidrager til forklaringen af skadesætiologi. De generiske fund fra denne heterogene kohorte af skolebørn giver grund til især at gennemtænke strategier til at forebygge overbelastningsskader på alle ansvarlige niveauer fra børn, forældre, trænere, idrætslærere, sundhedsprofessionelle til beslutningstagere i sportsorganisationer og politik.

Acknowledgements

This thesis was conducted at the Research Unit of Exercise Epidemiology, Department of Sport Science and Clinical Biomechanics, Faculty of Health Sciences, University of Southern Denmark, in the period 2008 – 2013. I would like to thank all of you that have contributed to this thesis.

Especially I would like to thank:

Children and parents participating in the CHAMPS Study-DK. I will never stop being impressed by the high participation rate and the kind willingness to share information, making this study possible.

The Municipality of Svendborg, the Svendborg Project, Sports Study Sydfyn and the teachers in the schools involved in the project. An exemplary cooperation.

'The Champs Study-DK Team': Heidi Klakk, Claudia Franz, Christina T Rexen, Malene Heidemann, Niels Christian Møller and Niels Wedderkopp. What a team – what a spirit!

'The Injury Team': Christina T Rexen, Claudia Franz, Tina Junge, Heidi Klakk and Niels Wedderkopp. My hard working and dedicated colleagues and friends – together we did it!

Niels Wedderkopp: Always only a phone call away! Thank you for your endless trust and support.

René Holst: Helping me to disentangle, exploit and analyse data … 'patience' is a telling word, but still a huge understatement!

Karsten Froberg: In times of trouble, in times of joy – you were solid as a rock!

All the clever, warm-hearted and funny people around my office at the Centre of Research in Childhood Health, University of Southern Denmark. Especially Lars Bo Andersen, Karsten Froberg, Birgitte Laursen and Charlotte Dichmeiss for setting the agenda of the spirit being clever, warm-hearted and funny.

The EMGO institute, Vrieje Universitet, Amsterdam: Thanks to Willem van Mechelen for hosting a 3 months stay and to Evert Verhagen for pleasant and meaningful supervision. Being a foreigner in Amsterdam, I would also like to thank Diana van Dongen, who showed such great hospitality and is now a dear friend of mine.

Heidi Klakk: Some people share work, some share friendship, some share a study period in Amsterdam, some share times of adversity and some share only the good times – we shared it all! Thanks for never-ending support and a lot of laughing, my friend.

Friends: Sorry, for a period of being introvert - 5 years … but I sure did notice your warm support all along. It meant the world to me! I dare not mention any specific names, even not ‘The Lams’.

Family: My husband, Claus, and my two sons, Peter and Kristian, deserves the biggest appreciation for kind tolerance, whole-hearted support and reminding me of the important things in life. To the three of you, my sweet mother, siblings and the rest of my lovely family: In times of doubt, you made the difference!

Oh, pardon me - I almost forgot: John Bolton, my dear English father-in-law, who apparently “almost lost his will to live” at several occasions, while he was trying to correct my very long sentences in the four manuscripts and this thesis.

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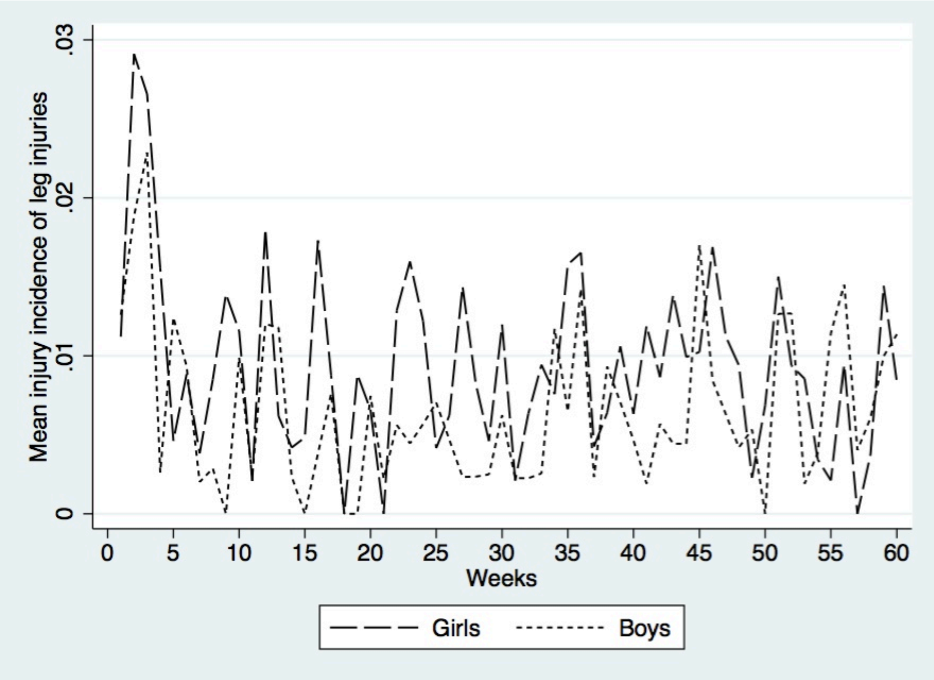
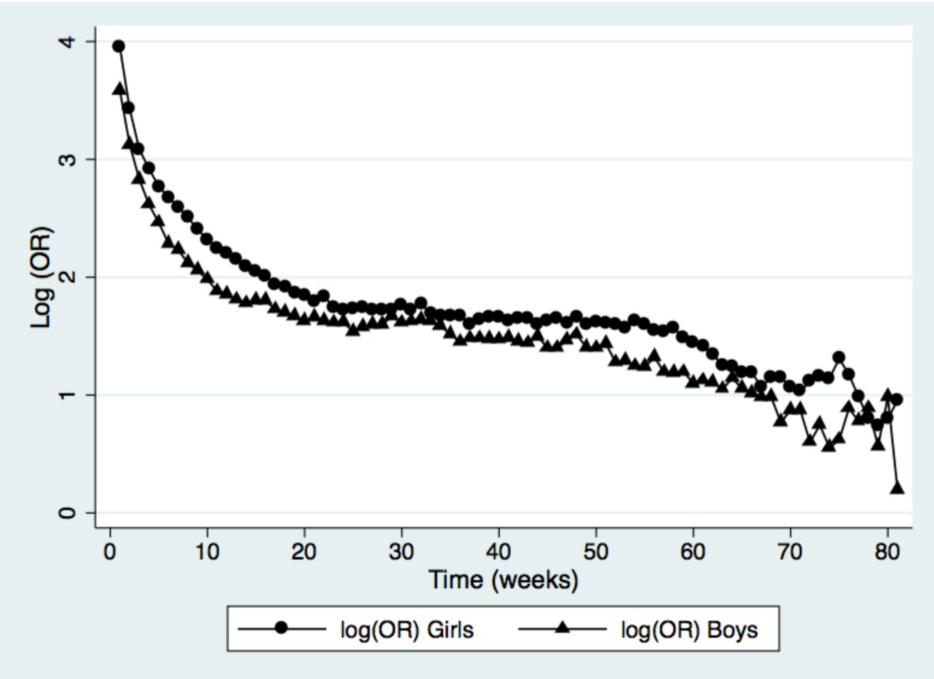
List of appendences

Figure 1: Mean lower extremity injury incidences by gender over time.



Weeks are relative to each school included in SMS-track, thus week 1 is the first week for all ten schools even though the inclusion of schools was gradual.

Figure 2: Lorelogram illustrating serial correlation in leg pain by gender



Study I

Scand J Med Sci Sports 2013: ••: ••–••
doi: 10.1111/sms.12095

SCANDINAVIAN JOURNAL OF
MEDICINE & SCIENCE
IN SPORTS

Overuse and traumatic extremity injuries in schoolchildren surveyed with weekly text messages over 2.5 years

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Accepted for publication 28 May 2013

The objectives of this prospective cohort study were to report the incidence, prevalence, and duration of traumatic and overuse injuries during a period of 2.5 years and to estimate the odds of injury types. In all, 1259 schoolchildren, aged 6–12, were surveyed each week with an automated mobile phone text message asking questions on the presence of any musculo-skeletal problems and participation in leisure-time sport. Children were examined and injuries classified as overuse or traumatic. The overall injury incidence and prevalence were 1.2% and 4.6% per week, with 2.5 times more overuse than traumatic injuries in lower extremities, and mean injury duration of 5.3 and 4.8 weeks, respectively. A reverse pattern was found for upper extremities, with 3.1 times more traumatic than overuse injuries and mean durations of 3.3 and 5.2 weeks, respectively. Grade level, school type, leisure-time sport, and seasonal variation were associated with the risk of sustaining lower extremity injuries. Only grade level was associated with upper extremity injuries. The magnitude of overuse and traumatic limb injuries emphasizes the need for health professionals, coaches, and parents to pay special attention in relation to the growing and physically active child.

Children gain many health benefits from participating in regular physical activity (PA) (Ekblom & Astrand, 2000; Janssen & Leblanc, 2010; Andersen et al., 2011). Injuries sustained in sports activities have, however, been established as a leading cause of pediatric injuries in Western countries (Finch et al., 1998; Brudvik & Hove, 2003; Conn et al., 2003). Sports injuries in children constitute a significant public health burden, leading to high direct and indirect costs for both children and parents (Collard et al., 2011). Injuries may cause short-term disability, absence from school and PA, loss of enthusiasm for participating in PA, and long-term consequences such as osteoarthritis (Kujala et al., 1995; Mikkelsson et al., 1997; Abernethy & MacAuley, 2003; Oiestad et al., 2010).

Injuries are commonly defined according to injury mechanism, in terms of whether injuries are traumatic or caused by overuse. Traumatic injuries are those resulting from a single, specific, and identifiable event, whereas overuse injuries are caused by repeated microtrauma without a single, identifiable event responsible for the injury (Fuller et al., 2006). There are no studies providing incidence or prevalence of overuse injuries in children and adolescents, whereas data on traumatic injuries are commonly collected in emergency departments but might only reveal "the tip of the iceberg." There is a growing concern about overuse injuries (Brenner, 2007; Mayranpaa et al., 2010) and it has been estimated that approximately half of all sports-related injuries are in fact caused by overuse (Valovich McLeod et al., 2011). It has been speculated that early specialization, increased intensity of training, and competition in sport at younger ages, maybe on multiple teams simultaneously, and often year round, could be a cause for an increased number of overuse injuries (Brenner, 2007; Mayranpaa et al., 2010). Concerns have been raised that the consequences of overuse injury might be more serious to children and adolescents because the growing tissues are particularly vulnerable to stress (Olsen et al., 2006; O'Malley et al., 2012).

There are probably three main reasons why it is difficult to quantify and describe overuse injuries in childhood. First, they can be difficult to diagnose, as symptoms have a vague and gradual onset. Second, their presence may not result in a measurable consequence such as medical care seeking or absence from school or physical activities and third, there has been a lack of valid, reliable, and user-friendly methods for collecting this type of data.

The common use of mobile phones now makes it possible to collect frequent data of self-reported symptoms indicative of musculo-skeletal injuries and amount of PA for long periods in large populations. In this study a large cohort of Danish schoolchildren was monitored closely with frequent and real-time data on musculo-skeletal pain and diagnosed injuries. This provided an opportunity to obtain improved estimates of the prevalence and incidence on both traumatic and overuse injuries.

The objectives of this study were to report the incidence, prevalence, and duration of traumatic and overuse injuries in a Danish cohort of schoolchildren using weekly assessments for 2.5 years and to estimate the odds of injury types when looking at sports participation in school and leisure-time as a risk factor, adjusting for gender, age, previous injuries, and seasonal variation.

Materials and methods

Setting

Data from the Childhood Health, Activity, and Motor Performance School Study Denmark (CHAMPS Study–DK) August 2008 to July 2011 were used (Wedderkopp et al., 2012). This investigation is a large prospective controlled school-based study in Denmark using the design of a natural experiment (Craig et al., 2012) to evaluate the effect of increased physical education (PE) on childhood health in general. Six schools were assigned to become sport schools with six PE lessons per week and four normal schools served as control with two PE lessons per week. Parents and children were unaware of the initiation of this project until 2 months before the following school year, avoiding parents making an influenced school choice. The project is extensively described elsewhere (Wedderkopp et al., 2012).

Ethics committee approval was obtained before the start of the project; ID S20080047 and registration in the Danish Data Protection Agency was made, as stipulated by the law J.nr. 2008-41-2240. Written informed consent was obtained from the child's parent. Prior to every clinical examination, both child and parent gave verbal acceptance. All participation was voluntary with the option to withdraw at any time.

Participants

All boys and girls from preschool to fourth grade in 10 public schools participating in the CHAMPS Study-DK also agreed to participate in the registration of musculo-skeletal pain and injuries. The overall participation rate was 697 (90%) for the sport schools and 521 (71%) for the normal schools. The study was kept open, with the possibility for new children to enter. Due to the novel data collection method of automated mobile phone text message (SMS-track), the 10 schools were included gradually over 8 months to allow for a phasing-in process.

Measurements

Musculo-skeletal pain and injuries

Weekly information on musculo-skeletal pain and injuries was collected using SMS-track. This approach provides real-time measurements and thereby improves the validity of data relative to data collected retrospectively (Shiffman et al., 2008). Each Sunday, parents answered a text message that asked questions on the presence or absence of any musculo-skeletal pain during the previous week. If pain was reported, a telephone consultation was carried out Monday and if the problem still persisted, the complaint was defined as "nontrivial." Physiotherapists, chiropractors, and a medical practitioner were responsible for the clinical examination of the children within the coming fortnight. Injuries were diagnosed using the International Classification of Diseases (ICD-10). If necessary, the child was referred for further para-clinical examination, such as X-ray, ultrasound, or magnetic resonance imaging scan, and possibly seen by a medical specialist. Information on children being seen or treated elsewhere (e.g., emergency department, general practitioner) during the study period was collected concurrently to get a complete data collection on injuries. Collection of data was suspended during the 6 weeks of summer holiday.

A traumatic injury is defined as an injury resulting from a specific, identifiable event, whereas an overuse injury is an injury caused by repeated microtrauma without a single identifiable event responsible for the injury (Fuller et al., 2006). Injuries were classified into these two categories by looking at diagnosis and medical records, where the injury mechanisms were documented.

Sports participation in school and leisure-time

Weekly amount of PE was 4.5 h for sport schools and 1.5 h for normal schools, corresponding to three and one double lesson per week, respectively. Children at sport and normal schools were therefore assigned three and one sport exposure unit per week, respectively. Leisure-time sport was assessed using SMS-track by parental reports on how many times the child had participated in leisure-time sport during the past week.

Socioeconomic information

Socioeconomic information on parental educational level and income was collected in a baseline questionnaire.

Statistical methods

Data from SMS-track and data on diagnosed injuries were analyzed using STATA 12.0 (StataCorp, College Station, Texas, USA).

Excessive levels of pain and injuries were reported during the start-up phase. This is possibly explained by the novelty of the study and the method. Observations from the first 4 weeks relative to the time of inclusion were therefore excluded.

Potential confounders and effect modifiers for the prevalence and incidences of injuries were assessed by exploratory tables and figures. This involved the calculation of observed weekly means of prevalence, incidence, and duration of complaints and injuries. The calculation of injury incidence rates accounted for the total sum of exposure expressed in 1000 athletic exposure units. These comprised the PE exposures and the participations in leisure-time sport.

The selection of potential confounder effects for the analysis included gender, age, and previous injuries, the latter up till 8 weeks prior to index injury. These are commonly acknowledged modifying factors (Emery, 2003; Caine et al., 2008). Plots of observed incidence and prevalence over time indicated a high-risk period during autumn and spring and a low-risk period. Seasonal variation was therefore also included as a potential effect modifier.

The focal point of interest was the risk of the three competing states: no injury, a traumatic injury, or an overuse injury. The analysis aimed at describing how the risk for entering these states depended on the explanatory variables. This was suitably modeled by a multinomial logistic regression extended to the longitudinal and multilevel setting (Steele et al., 2004), using children, classes, and schools as random effects. The multilevel model and the random effects reflect the hierarchical sampling structure and were chosen to allow for potential variation between schools, between classes within schools, and between pupils within classes and ensure correct modeling of the variances. The sources of variation (e.g., environments, teachers, atmosphere) in themselves were not of interest and were therefore deemed to be random effects.

The explanatory variables included school type, leisure-time sport, gender, age, previous injury, and seasonal variation.

Potential patterns for the missing values were addressed by a logistic regression analysis controlling for gender, age, school type, and leisure-time sports effects. Missing values because of practicalities concerning changed or wrong mobile numbers were dropped for analyses.

Results

There was a gradual inclusion of schools starting with 231 children from three schools and ending up including children from all 10 schools 8 months later, with all the schools participating from the start of the 2009–2010 school year. In total, 1259 children participated during the study period. The range of participation time was 1–113 weeks, with 90.2 weeks being the mean value. Dropouts were due to children moving away from the municipality or changing to a nonproject school, but were counterbalanced by new children moving to project schools. Fifteen children dropped out for other reasons, the main one being that answering SMS questions every week was too bothersome. An average weekly response rate of 96.2% was recorded during the study period of 113 weeks. A total number of 109 245 observations were recorded and 4297 (3.8%) were missing. Analysis of missing data did not show any patterns when looking at gender, age, school type, and leisure-time sports. Parental education and income levels were comparable between participating schools in the project.

The overall weekly injury incidence and prevalence rates were 1.2% and 4.6%, respectively. The number of injuries and incidence rate of injuries for athletic exposures are shown in Table 1. In the participating 1259 children, a total of 1229 injuries were registered, of these 794 were overuse injuries and 435 were traumatic injuries. Some children experienced more than one injury; the range was from zero injuries and up to nine episodes of lower extremity (LE) injuries and up to three episodes of upper extremity (UE) injuries. The injury incidence per 1000 athletic exposures for overuse LE and traumatic LE injuries was 3.7 and 3.3, respectively, and 2.3 and 2.7 for overuse UE and traumatic UE injuries, respectively.

The weekly incidence, prevalence, and duration of pain and injuries are shown in Table 2. The ratio of overuse LE injuries to traumatic LE injuries was 2.5 : 1, with mean durations of 5.3 and 4.8 weeks, respectively. The reverse applied for UE injuries, with the corresponding ratio being 1 : 3.1 and mean durations of 5.2 and 3.3 weeks, respectively.

On average, the children participated 1.5 times per week (range 0–7.2) in leisure-time sport. Third and fourth grade had a significant higher mean sports participation in leisure-time, compared with preschool, first and second grade. Children in higher grades also had higher odds of both LE and UE overuse and traumatic injuries, with odds increasing by 20% for each grade level for both types of injuries.

Table 1. Descriptive characteristics of 1259 schoolchildren by five grades followed over 2.5 years with number of injuries, number and percentage of children with injuries, mean athletic exposures in school and leisure-time sport, and injury incidence rate per 1000 athletic exposures

	Preschool	Grade 1	Grade 2	Grade 3	Grade 4	Total
Numbers	224	252	271	249	263	1259
Age (years)	6–8	7–9	8–10	9–11	10–12	6–12
Gender						
Girls	120	134	124	138	145	661
Boys	104	118	147	111	118	598
Overuse injuries						
No. of UE overuse injuries	0	7	7	17	13	44
No. of children (%)	0 (0)	6 (2.4)	6 (2.2)	15 (6.0)	13 (5.0)	40 (3.2)
No. of LE overuse injuries	67	134	182	193	174	750
No. of children (%)	52 (23.2)	89 (35.3)	120 (44.3)	116 (46.6)	113 (43.3)	490 (39.0)
Traumatic injuries						
No. of traumatic UE injuries	12	22	38	28	36	136
No. of children (%)	12 (5.4)	19 (7.5)	34 (12.5)	25 (10.0)	33 (12.6)	123 (9.8)
No. of traumatic LE injuries	30	56	79	62	72	299
No. of children (%)	25 (11.2)	39 (15.5)	55 (20.2)	48 (19.3)	56 (21.5)	223 (17.7)
Sports participation (athletic exposures)						
Mean PE (± SD)	2.2 (± 1.0)	2.2 (± 1.0)	2.2 (± 1.0)	2.2 (± 1.0)	2.1 (± 1.0)	2.2 (± 1.0)
Mean leisure-time sport (± SD)	1.0 (± 1.1)	1.4 (± 1.4)	1.6 (± 1.5)	1.8 (± 1.6)	1.8 (± 1.7)	1.5 (± 1.5)
Overuse injuries per 1000 athletic exposures						
UE (95% CI)	0	2.4 (0.6–4.2)	2.0 (0.5–3.4)	2.7 (1.2–3.3)	2.7 (1.2–4.1)	2.3 (1.6–3.0)
LE (95% CI)	3.7 (2.8–4.6)	3.8 (3.2–4.5)	3.6 (3.1–4.1)	3.8 (3.3–4.4)	3.7 (3.2–4.3)	3.7 (3.5–4.0)
Traumatic injuries per 1000 athletic exposures						
UE (95% CI)	2.7 (1.2–4.2)	2.8 (1.6–4.0)	2.9 (1.9–3.8)	2.7 (1.7–3.6)	2.6 (1.7–3.4)	2.7 (2.3–3.2)
LE (95% CI)	3.6 (2.3–4.8)	3.6 (2.7–4.6)	3.2 (2.5–4.0)	3.0 (2.2–3.7)	3.2 (2.5–4.0)	3.3 (2.9–3.6)

CI, confidence interval; LE, lower extremity; PE, physical education; UE, upper extremity.

Table 2. Weekly mean incidence, prevalence, and duration of musculo-skeletal pain and injuries in total group of 1259 participants in SMS-track during 2.5 years of weekly registration

	Weekly mean incidence in percentage (± SD)	Weekly mean prevalence in percentage (± SD)	Mean duration in weeks (± SD)
Lower extremity			
Reported pain	3.2 (± 17.6)	8.8 (± 28.4)	2.8 (± 4.5)
Injury	1.0 (± 9.7)	4.1 (± 19.9)	5.0 (± 7.1)
Overuse injury	0.7 (± 8.2)	3.2 (± 17.7)	5.3 (± 7.7)
Traumatic injury	0.3 (± 5.2)	1.1 (± 10.4)	4.8 (± 7.2)
Upper extremity			
Reported pain	0.7 (± 8.2)	1.3 (± 11.1)	2.2 (± 4.5)
Injury	0.2 (± 4.0)	0.5 (± 7.2)	3.8 (± 8.3)
Overuse injury	0.04 (± 2.0)	0.2 (± 4.9)	5.2 (± 13.6)
Traumatic injury	0.1 (± 3.5)	0.3 (± 5.8)	3.3 (± 4.6)

Table 3. Adjusted odds ratio estimates by injury types for all included covariates

	Lower extremity		Upper extremity	
	Traumatic injuries OR (95% CI)	Overuse injuries OR (95% CI)	Traumatic injuries OR (95% CI)	Overuse injuries OR (95% CI)
Leisure-time sport				
0	1	1	1	1
Increasing per exposure	1.2 (1.1–1.3)*	1.2 (1.1–1.3)*	1.1 (0.96–1.3)	1.1 (0.9–1.4)
School type				
Normal school	1	1	1	1
Sports school	1.6 (1.0–2.5)*	1.3 (0.9–1.9)	1.3 (0.8–1.9)	1.8 (0.9–3.5)
Gender				
Girls	1	1	1	1
Boys	1.0 (0.7–1.3)	0.89 (0.7–1.1)	0.7 (0.5–1.01)	0.7 (0.4–1.2)
Age groups (grade level)				
Preschool (6 years)	1	1	1	1
Increasing per year	1.2 (1.1–1.3)*	1.2 (1.1–1.3)*	1.2 (1.0–1.3)*	1.6 (1.3–2.0)*
Previous injuries				
0	1	1	1	1
Previous injury	1.0 (0.4–2.6)	0.5 (0.3–1.2)	1.4 (0.1–21.3)	4.3 (0.3–65.3)
Season				
Low-risk season	1	1	1	1
High-risk season	1.4 (0.99–2.0)	1.9 (1.5–2.4)*	1.1 (0.7–1.7)	2.0 (0.9–4.8)

*Statistical significance based on $P < 0.05\%$.
CI, confidence interval; OR, odds ratio.

The multilevel adjusted odds ratios by injury types are summarized in Table 3. With normal school as reference, the children in sport schools increased the odds significantly by 60% for traumatic LE injury. No other differences were found between normal and sport schools. Each additional time a child participated in leisure-time sport, the odds for an overuse and a traumatic injury increased by 20%. The odds of sustaining an overuse LE injury increased significantly by 90% in high-risk season. Only age was associated with UE injuries, with odds for traumatic and overuse UE injuries increasing by 20% and 60%, respectively, for each step in grade level. Summing up, age showed a significant association across both injury types on both LE and UE injuries (Fig. 1).

Discussion

This study is to our knowledge the first to report numbers of overuse and traumatic limb injuries, their duration, and the association with sports participation, gender, age, previous injuries, and seasonal variation in a prospective cohort study of schoolchildren. A high number of 1229 injuries were diagnosed in 1259 children and close to twice as many overuse injuries (794) as traumatic injuries (435). Injuries at the lower extremities were the most common, with 1049 LE injuries versus 180 UE injuries. The incidence and prevalence rates of injuries were 1.2% and 4.6% per week and the average duration of the injuries varied from 3.3 to 5.3 weeks, with overuse injuries having the longest duration. Previous recommendations for a standardized methodology to quantify overuse injuries in sports have mentioned the advantage of frequent and prospective measurements, using sensitive scoring instruments to measure pain symptoms and define injuries by other means than time lost from sport or the need for medical attention (Bahr, 2009). This study followed a cohort of children for 2.5 years with weekly recordings on incidence and

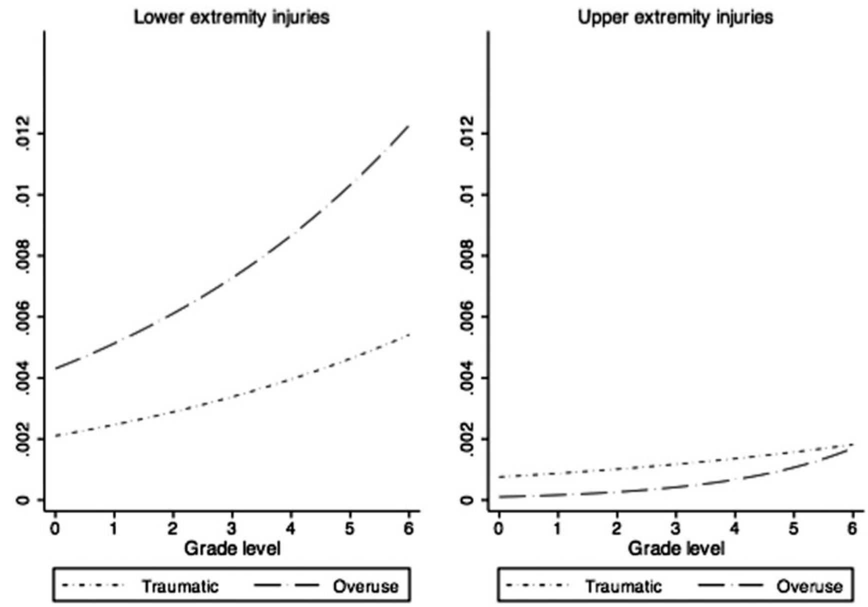

Fig. 1. Adjusted probability of traumatic and overuse LE and UE injuries in relation to grade level. LE, lower extremity; UE, upper extremity.

prevalence of musculo-skeletal pain and injuries and severity based on diagnosis and duration of pain.

A study on a Dutch school cohort reported acute injuries incidence rate of 0.46 (Bloemers et al., 2012). The findings in the present study therefore appear high when taking into account the variation in how physically active children were by means of PE classes and organized sport in leisure-time (overuse injuries: 3.01, acute injuries: 2.99). One of the differences is that exposure hours reported in the Dutch study also included self-reported hours of being physically active in leisure-time outside organized sports participation. This resulted in lower rates of injuries measured per 1000 exposure hours. Incidence rates in this study were more comparable to sports-specific studies (Caine et al., 2008; Moller et al., 2012). The lack of information on nonorganized PA is a limitation to this study, when taking exposure time into consideration.

The relatively high number of injuries and injury rates in this study might also be due to the registration method using weekly text messages to gain knowledge about children possibly having sustained an injury. It could be argued that the numbers and rates were high because of the prospective, frequent, and sensitive monitoring, compared with studies using methods where injuries are registered retrospectively. The possible issue of parents reporting events that would normally be ignored was dealt with by a telephone consultation as a first screen between trivial complaints and persisting symptoms in relation to injury. If the latter was the case, a clinical examination, and if needed, para-clinical investigations and/or further examination by medical specialists was carried out before an injury was finally defined. It was a strength to this study that parental reporting on pain and injuries was validated through objective examinations by clinicians.

Risk of injuries consistently increases with age across most studies when looking at specific sports (Emery, 2003; Caine et al., 2008). This pattern was reproduced in this cohort of children with a broad diversity in choice of sports, amount of participation, competitive levels, etc. This suggests increasing age as a robust risk factor and although not modifiable, age should be considered when targeting groups of children and adolescents for injury prevention.

Previous studies have found evidence that males are generally at higher risk of injury in child and adolescent sport (Emery, 2003; Caine et al., 2008). We found no association between gender and overuse and traumatic injuries. This may be explained by the heterogeneity of the cohort and because it was not selected by any specific clinical condition or sports. Furthermore, it could be speculated that gender differences in injury patterns are more pronounced after puberty, because of the developmental differences in physique.

Previous injuries have shown to be one of the most consistent risk factors for sustaining new injuries, with relative risks ranging from 2.88 to 9.41 (Emery, 2003). These findings are from studies of adults where a previous injury has been defined as an incidence that has caused time lost from sport or the need of medical attention (Emery, 2003; Caine et al., 2008). This motivated the adjustment for previous injuries but it appeared to have no influence on the risk of sustaining a new injury. Possible explanations could be differences in definitions of previous injuries and different methods of sampling across studies. It could also be speculated that most children are not marked by potential implications of inadequate rehabilitation after an injury to the same extent, as could be the case for adults.

In this study, the risk of sustaining overuse LE injuries almost doubled in high-risk periods of season (autumn and spring). Previous studies have suggested that the different levels of PA partly explain the variation in number of injuries across seasons (Tucker & Gilliland, 2007). The proposition of seasonal variation being a proxy measurement for levels of sport participation was ruled out, as there were no indications of colinearity. Other potential extrinsic risk factors include weather conditions, training surface/field conditions, time of season in relation to level of physical fitness, etc., which might explain the difference in risk. The assessment of injuries and seasonal variation was weakened by the lack of recordings during the 6-week period of children's summer holiday.

Repeated data collection inevitably implies missing data. In this study a surprisingly low percentage (3.8%) of the answers were missing. One reason could be the mutual benefit of parents getting their children clinical examined if required and researchers getting answers. Using a mobile texting method as the SMS-track system in research is still a novel method, but has so far proven valid, reliable, feasible, and user-friendly, with high compliance rates (Alfven, 2010; Johansen & Wedderkopp, 2010; Axen et al., 2012; Moller et al., 2012).

Perspectives

This study has shed further light on the area concerning the magnitude and patterns of overuse and traumatic injuries in children and underlined the need to pay special attention to the risks related to the growing, physically active child. The generalizability of the findings in this nonclinical, heterogenic cohort of schoolchildren gives suggestions for focus areas in public health, among practitioners and for increased injury prevention and implementation research. Emery et al. (2006) have emphasized the need for policy-based strategies and for sports organizations, health professionals, coaches, and parents to show responsibility to child sport injury prevention. Our results concerning overuse injuries and the risk factors involved in the etiology of overuse injuries confirm the need for guidelines and recommendations on the prevention of overtraining, burnout, and overuse injuries in children and adolescents as suggested by Brenner (2007) and Valovich McLeod et al. (2011).

Key words: children, short message service (SMS), overuse injuries, traumatic injuries, incidence, prevalence, incidence rate.

Acknowledgements

The authors wish to acknowledge K Froberg and LB Andersen, Research in Childhood Health, University of Southern Denmark. The authors thank the participants and their parents and the participating schools, the Svendborg Project, and the municipality of Svendborg. Finally, the authors wish to acknowledge the members of the CHAMPS Study-DK not listed as coauthors of this paper: T Junge, M Heidemann, and NC Møller.

This study was supported by grants from the IMK Foundation, the Nordea Foundation, the TRYG Foundation – all private, nonprofit organizations that support research in health prevention and treatment – and TEAM Denmark, the elite sport organization in Denmark that provided the grant for the SMS-track system.

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Study II

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Journal Code: SMS	Proofreader: Mony
Article No: SMS12177	Delivery date: 09 Jan 2014
Page Extent: 8	

Scand J Med Sci Sports 2014: ••: ••–••
doi: 10.1111/sms.12177

SCANDINAVIAN JOURNAL OF
MEDICINE & SCIENCE
IN SPORTS

Musculoskeletal extremity injuries in a cohort of schoolchildren aged 6–12: A 2.5-year prospective study

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Accepted for publication 12 December 2013

The objectives of this prospective school cohort study were to describe the epidemiology of diagnosed musculoskeletal extremity injuries and to estimate the injury incidence rates in relation to different settings, different body regions and injury types. In all, 1259 schoolchildren, aged 6–12, were surveyed weekly during 2.5 years using a new method of automated mobile phone text messaging asking questions on the presence of any musculoskeletal problems. All injuries were clinically diagnosed. Physical activity was measured from text messaging and accelerometers. A total number of 1229 injuries were diagnosed; 180 injuries in the upper extremity and 1049 in the lower extremity, with an overall rate of 1.59 injuries per 1000 physical activity units [95% confidence interval (CI) 1.50–1.68]. Upper extremities accounted for a rate of 0.23 (95% CI 0.20–0.27) and lower extremities accounted for 1.36 (95% CI 1.27–1.44). This study has added a wide overall perspective to the area concerning incidence and incidence rates of musculoskeletal extremity injuries in schoolchildren aged 6–12 years, including severe and less severe, traumatic, and overuse injuries. The understanding of injury epidemiology in children is fundamental to the acknowledgement and insurance of the appropriate prevention and treatment.

It has been shown that regular physical activities (PAs) is associated with numerous physical health benefits, improved cognitive performance, mental well-being, higher self-esteem, and social skills (Biddle et al., 2004; Janssen & Leblanc, 2010; Andersen et al., 2011; Voss et al., 2011). However, injuries sustained during PAs, have been established as a leading cause of the pediatric injury burden in western countries (Finch et al., 1998; Brudvik & Hove, 2003; Conn et al., 2003) leading to high direct and indirect costs for both children and parents (Collard et al., 2011). Injuries may cause short-term disability, absence from school and PAs, loss of enthusiasm for participating in PAs, and long-term consequences such as osteoarthritis (Kujala et al., 1995; Mikkelsson et al., 1997; Abernethy & MacAuley, 2003; Oiestad et al., 2010).

A majority of published studies in the area of PA-related injuries in children have presented selected study populations and selected injury types, because of extracting data from selected settings (i.e., emergency departments, specific sports), selected clinical conditions (i.e., ankle–ligament sprains, anterior cruciate ligament ruptures), or because of injury definitions that exclude some injury types. PA-related injuries are commonly defined by one of three possible criteria: the criteria of all physical complaints regardless of their consequences ("any physical complaint" definition), the criteria of needing medical care seeking ("medical attention" definition), or by the criteria of being unable to fully participate in normal training and competition ("time-loss" definition) (Fuller et al., 2006).

Although all studies are informative, it would seem that only part of the total injury problem is revealed, and that the less severe injuries and overuse injuries are under-represented as pointed out by Norwegian and Dutch injury research groups (van Mechelen et al., 1992; Collard et al., 2008; Bahr, 2009; Clarsen et al., 2013).

Studies of PA-related injuries in school-based cohorts of children provide the opportunity to gain more generic data on injury incidence across the different settings comprising PE lessons, organized sports, and non-organized PA in leisure time. A Dutch study carried out during 12 months reported an incidence rate (IR) of 0.48 per 1000 h of exposure for all PA-related injuries in children aged 10–12 years (Verhagen et al., 2009). In a comparable Australian study, the injury rate was 0.59 injuries per 1000 h of exposure outside school hours (Spinks et al., 2006). Limitations to these studies, as pointed out by the authors, were the self-reported and not so frequent collected data on injuries and exposure time, leaving the possibility of underreporting of injuries and overestimation of actual exposure time to sport and [8] [9] leisure time PA (Spinks, McClure, 2006; Verhagen & Collard, 2009).

The common use of mobile phones now makes it possible to collect frequent data of self-reported symptoms indicative of musculoskeletal injuries for long periods in large populations. In this study, a large cohort of Danish schoolchildren aged 6–12 years was followed closely with real-time data on injuries diagnosed by clinicians and amount and type of PA. This provided an opportunity to obtain improved estimates of the incidence and IRs of all PA-related injuries occurring during a period of 2.5 years in a heterogeneous sample of children.

The objectives of this prospective school cohort study were to describe the epidemiology of diagnosed musculoskeletal extremity injuries and to estimate the injury IRs in relation to different settings, different body regions, and injury types.

Material and methods

Setting

Data from the Childhood Health, Activity, and Motor Performance School Study Denmark (CHAMPS Study–DK) August 2008 to July 2011 were used. This investigation is a large prospective controlled school-based study in Denmark using the design of a [10] natural experiment (Craig et al., 2012) to evaluate the effects of increased physical education (PE) on childhood health in general. Six schools were assigned to become sport schools with six PE lessons per week and four normal schools served as control with two PE lessons per week. The project is extensively described elsewhere (Wedderkopp et al., 2012).

Ethics committee approval was obtained before the start of the project; ID S20080047, and registration in the Danish Data Protection Agency was made, as stipulated by the law J.nr. 2008-41-2240. Written informed consent was obtained from the child's parent. Prior to every clinical examination, both child and parent gave verbal acceptance. All participation was voluntary with the option to withdraw at any time.

Participants

All boys and girls from preschool to fourth grade in 10 public schools participating in the CHAMPS Study-DK were invited to participate in the registration of musculoskeletal pain and injuries. The study was kept open, with the possibility for new children to enter. Because of the novel data collection method of automated mobile phone text message (SMS-track), the 10 schools were included gradually over 8 months in order to allow for a phasing-in process.

Measurements

Musculoskeletal pain and injuries

Weekly information on musculoskeletal pain and injuries was collected using SMS-track for 2.5 school years. This approach provides real-time measurements and thereby improves the valid- [11] ity of data relative to data collected retrospectively (Shiffman et al., 2008). Each Sunday, parents answered a text message that asked questions on the presence or absence of any musculoskeletal pain during the previous week. If parents forgot to answer, reminders were sent twice with an interval of 48 h. If parents did not answer at all, or answered in text or other invalid ways, research assistants contacted them by telephone to clarify facts.

Parents who reported that their child had pain in the previous week were contacted at the beginning of the subsequent week by one of four clinicians for a telephone consultation. If the pain was non-musculoskeletal, had disappeared, or was well explained by an earlier medical history, there would be no more intervention before the next pain reporting (if any). If the pain was still present and unexplained, a clinical examination was scheduled.

Physiotherapists, chiropractors, and a medical practitioner were responsible for the clinical examination of the children within the next fortnight. If necessary the child was referred for further paraclinical examination (such as X-ray, ultrasound, or magnetic reso- [12] nance imaging scan) and possibly seen by a medical specialist. Information on children being seen or treated elsewhere (e.g., emergency department, general practitioner) during the study [13] period was collected concurrently to get a complete data collection on injuries. An injury was not registered as a new injury if the condition was determined to be an exacerbation of a non-recovered index injury. Collection of data was suspended during the 6 weeks of summer holiday.

Classification of injuries

Injuries were diagnosed using the International Classification of Diseases (ICD-10; WHO, 1992). Furthermore, injuries were clas- [14] sified according to injury causation; whether they were traumatic or overuse injuries. A traumatic injury is defined as an injury resulting from a specific, identifiable event, whereas an overuse injury is an injury caused by repeated micro trauma without a single identifiable event responsible for the injury (Fuller et al., 2006). Injuries were classified into these two categories by looking at diagnosis and medical records, where the injury mechanisms were documented.

Overuse injuries are complex to describe when looking for the context in which they occur in a general, non–sports-specific cohort. The tissue damage is a result of repetitive demands over the course of time and probably an accumulation of different types of PAs across different settings. Thus, only the traumatic injuries were categorized and presented according to whether they happened during PE, sports or during leisure time PA.

PE

Weekly amount of PE was 4.5 h for sport schools and 1.5 h for normal schools, corresponding to three and one double lesson per week, respectively. Children at sport and normal schools were therefore assigned three and one exposure unit per week, respectively.

Sports

Organized sport was assessed using SMS-track, by parental reports on how many times the child had participated in organized sport during the past week. It was considered an easier task for the parents to count the times, than the hours/minutes spent in sport. The time spent in different sports per training or per match typically varies from 30 min (i.e., swim training) to 90 min (i.e., soccer and handball training) for Danish children aged 6–12.

If the child had participated in organized sport during the previous week, a third question was sent, asking for type of sport. The parents had 10 answering options: (1) Soccer; (2) Handball; (3) Basketball; (4) Volleyball; (5) Rhythmic gymnastics; (6) Tumbling gymnastics; (7) Swimming; (8) Horse-riding; (9) Dancing; and (10) Other sports. The parents were instructed to type the relevant number(s).

Leisure time PA

There were no weekly measures of the amount of PA besides organized sport and PE lessons, hereafter named leisure time PA. Instead, data from accelerometer measurements was used to estimate the amount of exposure in terms of leisure time PA. Accelerometer assessments were performed from November 2009 to January 2010, when the children attended first to fifth grade, using an Actigraph GT3X accelerometer (Pensacola, Florida, USA), designed to monitor human activity. The children were instructed to wear the device from the time they woke up in the morning until bedtime in order to capture their entire PA for each day. The only exception was to remove the monitor when showering or swimming in order to prevent damage to the device. The children were asked to wear the accelerometers for 7 full consecutive days, thus potentially including all weekdays and a full weekend. After the measurement period, the accelerometers were recollected and data downloaded to a computer.

A customized software program (Propero, version 1.0.18, University of Southern Denmark, Odense, Denmark) was used to process accelerometer data using information on PA for every 10 s. In order to distinguish between true intervals of inactivity and "false intervals of inactivity" recorded when the monitor had been taken off, consecutive strings of zeros of 30 min or longer were interpreted as "accelerometer non-worn." Activity data were included for further analyses, if the child had accumulated a minimum of 10 h of activity per day for at least 4 days. Cut-off points for four activity intensity levels, sedentary, light, moderate, and vigorous, were used according to Evenson et al. (2008).

For estimates of exposure time in relation to leisure time injuries, calculations of time spent in moderate and vigorous activities were chosen, as these activity types were regarded as the "risk[s] of injury activity." For this study, data were used on sample-level, meaning that a mean estimate of the total number of exposure units was extrapolated up to cover the total study period. An exposure unit was arbitrarily chosen to equal 60 min. Exposure time for the amount of leisure time PA is thus the number of exposure units in PE and organized sports subtracted from the total number of exposure units as estimated from accelerometer measurements.

Analysis

Data from SMS-track and data on diagnosed injuries were analyzed using STATA 12.0 (StataCorp, College Station, Texas, USA).

Excessive levels of pain and injuries were reported during the start-up phase. This is possibly explained by the novelty of the study and the method. Observations from the first 4 weeks relative to the time of inclusion were therefore excluded.

The calculation of injury IR accounted for the total sum of injuries across all participating children divided by the sum of exposure across all participating children expressed in 1000 PA units. These comprised the PE, the sports and the leisure time PA exposures.

Traumatic injuries IR were presented according to the average time spent in each specific setting of 10 types of sports, PE, and leisure time PA for the whole sample. Average time spent being physically active across all settings and across the whole sample was used to estimate IR for both traumatic and overuse injuries, presented according to body region.

Potential patterns for the missing values were addressed by a logistic regression analysis controlling for gender, age, school type, and leisure time sports effects. Missing values because of practicalities concerning changed or wrong mobile numbers were dropped for analyses.

Results

There was a gradual inclusion of schools starting with 231 children from three schools and ending with children from all 10 schools being included eight months later. In total, 1259 children participated during the study period. The range of participation time was 1–113 weeks with an average of 90.2 weeks. Dropouts were due to children moving away from the municipality or changing to a non-project school, but were counterbalanced by new children moving to project schools. Fifteen children dropped out for other reasons, the main one being that answering SMS questions every week was too bothersome. An average weekly response rate of 96.2% was recorded during the study period of 113 weeks of parents answering text messages concerning musculoskeletal pain. Analysis of missing data did not show any patterns when looking at gender, age, school type, and leisure time sports.

A total number of 44 overuse injuries were diagnosed in upper extremities, with soft tissue injuries being the most common. In lower extremities, a total of 750 overuse injuries were diagnosed with pain occurring at the growth plate of the heel or the knee (apophyses injuries) being the most common (Table 1). For traumatic injuries, a number of 136 upper-extremity and 299 lower-extremity injuries were diagnosed with ligament sprains being the most common (Table 2).

Injury rates of diagnosed traumatic injuries and the setting in which they occur are presented in Table 3. The estimated injury IR was highest for injuries sustained in sports; 1.57 per 1000 sport exposure units [95% confidence interval (CI) 1.3–1.8], followed by injuries sustained in leisure time PA; 0.57 per 1000 leisure time PA exposure units (95% CI 0.5–0.6) and lowest for injuries sustained in PE; 0.14 per 1000 PE exposure units (95% CI 0.1–0.2).

Injury rates according to body region and injury type, using the total amount of PA exposures (774 362 units) during 2.5 years are presented in Table 4. The estimated injury incidence was 1.03 per 1000 PA units (95% CI 0.95–1.10) for overuse injuries in total. In upper extremities the shoulder and upper arm was the most common region of overuse injury: $n = 26$, IR = 0.03 (95% CI 0.02–0.05). In lower extremities the heel was the most common region of overuse injury: $n = 275$, IR = 0.36 (95% CI 0.31–0.40). The estimated injury IR was 0.56 per 1000 PA units (95% CI 0.51–0.61) for traumatic injuries in total. In the upper extremities, the hand and wrist was the most common region of traumatic injury: $n = 60$, IR = 0.08 (95% CI 0.06–0.10). In the lower

Table 1. Number of diagnosed overuse injuries for upper and lower extremities in 1259 children

	Number of injuries	International Classification of Diseases – 10 codes
Upper-extremity injuries		
Soft tissue	31	M626, M709, M751, M754, M758, M759, M77, T923
Epicondylitis humeri	5	M771, M770
Apophysitis	3	M920, M921
Other	5	M080, M674, M796, M242B, M244B
Total	44	
Lower-extremity injuries		
Apophysitis		
Sinding-Larsen	141	M924
Osgood-Schlatter	48	M925
Sever's lesion	274	M928
Ilium, naviculare	3	M939, M922
Soft tissue	140	M621A, M626, M678, M709, M76, M761, M768, M769, M77, M775, M779, M779A, M786, M79, M791, M796
Plantar fasciitis	21	M722
Patellofemoral pain	36	M222, M222A, M224, M229, M239
Achilles tendinopathy	41	M766, M766B
Tibial traction periostitis	16	M869, M869B
Metatarsalgia	7	M774
Bursitis	5	M706, M766A
Other	18	M201, M248, M357, M659B, M674, Q658F, Q662, Q665, Q742, Z038
Total	750	
Total	794	

Table 2. Number of diagnosed traumatic injuries for upper and lower extremities in 1259 children

	Number of injuries	International Classification of Diseases – 10 codes
Upper-extremity injuries		
Sprains (ligament)	71	S434, S436, S534, S63, S635, S636, S636D, S636D, S636K, S637.
Fracture	34	S42, S420, S423, S424, S52, S525, S525B, S526, S62, S625, S626, T921.
Contusions	26	S400, S50, S500, S600, S600A, S602, S602A, S602B, S60, T92.
Strain (muscle/tendon)	3	S462A.
Other lesions	2	S633.
Total	136	
Lower-extremity injuries		
Sprains (ligament)	178	S83, S830, S834, S834B, S836C, S837, S93, S934, S934A, S934B, S934C, S934E, S935, S935A, S935F, S936, T933, T933A.
Contusions	60	S700, S800, S801S900, S901, S903, T938.
Strain (muscle/tendon)	37	S76, S760A, S761, S762A, S861, S861B, S862D, S868, S96.
Fracture	18	S724, S825, S828, S828D, S923, S923E, S924, S925.
Other lesions	6	S835E, S832, S932B.
Total	299	
Total	435	

extremities, the ankle was the most common region of traumatic injury: $n = 136$, IR = 0.18 (95% CI 0.15–0.21).

Discussion

This is the first study to use SMS-track to capture all symptoms indicative of musculoskeletal problems and having clinicians assigned to diagnose injuries prospectively during 2.5 school years in a cohort of 1259 schoolchildren aged 6–12 years. In addition, the variance in time-at-risk were accounted for and injury IRs were presented in relation to injury type, different body regions, and different settings comprising PE lessons, organized sports, and leisure time PA.

Epidemiology of diagnosed musculoskeletal extremity injuries

During a period of 2.5 years, a total number of 1229 injuries were diagnosed: 180 injuries in the upper extremity and 1049 in the lower extremity. Diagnosis concerning traumatic injuries such as ligament strains, fractures, contusions, and strains accounted for the largest part of the total number of upper-extremity injuries. From studies in emergency departments, the same patterns of sprains, contusions, fractures, and strains being the most frequent traumatic injury in children are well described (Sorensen et al., 1996; Gottschalk & Andrish, 2011).

For lower-extremity injuries, a reverse pattern was found, as overuse injuries were by far the most common

Table 3. Number of injuries, exposure units and incidence rates of lower- and upper-extremity traumatic injuries distributed on different settings

	Physical activity units	Number of traumatic lower-extremity injuries	Injury rate per 1000 physical activity units (95% CI)	Number of traumatic upper-extremity injuries	Injury rate per 1000 physical activity units (95% CI)	Total number of traumatic extremity injuries	Injury rate per 1000 physical activity units (95% CI)
Sports							
Soccer	25 982	50	1.92 (1.39–2.46)	10	0.38 (0.15–0.62)	60	2.31 (1.72–2.89)
Handball	16 822	31	1.84 (1.19–2.49)	18	1.07 (0.58–1.56)	49	2.91 (2.10–3.73)
Basketball	1 301	4	3.07 (0.06–6.09)	2	1.54 (0.00–3.37)	6	4.61 (0.92–8.30)
Volleyball	2 014	4	1.99 (0.04–3,93)	1	0.50 (0.00–1.47)	5	2.48 (0.31–4.66)
Rhythmic gymnastics	5 190	4	0.77 (0.02–1.53)	0	0.00	4	0.77 (0.02–1.53)
Tumbling gymnastics	8 345	11	1.32 (0.54–2.10)	9	1.08 (0.37–1.78)	20	2.40 (1.35–3.45)
Swimming	13 925	0	0.00	1	0.07 (0.00–0.21)	1	0.07 (0.00–0.21)
Horse-riding	7 208	2	0.28 (0.00–0.66)	2	0.28 (0.00–0.66)	4	0.55 (0.01–1.10)
Dance	3 550	0	0.00	0	0.00	0	0.00
Other sports	15 348	3	0.20 (0.00–0.42)	5	0.33 (0.04–0.61)	8	0.52 (0.16–0.88)
Total sports	99 685	109	1.09 (0.89–1.30)	48	0.48 (0.35–0.62)	157	1.57 (1.33–1.82)
PE lessons	248 679	26	0.10 (0.06–0.14)	9	0.04 (0.01–0.06)	35	0.14 (0.09–0.19)
Leisure time PA	425 998	164	0.38 (0.33–0.44)	79	0.19 (0.14–0.23)	243	0.57 (0.50–0.64)
Total	774 362	299	0.39 (0.34–0.43)	136	0.18 (0.15–0.21)	435	0.56 (0.51–0.61)

CI, confidence interval; PA, physical activity.

injury with a notable high number of apophysitis injuries located at the heel or knee being diagnosed. Thus, diagnosis as Sever's lesion, Sinding-Larsen and Osgood-Schlatter, accounted for 44% of all lower-extremity injuries. These are injuries expected in this age group, where skeletal growth zones are still immature, yet the epidemiology of these injuries in mostly prepubertal children have seldom been reported in school-based cohorts, which have focused mainly on traumatic injuries (Spinks et al., 2006; Verhagen & Collard, 2009). These studies have included injuries that demanded first aid treatment, professional health treatment, and/or time lost from PA and/or school. The "time-loss" injury definition does not capture all overuse injuries (Bahr, 2009) and the "medical attention" injury definition overlooks less severe injuries (Collard & Verhagen, 2008). We suggest that the gain from the present study is a broader insight into PA-related injuries in children, including also less severe injuries and overuse injuries by using a close and frequent method of monitoring musculoskeletal symptoms and having clinicians assigned to diagnose the injuries prospectively. It could be argued that the epidemiology of less severe injuries and overuse injuries have little relevance as they are less costly in terms of needing medical care or losing time from school and PA than severe injuries. Still, it is noteworthy that even in the less severe injuries, pain is a present symptom that affects the child and might predict future pain (Mikkelsson et al., 1997; El-Metwally et al., 2004). The duration of musculoskeletal pain in relation to overuse injuries were measured in a previous study on the same cohort and showed mean durations of 5.3 and 5.2 weeks for lower- and upper-extremity overuse injuries, respectively (Jespersen et al., 2013). Reporting of all injuries causing physical complaints is advocated in the case of the young, growing, and playing child.

Age and gender differences have been presented in a previous study and showed that the risk of injuries increased with age, but found no significant association between gender and injury risk (Jespersen & Holst, 2013). This study lacks the age- and gender-specific information on injury diagnoses and injury IR, but presents the overall picture of musculoskeletal extremity injuries in a sample of 6–12-year-old schoolchildren with a broad diversity in choice of sports, competitive levels, leisure time PA, level of PA, etc.

Injury IRs

The present injury data accounting for the total time-at-risk showed an overall rate of 1.59 injuries per 1000 PA units (95% CI 1.50–1.68). Calculating from the mean number of hours in moderate to vigorous activity per week, this would correspond to a child sustaining an injury every 1.6 years. Injury rates were somewhat lower in two school cohort studies in children aged 10–12 years, reporting IR of 0.48 per 1000 h of exposure for all PA-related injuries (Verhagen & Collard, 2009) and 0.59 injuries per 1000 h of exposure outside school hours (Spinks & McClure, 2006). This is possibly explained by these injuries rates being mainly traumatic injuries, and thus more comparable with the IR of 0.56 per 1000 units of PA for traumatic injuries in the present cohort.

Direct comparison between studies is hampered by differences in the aforementioned injury definition, and in particular, the injury data collection methods. It could be speculated that the numbers and rates were high in the present study because of the prospective, frequent and sensitive monitoring. It was a strength of this study that potential parental overreporting on pain and injuries, were validated through objective examinations by clinicians before an injury was finally diagnosed.

Table 4. Number of injuries and incidence rates in 1259 schoolchildren by injury type and body region

	Overuse lower-extremity injuries		Traumatic lower-extremity injuries		Overuse upper-extremity injuries		Traumatic upper-extremity injuries		Total overuse injuries		Total traumatic injuries	
	Number	IR	Number	IR	Number	IR	Number	IR	Number	IR	Number	IR
Shoulder/upper arm					26	0.03 (0.02–0.05)	21	0.03 (0.02–0.04)	26	0.03 (0.02–0.05)	21	0.03 (0.02–0.04)
Elbow/under arm					9	0.01 (0.00–0.02)	16	0.02 (0.01–0.03)	9	0.01 (0.00–0.02)	16	0.02 (0.01–0.03)
Hand/wrist					6	0.01 (0.00–0.01)	60	0.08 (0.06–0.10)	6	0.01 (0.00–0.01)	60	0.08 (0.06–0.10)
Finger					3	0.00 (0.00–0.01)	39	0.05 (0.03–0.07)	3	0.00 (0.00–0.01)	39	0.05 (0.03–0.07)
Hip/groin	40	0.05 (0.04–0.07)	4	0.01 (0.00–0.01)					40	0.05 (0.04–0.07)	4	0.01 (0.00–0.01)
Thigh	34	0.04 (0.03–0.06)	24	0.03 (0.02–0.04)					34	0.04 (0.03–0.06)	24	0.03 (0.02–0.04)
Knee	241	0.31 (0.27–0.35)	70	0.09 (0.07–0.11)					242	0.31 (0.27–0.35)	70	0.09 (0.07–0.11)
Lower leg	37	0.05 (0.03–0.06)	10	0.01 (0.00–0.02)					37	0.05 (0.03–0.06)	10	0.01 (0.00–0.02)
Achilles	47	0.06 (0.04–0.08)	0	0.00					47	0.06 (0.04–0.08)	0	0.00
Heel	275	0.36 (0.31–0.40)	0	0.00					275	0.36 (0.31–0.40)	0	0.00
Ankle	6	0.01 (0.00–0.01)	136	0.18 (0.15–0.21)					6	0.01 (0.00–0.01)	136	0.18 (0.15–0.21)
Foot	70	0.09 (0.07–0.11)	55	0.07 (0.05–0.09)					70	0.09 (0.07–0.11)	55	0.07 (0.05–0.09)
Total	750	0.97 (0.90–1.04)	299	0.39 (0.34–0.43)	44	0.06 (0.04–0.07)	136	0.18 (0.15–0.21)	794	1.03 (0.95–1.10)	435	0.56 (0.51–0.61)

Physical activity units = 774 362 units.

IRs is per 1000 physical activity units; values in parenthesis are 95% CI.

CI, confidence interval; IR, incidence rate.

Looking at traumatic injuries, the injury IR was highest in sport settings, with ball games and a high-impact sport (tumbling gymnastics) being the most risky sports. Leisure time PA were less risky, but still with a higher injury IR than PE. It could be argued that in addition to being supervised by teachers, PE lessons have a more pedagogic aim and are less competitive than most sports, thus resulting in the lowest injury IR for the three different types of setting.

In general, most injuries were sustained in the lower extremities (85%), of which the knee, heel, and ankle accounted for 30%, 26%, and 14%, respectively. It is well established that injuries in weight-bearing extremities are predominant, and of those, knee and ankle injuries present the majority (Caine et al., 2006). The diagnosing of overuse injuries in the present study has added the heel to a body part commonly injured in this age group.

A general limitation to the presented injury IR is the use of sample-level exposure data done for feasibility reasons. Taking the point estimate for the IR in the sample as the sum of injuries across all individuals divided by the sum of exposures across all individuals, is the method used in most injury research, but this assumes that there is a fixed overall injury rate that is the same for every individual, which is rarely the case (Verhagen & van Mechelen, 2010). Another weakness is that with a follow-up of 2.5 school years, both incidences of injury and exposure time might have varied in a way that makes causal inferences more uncertain. Finally, the uncertainty by extrapolating estimates from 1 week of accelerometer measurements must be mentioned, i.e., the PA patterns shown across 1 week in winter might not reflect the child's activity level in general.

Exposure time based on exact hours of participation instead of units of participation would have been more accurate to account for the variance in time-at-risk. Injury incidence expressed as incidence per 1000 participation hours, has been the preferred measure of IRs in sports injury research studies (Spinks & McClure, 2007; Caine et al., 2008). Still, it has been argued that the content of, e.g., a training/match session or a leisure time activity, just as much as the length of time is associated with injury risk (Kopjar & Wickizer, 1995; Stuart et al., 2002).

Perspectives

This study has added a broader perspective to the area concerning incidence and IRs of musculoskeletal extremity injuries in schoolchildren aged 6–12 years. The method of using SMS-track to capture all symptoms indicative of musculoskeletal problems and subsequently having clinicians assigned to diagnose injuries, supplemented by data on injuries diagnosed in other clinical settings, ensures a larger probability of recording both severe and less severe, traumatic, and overuse injuries.

The understanding of injury epidemiology in children is fundamental for acknowledging that despite of the many health benefits of PA, there are drawbacks in terms of related injuries. Appropriate interventions on all responsible levels ranging from policy-based strategies, sports organizations, PE teachers, coaches to parents, are important to prevent child sport injuries (Emery et al., 2006). While the prevention and treatment of the severe "time-loss" and medical care needing injuries have been described to some extent (Caine & Maffulli, 2008; Myklebust et al., 2003; Wedderkopp et al., 2003; Collard et al., 2010; McBain et al., 2011; Ladenhauf et al., 2013), a suitable approach toward less severe injuries needs more attention. Efforts to keep the child physically active, but with consideration for the injury, are suggested to ensure fitness and continued contact with the preferred activities, but further intervention research is needed to clarify best practice.

Key words: child, injury, upper extremity, lower extremity, incidence.

Acknowledgements

The authors thank the participants and their parents, the participating schools, The Svendborg Project, and the Municipality of Svendborg. The authors wish to acknowledge members of the CHAMPS Study-DK not listed as co-authors of this article: H. Klakk, M. Heidemann, and T. Junge. Finally, the authors wish to acknowledge L. B. Andersen, Research in Childhood Health, University of Southern Denmark.

Funding

This study was supported by grants from The IMK Foundation, The Nordea Foundation, and The TRYG Foundation – all private, non-profit organizations that support research in health prevention and treatment, and TEAM Denmark, the elite sport organization in Denmark, which provided the grant for the SMS-track system.

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Study III

BMJ Open

Seasonal variation in musculoskeletal extremity injuries in school children aged 6–12 followed prospectively over 2.5 years: a cohort study

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To cite: Jespersen E, Holst R, Franz C, *et al*. Seasonal variation in musculoskeletal extremity injuries in school children aged 6–12 followed prospectively over 2.5 years: a cohort study. *BMJ Open* 2014;**4**:e004165. doi:10.1136/bmjopen-2013-004165

▸ Prepublication history for this paper is available online. To view these files please visit the journal online (http://dx.doi.org/10.1136/bmjopen-2013-004165).

Received 2 October 2013
Revised 18 November 2013
Accepted 20 November 2013

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ABSTRACT

Objectives: The type and level of physical activity in children vary over seasons and might thus influence the injury patterns. However, very little information is available on the distribution of injuries over the calendar year. This study aims to describe and analyse the seasonal variation in extremity injuries in children.

Design: Prospective cohort study.

Setting: 10 public schools in the municipality of Svendborg, Denmark.

Participants: A total of 1259 school children aged 6–12 years participating in the Childhood Health, Activity, and Motor Performance School Study Denmark.

Methods: School children were surveyed each week during 2.5 school-years. Musculoskeletal injuries were reported by parents answering automated mobile phone text questions (SMS-Track) on a weekly basis and diagnosed by clinicians. Data were analysed for prevalence and incidence rates over time with adjustments for gender and age.

Results: Injuries in the lower extremities were reported most frequently (n=1049). There was a significant seasonal variation in incidence and prevalence for lower extremity injuries and for lower and upper extremity injuries combined (n=1229). For the upper extremities (n=180), seasonal variation had a significant effect on the risk of prevalence. Analysis showed a 46% increase in injury incidence and a 32% increase in injury prevalence during summer relative to winter for lower and upper extremity injuries combined.

Conclusions: There are clear seasonal differences in the occurrence of musculoskeletal extremity injuries among children with almost twice as high injury incidence and prevalence estimates during autumn, summer and spring compared with winter. This suggests further research into the underlying causes for seasonal variation and calls for preventive strategies to be implemented in order to actively prepare and supervise children before and during high-risk periods.

Strengths and limitations of this study

- The main strength was the frequent, prospective and fine-meshed method of collecting data on injury incidence and prevalence in a population-based large sample of school children with high participation compliance during 2.5 years.
- A general limitation to the data collection was the lack of information on injuries during 6 weeks of children's summer holidays, thus the descriptive data were presented with the lack of observations during summer holidays, while the modelled data were extrapolated to full annual variation.

BACKGROUND

Musculoskeletal problems are common in childhood.[1 2] Definite pathological states are uncommon at this age, but various types of injuries can cause pain and disability. Physical activity-related injuries have been established as a leading cause of paediatric injuries in western countries[3–5] and they constitute a significant public health burden, with high direct and indirect costs for children, parents and society.[6 7] Injuries sustained in sports activities may cause short-term disability, absence from school, sports and physical activity, and long-term consequences such as osteoarthritis.[8–10]

The most common injuries in school-aged children are ligamentous sprains, contusions, muscle/tendon strains, fractures and different types of overuse injuries, located primarily in lower extremities but also in upper extremities.[11–14] It seems reasonable that different types of physical activities engender different types of injuries and those different times of the year invite different types and intensities of physical activities.

A review of the literature reveals that very little information is available on the injury pattern in children over the calendar year. Only data on more serious injuries from emergency room treatments and hospitalised children are available and show an indication of seasonal pattern in the incidence and type of injuries.[15–19] The literature on the seasonal injury pattern among children in the general population is scarce,[19] but is necessary in order to obtain proper incidence and prevalence data including less serious injuries and overuse injuries.

An efficient preventive approach to musculoskeletal injuries in children requires an insight in the circumstances under which they occur. The purpose of this study was to determine the seasonal pattern in extremity injuries in children by following the children during 2.5 consecutive school-years with systematic weekly automated mobile phone text messaging (SMS-Track) and clinical examinations and diagnosing.

METHODS

The study method has been extensively reported elsewhere[20] and the relevant aspects are briefly described below.

Study participants

Children from the preschool to the sixth grades from 10 public schools in the county of Svendborg, Denmark, who participated in a natural experiment (the Childhood Health, Activity, and Motor Performance School Study Denmark, CHAMPS Study-DK) were surveyed weekly during 2.5 school-years. The study consisted of a comparison between sports schools and normal schools and included a total of 1218 children at baseline.

All boys and girls participating in the CHAMPS Study-DK were invited to participate in the registration of musculoskeletal pain and injuries. The study was kept open, with the opportunity for children moving to project schools to enter the study. Owing to the novel data collection method (SMS-Track), the schools were included gradually in order to allow for a phasing-in process.

Data collection from parents

SMS-Track[21] is a web-based IT system, developed as a tool for frequent monitoring, complying with Shiffman's principle of Ecological Momentary Assessment. It was used in this study to investigate the fluctuations in musculoskeletal symptoms over time. Every week on Sunday, the parents received the following question: "Has [NAME OF CHILD] during the last week had any pain in: (1) Neck, back or low back; (2) shoulder, arm or hand; (3) hip, leg or foot and (4) no, my child has not had any pain." The parents were asked to type the number in front of the correct answer in a return text message. Data used in this report relate to items 2, 3 and 4.

Quality of the SMS-Track data

The returned answers were automatically recorded and inserted into a database. If no response was received or if the answer was inaccurate (eg, a response in words), the responders were contacted by telephone. It was deemed better to use parents as the informants than the child, as self-report questionnaire data from young children may be inaccurate.[22] Frequent data collection in large cohorts with short recall intervals (in this case 1 week) is well suited to obtain valid information on the periodic dynamics of the injury incidence and prevalence rates over time intervals covered by the study period. Data collection was put at hold during the 6 weeks of summer holidays.

A validation study was undertaken in order to determine the reproducibility of the SMS-Track reporting when comparing it with verbal reporting. The sensitivity for the SMS data was 0.98, specificity 0.87, positive predictive value 0.94 and the negative predictive value 0.95, indicating high validity of the data.[23]

Clinician-generated data

Parents who reported that their child had pain in the previous week were contacted by telephone at the beginning of the subsequent week by one of the four clinicians. Children, whose symptoms still persisted, were examined by physiotherapists, chiropractors and/or a medical practitioner within the next fortnight.

Injuries were diagnosed according to the International Classification of Diseases, 10th revised edition (ICD-10).[24] If necessary, the child was referred for further paraclinical examination (such as X-ray, ultrasound or MRI) or to be seen by a medical specialist. Information on children being seen or treated elsewhere (eg, emergency department and GP) during the study period was collected concurrently to get a complete data collection on injuries. Only children with a diagnosed injury were included in the data analysis.

Analysis and presentation of data

Explorative plots of the observed injury incidence and prevalence rates for all extremity injuries combined over the period of the study indicated an annual pattern peaking during the autumn and spring seasons, reaching a minimum incidence and prevalence rate during wintertime. This suggested a harmonic regression model where the annual variation was accounted for by sine and cosine terms with periods of 52 weeks.

A mixed effect logistic regression model was used to estimate injury incidence and prevalence risk with seasonal variation being of primary interest and represented by the sine and cosine terms. Incidence and prevalence analyses were conducted separately. The incidence models included gender, grade, grade squared and with separate grade effects for the two genders represented by interaction terms. These models were based only on the data from the risk episodes, as a child carries no information on the risk of injury, when being in a state of injury. The prevalence models were based on all data, but allowed for different effects for the states of being at risk and the state of being injured. These included gender, grade, grade squared and the current duration for the states of being injured. The latter variable accounted for the serial correlation between consecutive weeks in episodes of injury. Finally, the prevalence models included a state variable to account for the different risks of observing an injury in the two states.

The heterogeneity induced by the hierarchical sampling scheme was handled in a mixed model framework with schools, classes and individuals representing the three levels of random variation.

Potential patterns for the missing values were addressed by a logistic regression analysis controlling for gender, age, school type and leisure time sports effects.

The model-based estimates in tables and figures are presented separately for lower and upper extremity injuries, and also for lower and upper extremity injuries aggregated. Hereafter, these will be termed extremity injuries or extremity injuries combined.

While the descriptive data are presented with the lack of observations during 6 weeks of summer holidays, modelled data will be presented extrapolated to full annual variation.

All analysis was performed using STATA V.12.1 (StataCorp, Texas, USA) and R 2.15.1.[25]

RESULTS

Descriptive data

There was a gradual inclusion of schools starting with 231 children from 3 schools and ending with children from all 10 schools being included 8 months later. In total, 1259 children participated in the study. The range of participation time was 1–113 weeks with an average of 90.2 weeks. New children moving to project schools counterbalanced dropouts due to children moving away from the municipality or changing to a non-project school. Only a small number (n=15) chose to drop out for other reasons, the main one being that answering SMS questions every week was too bothersome. The overall response rate throughout the study period of 113 weeks was 96.2%. A total number of 109 245 observations were recorded and 4297 (3.8%) were missing. Analysis of missing data did not show any patterns when looking at gender, age, school type and leisure time sports.

Table 1 shows the number of injuries by gender and age (grade) of 1259 participating children. A total of 1229 extremity injuries were observed and the overall observed weekly injury incidence and prevalence rates were 1.1% and 4.6%, respectively.

Seasonal pattern

There was a clear seasonal variation in the observed incidences of extremity injuries. The highest injury incidence and prevalence rates for extremity injuries were observed for autumn, 1.3% and 5.1%, respectively, and for spring, 1.2% and 5%, respectively, whereas they decreased to 0.8% and 3.6%, respectively, in winter (table 2).

The analysis showed a significant seasonal variation for extremity injuries on incidence and prevalence rates (table 3). Other significant effects on the incidences were gender and grade, with different effects of grade for the two genders. The prevalence rates of extremity injuries showed significant effects of gender, class, the current duration of the injury and a state effect reflecting the difference between the risk and the prevalence states (table 3).

The model-based estimates of the incidence rates reached a maximum of 1% (girls) and 0.9% (boys) in week 29.3 (mid-July) and a minimum of 0.7% (girls) and 0.6% (boys) in week 3.3 (mid-January). The corresponding estimates for the prevalence rates reached a maximum of 4.5% (girls) and 3.7% (boys) in week 26.9 (late June) and a minimum of 3.4% (girls) and 2.8% (boys) in week 0.9 (early January).

Figure 1 shows the fitted curves for the seasonal variation for the injury incidence and prevalence for extremity injuries by gender and age with grade level (0–6) as a proxy of age. The corresponding results can be found in figures 2 and 3, but now showing patterns separately for upper and lower extremity injuries.

Table 1 Number of children and number of injuries by gender and age (grade) of 1259 school children followed over 2.5 years

	Preschool	Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Grade 6
Number	168	415	643	691	696	476	239
Age (year)	6–7	7–8	8–9	9–10	10–11	11–12	12–13
Gender							
Girls	90	222	334	348	360	261	131
Boys	78	193	309	343	336	215	108
Upper extremity injuries							
Number of injuries	2	7	20	37	44	51	19
Lower extremity injuries							
Number of injuries	9	43	149	243	256	226	123

Note: The same cohort of children was followed for 2.5 years, starting with them being preschool to fourth grade pupils and ending with them being second to sixth grade pupils. This explains the larger proportion of pupils in some grades.

Table 2 Observed seasonal numbers and injury incidence and prevalence rates of upper extremity injuries, lower extremity injuries and extremity injuries combined diagnosed during 2.5 years

	Autumn (September, October and November)	Winter (December, January and February)	Spring (March, April and May)	Summer* (June, July and August)	Total
Upper extremity injuries					
Number	57	31	63	29	180
Incidence rate in percentage (±SD)	0.2 (±4.4)	0.1 (±3.2)	0.2 (±4.1)	0.2 (±4.2)	0.2 (±4.0)
Prevalence rate in percentage (±SD)	0.6 (±7.6)	0.3 (±5.9)	0.6 (±7.7)	0.6 (±7.6)	0.5 (±7.2)
Lower extremity injuries					
Number	322	188	386	153	1049
Incidence rate in percentage (±SD)	1.1 (±10.6)	0.7 (±8.1)	1.0 (±10.1)	1.0 (±9.8)	1.0 (±9.7)
Prevalence rate in percentage (±SD)	4.6 (±20.9)	3.3 (±17.9)	4.5 (±20.6)	4.1 (±19.9)	4.1 (±19.9)
Extremity injuries combined					
Number	379	219	449	182	1229
Incidence rate in percentage (±SD)	1.3 (±11.5)	0.8 (±10.5)	1.2 (±10.9)	1.2 (±10.7)	1.1 (±10.5)
Prevalence rate in percentage (±SD)	5.1 (±22.1)	3.6 (±18.8)	5.0 (±21.8)	4.7 (±21.1)	4.6 (±21.0)

*The summer season is not complete due to 6 weeks of summer holidays (July and first 2 weeks of August).

DISCUSSION

This is the first prospective study showing a seasonal variation in injuries of the extremities in a cohort of school children followed closely during 2.5 years. The weekly data showed 46% increase in injury incidence and 32% increase in injury prevalence during summer compared with winter for extremity injuries.

Table 3 Mixed model analysis presenting factors explaining incidence and prevalence of upper extremity injuries, lower extremity injuries and extremity injuries combined

	Upper extremity injuries	Lower extremity injuries	Extremity injuries combined
Incidence			
Seasonal effect	(√)	√	√
Gender		√	√
Grade	√	√	√
Grade squared		√	√
Effect modification: gender#grade		√	√
Prevalence			
Seasonal effect	√	√	√
Gender	√	√	√
Grade	√	√	√
Grade squared		√	√
Current duration of prevalence*	√	√	√
State of risk/injury†	√	√	√

√ Statistical significance based on p<0.05. (√) Borderline significant (0.08).
*The risk of prevalence when already being injured, taking into account the current duration (1st, 2nd, 3rd, etc weeks in a state of injury prevalence).
†The risk of prevalence when being in a state of risk (no prevalence the week before) or when being in a state of already injured (prevalence the week before).

There seem to be no studies on the overall incidence and prevalence of injury of the extremities in the general population. However, a few studies have looked at children hospitalised or treated in emergency rooms.[15–17] The present results are in accordance with Park *et al*[19] when looking at four categories of upper extremity fractures in the whole population of South Korean children and adolescents from 0 to 18 years, where the highest incidence was observed in summer, followed in order by autumn, spring and winter. In the same study, the reverse was observed for two groups of lower extremity fractures, with peak fracture incidence in winter.[19] Foltran *et al*[15] who looked at all serious paediatric injuries in an Italian region found a clear seasonal variation in serious injuries, with distinct peaks in the prevalence of hospitalisation of seriously injured children in the summer, and a low prevalence during the winter. Graham *et al*[16] also demonstrated this in a Scottish population of children with injuries needing emergency treatment. The very large retrospective study of Loder and Abrams[17] was also in agreement with the present results.

Proposed explanations of the variation in number of injuries across seasons vary across a broad spectrum of potential extrinsic risk factors, including weather and playing surface,[26–28] venue being indoor or outdoor[11 29] and time of season.[30] It also appears that the levels of physical activity vary with weather and season, thereby influencing the time-at-risk.[31] Thus, several mechanisms can be at play, for example, the high injury incidence and prevalence in the autumn could have resulted from children starting organised sports participation without appropriate preparation. The results from the study of Wareham *et al*[18] suggest that the overall physical activity and the use of outdoor recreational activities might be the significant factors as they found that children have a clear increased prevalence of wrist fractures in spring

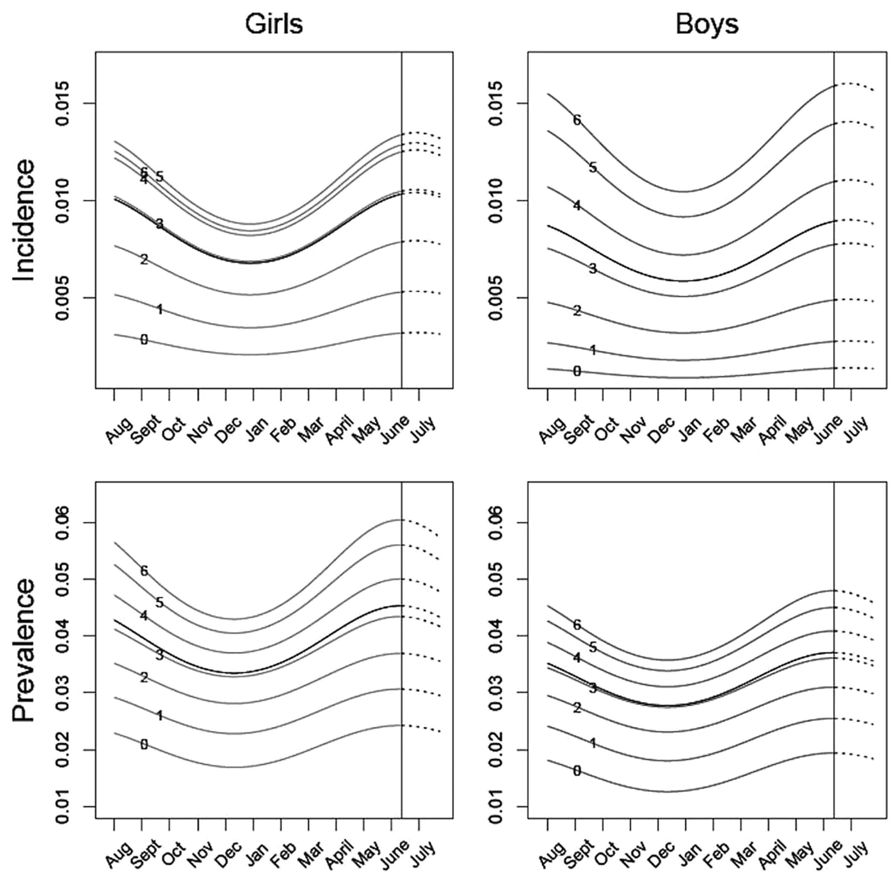

Figure 1 Fitted curves for seasonal variation for extremity injury incidence and prevalence, showing curves with regard to gender and grade level (0–6) as a proxy of age. The thick, solid line illustrates the mean curve. The dotted lines illustrate the period of 6 weeks of extrapolated data.

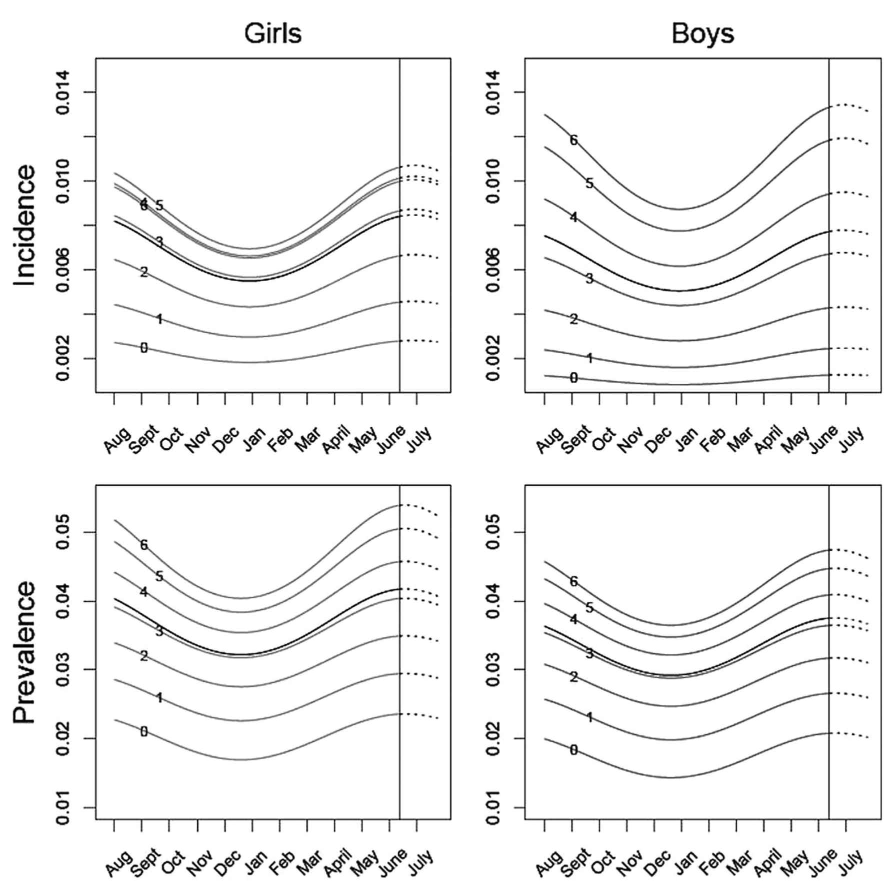

Figure 2 Fitted curves for seasonal variation for extremity injury incidence and prevalence, showing curves separately for lower extremity injuries with regard to gender and grade level (0–6) as a proxy of age. The thick, solid line illustrates the mean curve. The dotted lines illustrate the period of 6 weeks of extrapolated data.

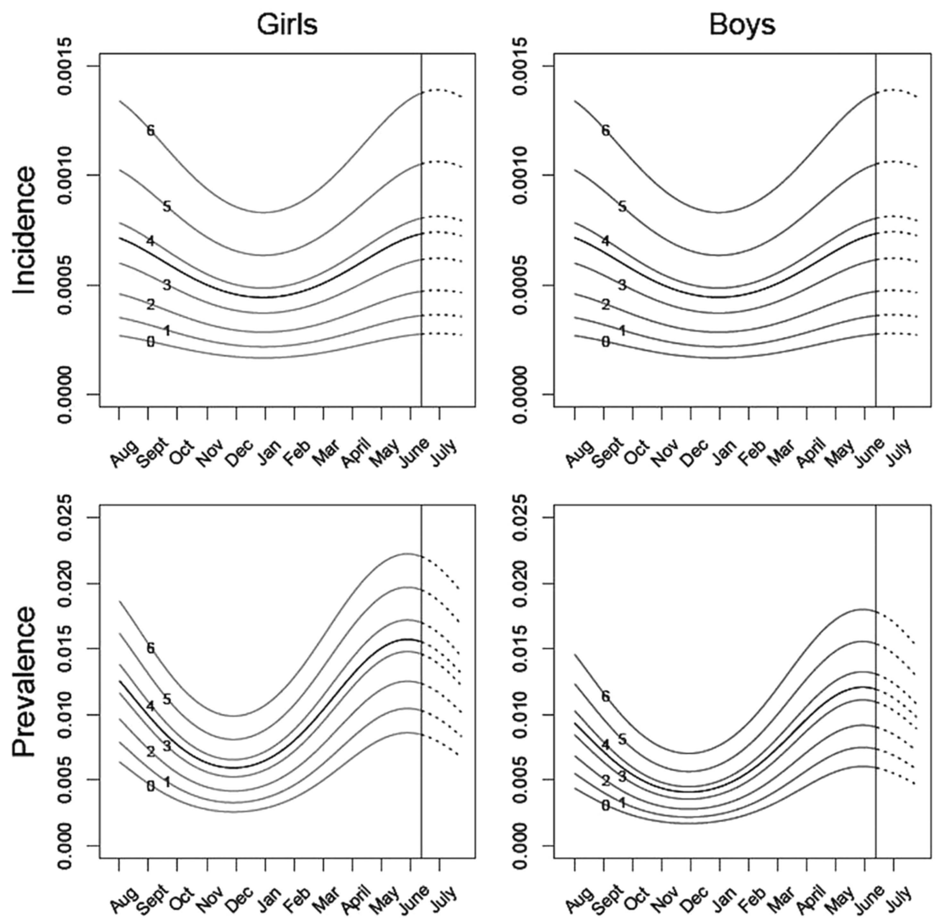

Figure 3 Fitted curves for seasonal variation for extremity injury incidence and prevalence, showing curves separately for upper extremity injuries with regard to gender and grade level (0–6) as a proxy of age. The thick, solid line illustrates the mean curve. The dotted lines illustrate the period of 6 weeks of extrapolated data.

and summer. A Dutch school cohort study used a correction factor of 0.8 in order to account for the seasonal effects on physical activity participation throughout a 12-month follow-up period.[13] Although arbitrarily chosen, the correction factor was in line with the decrease in physical activities during winter, found in a previous review study.[31]

The model-based estimates for seasonal variation showed a noticeable and surprising difference between the highest and lowest incidence and prevalence rates. A pattern was observed for the lowest prevalence rate early January preceding the lowest incidence rate 3 weeks later. Likewise, a pattern of the highest prevalence rate in late June was followed by the highest incidence rate 3 weeks later. Logically, high incidence rates should precede high prevalence rates and likewise with low rates. The prevalence of injury is the proportion of individuals who have an existing injury at any given point in time and is logically affected by the duration of injury. Injury durations vary,[14] possibly reflecting different types of injuries and time for tissue to heal. It can be speculated that high prevalence rates at certain time points are the result of accumulated severe and long-lasting injuries and vice versa for low prevalence rates.

Looking at adjusted estimates, in the present study, all age groups followed the same pattern of seasonal variation for musculoskeletal extremity injury incidence and prevalence, but with more pronounced seasonal differences with increasing age. Risk of injury incidence consistently increases with age across most of the studies when looking at specific sports.[32 33] This pattern was reproduced in this cohort of children with a broad diversity in choice of sports, amount of participation, competitive levels, etc.[14]

The same patterns of higher injury incidence and prevalence estimates during warmer seasons than during winter were shown for both genders. A US study, analysing all paediatric emergency department visits during 4 years from seven selected activities (bicycles/tricycles, scooters, playground equipment, swimming/water activities, skiing/snowboarding, trampolines and skating activities) found different peaks for girls and boys (mean age 9.5 years). Girls had the highest number of emergency department visits in the spring and boys in the autumn. This were explained by the most common activity by gender peaking at the same time (girls=playground equipment activities, boys=cycling).[17] The present study did not look at seasonal risk by specific activities, which might have disclosed the gender differences.

In this school-based cohort, approximately half of the children attended sports schools having three times as many physical education (PE) lessons as the rest of the children. This study has not taken the amount of physical activity into account, but it could still be speculated that the circumstances surrounding children being pupils at sports schools influences the injury risk. It is possible that not only the amount of PE lessons makes a difference, but also that the form and content of PE have a more pedagogic aim and are less competitive than sports participation in leisure time, thereby influencing the injury rates and the seasonal variation in injury risk.

Data collection was put on hold during 6 weeks of summer holidays, which is a limitation to this study. The predicted times of peak incidence and prevalence fall within this period. It seems, however, plausible to assume a consistent pattern all year round. Children being more physically active during the warmer season may likely explain the high rates of injuries at this time of the year. More activities take place outdoor, possibly under less rigorous supervision than during the winter indoor activities. In relation to injury prevention, attention should therefore be focused on outdoor activities and leisure time sport during this time of the year.

The registration method using weekly text messages resulted in a high response rate, strengthening this study. The high compliance is possibly explained by the benefit of parents having their children clinically examined if required. It could be argued that the frequent, prospective and sensitive monitoring potentially could result in a too high number of injuries. It was considered as a strength to this study that potential parental overreporting on pain and injuries was validated through objective examinations by clinicians before an injury was finally diagnosed. This fine-meshed method of recording all symptom-giving injuries has added a broader perspective to the area concerning musculoskeletal extremity injuries in children aged 6–12. Using SMS-Track to capture all symptoms indicative of musculoskeletal problems and subsequently having clinicians assigned to diagnose injuries, supplemented by data on injuries diagnosed in other clinical settings in the same time period, all ensure a larger probability of recording severe and less severe, traumatic and overuse injuries. Reporting of all injuries causing physical problems seems relevant in the case of the young, growing and playing child.

This study confirms the need to look into the dynamic and cyclic nature of risk factors and causation to understand injury aetiology. Risk factors are not stable, but may change through preceding cycles of exposure, circumstances and season as suggested by Meeuwisse *et al*.[34]

CONCLUSION

There is a clear indication of a seasonal variation in musculoskeletal extremity injuries among children with almost twice as high injury incidence and prevalence estimates during autumn, summer and spring compared with winter.

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Acknowledgements The authors wish to acknowledge K Froberg and LB Andersen, Research in Childhood Health, University of Southern Denmark. The authors thank the participants and their parents and the participating schools, The Svendborg Project and the municipality of Svendborg. The authors also wish to thank Professor Charlotte Leboeuf-Yde for having assisted in drafting the manuscript, helped with the interpretation of data and revising the final manuscript. Finally, the authors wish to acknowledge the members of the Childhood Health, Activity, and Motor Performance School Study Denmark (CHAMPS Study-DK) not listed as co-authors of this article: H Klakk, M Heidemann, T Junge and NC Møller.

Contributors NW was responsible for the overall study concept and design. EJ, CTR, CF and NW were responsible for the acquisition of the data. EJ, RH and NW were responsible for the analysis and interpretation of data. EJ and NW drafted the manuscript. All authors took part in critical revision of the manuscript. RH provided statistical expertise.

Funding This study was supported by grants from The IMK Foundation, The Nordea Foundation, The TRYG Foundation—all private, non-profit organisations, which support research in health prevention and treatment, and TEAM Denmark, the elite sport organisation in Denmark, that provided the grant for the SMS-Track system.

Competing interests NW obtained the funding.

Patient consent Obtained.

Ethics approval The study was approved by the Ethics Committee for the region of Southern Denmark (ID S20080047).

Provenance and peer review Not commissioned; externally peer reviewed.

Data sharing statement The CHAMPS Study-DK is an on-going cohort study and results are being published continuously. Specific questions regarding data can be addressed by mailing EJ, ejespersen@health.sdu.dk or NW, Nwedderkopp@health.sdu.dk.

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Study IV

BJSM Online First, published on November 22, 2013 as 10.1136/bjsports-2013-092790

Total body fat percentage and body mass index and the association with lower extremity injuries in children: a 2.5-year longitudinal study

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Accepted 26 October 2013

ABSTRACT

Background Overweight youths are generally recognised as being at increased risk of sustaining lower extremity injuries in sports. However, previous studies are inconclusive and choices for measuring overweight are manifold.

Objective To examine two different measures of overweight, body mass index (BMI) and total body fat percentage (TBF%), as risk factors for lower limb injuries in a school-based cohort.

Study design A longitudinal cohort study.

Methods A total of 632 school children, baseline age 7.7–12.0 years, were investigated. Whole body dual energy x-ray absorptiometry scans provided measures of TBF%. Measures of BMI were obtained by standard anthropometric methods. Musculoskeletal complaints were reported by parents answering weekly mobile phone text messages during 2.5 years. Injuries were diagnosed by clinicians. Leisure time sports participation was reported weekly using text messaging.

Results During 2.5 years of follow-up, 673 lower extremity injuries were diagnosed. Children being overweight by both BMI and TBF% showed the highest risk of sustaining lower extremity injuries (IRR 1.38 (95% CI 1.05 to 1.81)). Children who were overweight using BMI and TBF% showed the highest risk of sustaining lower extremity injuries (IRR 1.38 (95% CI 1.05 to 1.81)).

Conclusions The risk of lower extremity injuries appeared to be increased for overweight children. When comparing two different measures of overweight, overweight by TBF% is a higher risk factor than overweight by BMI. This suggests that a high proportion of adiposity is more predictive of lower extremity injuries, possibly due to a lower proportion of lean muscle mass.

BACKGROUND

Injuries sustained in sports and leisure time activities have been established as a leading cause of the paediatric injury burden in Western countries.[1–5] These induce high direct and indirect costs for children and parents and may cause short-term disability, absence from school and/or physical activity (PA), lost enthusiasm for participating in PA and long-term consequences such as osteoarthritis.[6–11]

Both intrinsic and extrinsic risk factors have previously been investigated and some attention has been shown to body weight and body composition as a potentially modifiable risk factor on sport injury risk.[12 13] The importance is emphasised as overweight and obesity is affecting an increasing proportion of children globally.[14] Hence the paradox is that while PA is associated with numerous health benefits, including lowering the levels of overweight and obesity,[15] overweight might at the same time cause a rise in injury rates as the prevalence of overweight and obesity increases.

Overweight youths are generally considered as being at increased risk of sustaining lower extremity injuries in sports, due to a corresponding increase in the forces that joints, ligaments, tendons and muscular structures must endure.[16–18] However, findings in studies on the association between body composition and injuries are inconclusive and choices of measures of body composition have been varied, such as height and weight, lean muscle mass, body fat content and most commonly body mass index (BMI).[18]

Overweight and obesity should be defined as excess body fat. The most widely used measurement to define obesity is BMI. It is an indicator of overweight and obesity from a population perspective, but has limitations on an individual level and is only a proxy measurement of body fat.[19] The association between BMI and total body fat percentage (TBF%), especially in athletes, has been shown to be lower than in non-athlete controls.[20–23]

Moreover, the common use of BMI as a criterion measurement may be an issue when it involves physically active children. A high BMI might in that case be an expression of a high proportion of lean muscle mass, rather than overweight or 'unhealthy' weight. TBF% is a measure of adiposity and in the area of sports it has been shown to be a more precise measure for classification of overweight.[21–24]

Different mechanisms by which overweight increases the risk of injuries have been proposed. These include a relatively higher musculoskeletal strain and impaired postural control when controlling for a disproportionately large body mass in sport activities that require rapid alterations during changes in direction.[16] Poor physical fitness and low PA levels among overweight young people add to this risk.[15 16] Based on this, overweight caused by a high proportion of TBF% appears to be a more obvious risk factor than overweight caused by a high proportion of lean muscle mass. Overweight, defined by measures of TBF%, possibly associates differently with PA-related injuries than overweight defined by measures of BMI.

The objective of this study was to examine two different measures of overweight, BMI and TBF%, as risk factors for lower limb injuries in school children, followed for 2.5 years in a longitudinal

To cite: Jespersen E, Verhagen E, Holst R, *et al*. *Br J Sports Med* Published Online First: [*please include* Day Month Year] doi:10.1136/bjsports-2013-092790

setting, while considering the potential confounding effects of gender, age, fitness levels and exposure times in physical education (PE) and leisure time sports participation.

MATERIAL AND METHODS

Setting

Data from the Childhood Health, Activity, and Motor Performance School Study Denmark (CHAMPS Study-DK) August 2008 to July 2011 were used.[25] This investigation is a large prospective controlled school-based study in Denmark using the design of a natural experiment to evaluate the effect of increased levels of PE on childhood health in general.[26]

Participants

All boys and girls from preschool to fourth grade in 10 public schools participating in the CHAMPS Study-DK also agreed to participate in the registration of musculoskeletal pain and injuries. The study was kept open, with the possibility for new children to enter. Owing to the novel data collection method of automated mobile phone text messaging, the schools were included gradually in order to allow for a phasing-in process.

A subsample of children attending second to fourth grade (age range 7.7–12.0 years) was invited to a dual energy X-ray absorptiometry (DXA) scan providing TBF% in 2008. Children were examined at baseline and at a 2-year follow-up. Height and weight were assessed at the same time points. Data on injuries and participation in organised sport were recorded from November 2008 to June 2011.

Measurements

Musculoskeletal pain and injuries

Weekly information on musculoskeletal pain and injuries was measured using mobile phone text messaging. Each week, parents answered a text message asking questions on the presence or absence of musculoskeletal pain. A report of pain elicited a telephone consultation, to distinguish children with trivial complaints from those in need of clinical examination.

Physiotherapists, chiropractors or a medical doctor clinically examined the children during the coming fortnight and a standard medical record was performed. Injuries were diagnosed using the International Classification of Diseases (ICD-10), WHO.[27] If needed, the child was referred for further examination, such as X-ray, ultrasound or MR scans, or to consulting specialist doctors. Information on children being treated elsewhere during the study period, for example, emergency department, general practitioner, was collected concurrently to get a complete data collection on injuries in this cohort.

Physical activity

Weekly amount of PE was 4.5 h for children in sport schools and 1.5 h for children in normal schools, corresponding to three and one double lesson per week, respectively. Pupils at sport and normal schools were therefore assigned three and one sport exposure units per week, respectively. Leisure time sport was also assessed using text messaging, by parental reports on how many times the child had participated in leisure time sport activities during the past week.

Total body fat percentage

TBF% was measured by DXA (GE Lunar Prodigy, GE Medical Systems, Madison, Wisconsin, USA), ENCORE software (V.12.3, Prodigy; Lunar Corp, Madison, Wisconsin, USA).

TBF% was calculated for each participant from the equation: ((FM (g) × 100)/total body weight (g)). Cut-offs to classify children as normal weight or overweight were defined using the cardiovascular health-related and gender-related TBF% standards according to Williams *et al*.[28] The cut-off for overweight boys was ≥25 TBF% and a similar cut-off for girls was ≥30 TBF%.

Body mass index

Weight was measured to the nearest 0.1 kg on an electronic scale (Tanita BWB-800S, Tanita Corporation, Tokyo, Japan). Height was measured to the nearest 0.5 cm using a portable stadiometer (SECA 214, Seca Corporation, Hanover, Maryland, USA).

BMI was calculated as (weight (kg)/height^2 (m)). BMI classifications for normal weight, overweight and obese were defined using age-specific and sex-specific cut-offs as recommended by the International Obesity Taskforce recommendations.[29] Dichotomised categories were made for weight classes as normal weight or overweight/obese (hereafter referred to as overweight) for easier comparison with the dichotomous variable of normal weight versus overweight as described above.

Fitness level

Fitness was assessed by the Andersen test. This is a 10 min intermittent running test to estimate maximal oxygen uptake and indicate aerobic fitness.[30] The test was carried out indoors in 20 m running lanes marked by cones. Children were urged to run as quickly as possible for 15 s, then stopped for the next 15 s and this pattern was repeated for 10 min. The total distance measured in metres was the test result. The validity and reliability of this field test were tested and described thoroughly for the age group of our cohort in a study by Ahler *et al*.[31]

Statistical methods

Data from the text messaging system and data on diagnosed injuries were analysed using STATA V.12.0 (StataCorp, Texas, USA).

Excessive levels of pain and the number of injuries were reported during the start-up-phase. This is possibly explained by the novelty of the study and the method. Observations from the first 4 weeks relative to the time of inclusion were therefore excluded.

The risk of getting injured according to absolute levels of baseline BMI and TBF% were explored. Furthermore, the potential effect of children changing body composition through the 2.5 years of injury surveillance was evaluated by a logistic regression using variables with 'no change', 'change to elevated BMI or TBF%' and 'change to normal BMI or TBF% values' as categories.

Concerns about children being underweight were addressed, as injury patterns could possibly be different in this group.[20 32] For this reason, the prevalence of underweight was determined in the baseline population, using the recommended cut-offs.[33 34] An initial analysis excluding the group of underweight children did not change the estimates of risk of injury or the estimated effect of other covariates. Underweight children were therefore not considered different from normal-weight children regarding the risk of injury. Hence, they were categorised as normal-weight children.

The calculation of incidence rates accounted for the total exposure expressed in 1000 athletic exposure units. These comprised the PE exposures and the participations in leisure time sport.

A multilevel mixed-effects Poisson regression was used to estimate the incidence-rate ratios (IRR) with BMI and TBF% as the

Table 1 Sample characteristics in numbers (%) and means (±SD) measured by gender during 2.5 years of follow-up

	Girls	Boys
Numbers	321 (50.8%)	311 (49.2%)
Age at baseline	9.6 (0.9)	9.6 (0.9)
Range	7.9–11.6	7.7–12.0
Baseline BMI	16.7 (2.1)	16.6 (2.1)
Baseline TBF%	23.0 (7.4)	17.1 (7.4)
Weekly exposure in PE and sports	3.9 (1.3)	3.9 (1.4)
Fitness level at baseline (metre)	892.7 (89.2)	967.8 (99.8)
Lower extremity injuries		
Number of lower extremity injuries	336	337
Number of children with lower extremity injuries	178 (55.5%)	179 (57.6%)

BMI, body mass index; PE, physical education; TBF%, total body fat percentage.

primary risk factors. BMI and TBF% were used as dichotomised variables (0=normal values, 1=elevated values) in separate regression analyses. For identification of groups of potential clinical interest, the four combinations of normal and elevated BMI with normal and elevated TBF% were likewise tested in a regression analysis, with normal BMI and normal TBF% being the reference groups.

Finally, BMI and TBF% were tested as continuous variables and used for illustrating the adjusted risk of lower extremity injuries in relation to the two measures of body composition.

The explanatory variables included gender, age, PE/leisure time sport and fitness levels. Classes and schools were used as random effects. The multilevel random effects model reflects the hierarchical sampling structure and was chosen to allow for potential variation between schools and between classes within schools and to ensure correct modelling of the variances. The number of weeks each child participated was included as an exposure term in the model.

Potential patterns for the missing values in injury data were addressed by a logistic regression analysis controlling for gender, age, school type and leisure time sports effects. Missing values because of practicalities concerning changed or wrong mobile numbers were dropped for analyses.

RESULTS

A total of 632 children, aged 7.7–12 years at baseline, participated at baseline and the follow-up DXA scan and in the registration of musculoskeletal injuries. The mean baseline BMI was 16.6 (±SD 2.1) and TBF% was 20.1% (±SD 8.0). A total number of 673 lower extremity injuries were diagnosed during the 2.5 years of follow-up. Some children experienced more than one injury; the range was from zero and up to eight episodes of lower extremity injuries. The range of participation time in injury registration was 1–113 weeks, with 98.1 weeks being the mean value. Dropouts were due to children moving away from the municipality or changing to a non-project school, but were counterbalanced by new children moving to project schools. Fifteen children dropped out because answering SMS questions every week was too bothersome. An average weekly response rate of 96% was recorded during the study period of 113 weeks. A total number of 62 001 observations were recorded and 2502 (4%) were missing. The analysis of missing data did not show any patterns when looking at gender, age, school type and leisure time sports. The mean weekly sport exposures units in PE and leisure time sport were 3.9 (±SD 1.3) and fitness level at baseline had a mean of 930 8 m (±SD101.9). Differences in gender are presented in table 1.

The injury rates per 1000 athletic exposures showed a trend, albeit not significant, towards higher risk for children being overweight, whether defined by BMI or by TBF%. Injury rates, 95% CI and gender differences are described in table 2.[28 29]

The multivariate and multilevel adjusted IRR estimates by different measures of overweight are summarised in table 3. Overweight children were generally at higher risk of sustaining lower leg injuries, by BMI: 1.28 (95% CI 0.98 to 1.66) and by TBF% 1.34 (95% CI 1.07 to 1.68), the latter being statistically significant.

Looking at the four combined groups of body composition, children with elevated BMI and TBF% showed the highest risk of sustaining lower leg injuries: 1.38 (95% CI 1.05 to 1.81) relative to children having a normal BMI and a normal TBF% (figure 1).

The possible effect of children changing body composition during the 2.5 years of injury surveillance was also accounted for in the adjusted analysis; it did not explain the risk of lower extremity injuries, and nor did it influence the estimated effects of other covariates.

Gender and age did not influence the risk, whereas the time participating in PE and leisure time sport and fitness level explained some of the lower extremity injury risk. The risk of injury significantly increased for each additional time a child participated in PE and leisure time sport from 0 to 6.5 weekly exposure units. For the 18 children with a mean of more than 6.5 exposures a week, the risk again decreased. A positive linear relationship was found between risk of lower extremity injuries and aerobic fitness.

The adjusted risk of lower extremity injuries in relation to the two measures of body composition measured on a continuous scale are illustrated in figure 2 for girls and boys. A positive linear relationship was found between risk of lower extremity injuries and the continuous values of TBF% and BMI across the full range.

Table 2 Lower extremity injury rates by BMI/TBF% groups, overall and by gender

Lower extremity injuries Injury rate (CI)*	BMI†		TBF%‡	
	Normal BMI	Overweight by BMI cut-offs	Normal TBF%	Overweight by TBF% cut-offs
Overall	4.4 (4.1 to 4.8)	5.3 (4.1 to 6.5)	4.4 (4.0 to 4.7)	5.2 (4.3 to 6.1)
Girls	4.4 (3.9 to 4.9)	5.1 (3.6 to 6.5)	4.3 (3.8 to 4.8)	5.2 (4.0 to 6.5)
Boys	4.4 (3.9 to 4.9)	5.8 (3.7 to 7.9)	4.4 (3.9 to 4.9)	5.1 (3.7 to 6.6)

*Injury rate is per 1000 athletic exposures; values in parentheses are 95% CI.
†Age-specific and gender-specific cut-offs according to IOTF/Cole *et al*.[29]
‡Cut-offs boys ≥25%, girls ≥30% according to Williams *et al*.[28]
BMI, body mass index; TBF%, total body fat percentage.

Table 3 Incidence-rate ratio estimates by different body composition measures, adjusted for age, gender, physical education/leisure time sport and fitness level

	BMI IRR (95% CI)	TBF% IRR (95% CI)
Normal weight	1.00	1.00
Overweight	1.28 (0.98 to 1.66)	1.34 (1.07 to 1.68)*

*Statistical significance based on p<0.05%.
BMI, body mass index; IRR, incidence-rate ratio; TBF%, total body fat percentage.

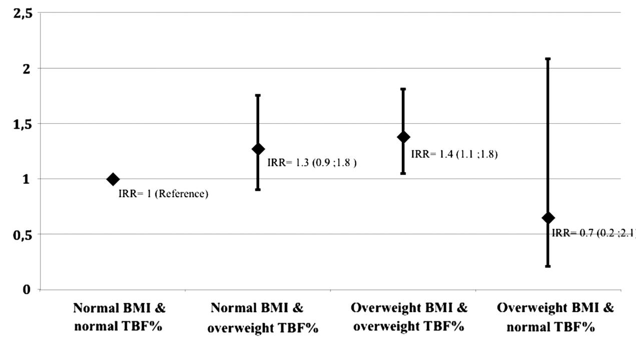

Figure 1 Incidence-rate ratio estimates (95% CI) by four groups of body compositions, adjusted for age, gender, physical education/leisure time sport and fitness level (BMI, body mass index; IRR, incidence-rate ratio; TBF%, total body fat percentage).

DISCUSSION

This study is the first to evaluate and compare two different measures of overweight as risk factors for lower extremity injuries in a school-based cohort of children. The risk of lower extremity injuries was observed to increase in overweight children. Being overweight measured by TBF% or a combination of elevated TBF% and BMI was more predictive than being overweight measured by BMI. This suggests that a high proportion of adiposity is more predictive of lower extremity injuries, possibly due to a lower proportion of lean muscle mass.

In contrast, Kaplan *et al*[35] found that body weight was a more powerful injury risk factor than adiposity, with no differences in injury risk between linemen and non-linemen in American football. This was shown in a study comparing different measures of body composition (body fat, BMI, weight, height) to injury risk in a group of 98 high school players with 28 injuries registered by trainers. This was reproduced in another American football study reporting injury rates by body fat, weight, BMI and lean body mass in high school football linemen,[36] whereas adiposity expressed as TBF% was a stronger predictor of the magnitude and type (overuse/traumatic) of musculoskeletal injuries in army cadets than BMI.[37] Direct comparisons may not be relevant because of differences in techniques to measure TBF%, injury registration methods, magnitudes of studies, ages and sports specific versus more heterogenic settings. Still, it is possible that in some sports, the effect of increased mechanical loading during weight bearing or collisions has a more pronounced effect than in other sports.

Injury patterns might also differ in relation to different injury types. Traumatic injuries provoked and/or aggravated by greater collision forces due to heavy weight could be argued to be independent of the muscle/fat distribution to a greater extent than overuse injuries, where the quality of tissue (eg, muscle strength and endurance) is important. The effect of overweight in relation to different injury types (overuse/traumatic), different diagnoses, different anatomical regions and different sports still needs to be clarified.

In this study, injury risk increased with increased participation in PE and leisure time sport. This is in accordance with the common understanding of the need to consider exposure time when estimating injury risk. Surprisingly, children with high fitness levels had a higher risk of sustaining lower extremity injuries. This is in contrast to earlier beliefs where lower fitness levels have been associated with muscle fatigue and subsequent injury.[38] A possible explanation could be that children with high aerobic capacities are also the children with the largest amount of exposure time. Even though analyses were carried out with adjustment for exposure time in terms of PE and leisure time sports, there may have been uncaptured exposure time in the most aerobically fit, as unorganised leisure time activity was unknown.

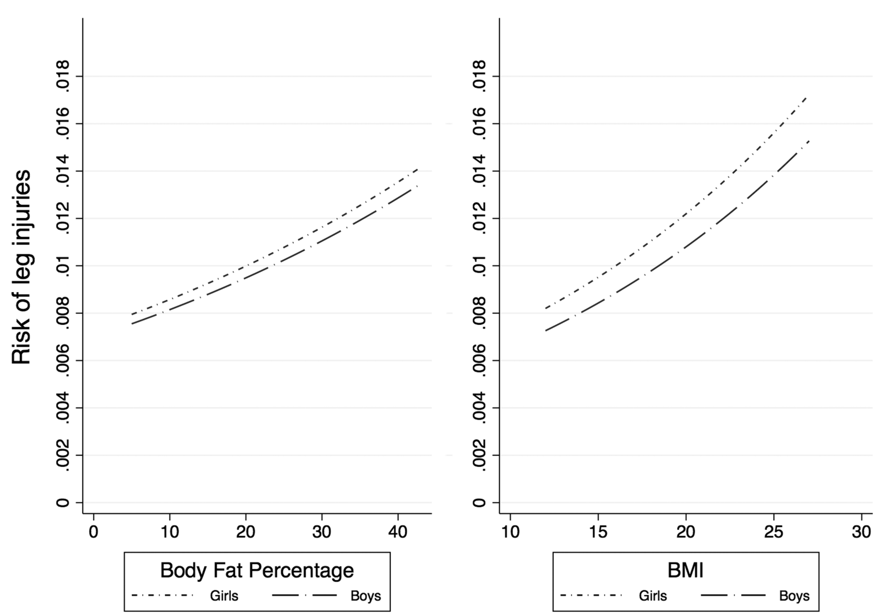

Figure 2 Adjusted risk of lower extremity injuries by different measures of body composition in girls and boys (BMI, body mass index).

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Cut-offs to classify children as normal weight or overweight were defined using cardiovascular health-related and gender-specific TBF% standards[28] and age-specific and gender-specific centiles from a pooled international dataset, linked to adult cut-offs for BMI classifications.[29] It can be questioned if these criteria have the same relevance in injury risk research, but they permit comparison across studies and contribute to a general evaluation of health risk among overweight children. The presentation of data in figure 2 does not suggest any obvious cut-off for a significant increase in risk of lower extremity injuries in relation to overweight. Specific overweight cut-offs for being at increased injury risk might be less important in the context of injury prevention, especially at an individual level where a more comprehensive screening of body composition involving an expression of TBF% would be more relevant.

CONCLUSION

The risk of lower extremity injuries in a heterogenic cohort of schoolchildren was shown to increase in overweight children. When comparing two different measures of overweight, a body composition of proportionally high levels of TBF% is a higher risk factor than overweight as measured by BMI. This suggests that a high proportion of adiposity is more predictive of lower extremity injuries, possibly due to a lower proportion of lean muscle mass.

Increased levels of PE and leisure time sports participation and fitness were also associated with increased risk of lower extremity injuries.

What are the new findings?

- This study is the first to evaluate and compare two different measures of overweight as risk factors for lower extremity injuries in a school-based cohort of children.
- Overweight children have an increased risk of lower extremity injuries.
- Overweight by measures of total body fat percentage is more predictive of lower leg injuries in children than overweight by measures of body mass index.

How might it impact on clinical practice in the near future?

- Injury prevention in children and adolescents should involve a screening of body composition involving an expression of total body fat percentage. While dual energy X-ray absorptiometry scans are expensive and not feasible in most settings, a measurement method such as waist circumference is cheap and easy to obtain.
- Further research is needed into the proposed underlying mechanisms for overweight children being at increased injury risk. Previously suggested mechanisms have been poor postural control—leading to problems with balance and co-ordination, poor physical fitness—associated with muscle fatigue, and subsequent injury and low preparticipation physical activity levels—associated with impaired neuromuscular and motor learning.

Acknowledgements The authors wish to acknowledge K Froberg and LB Andersen, Centre for Research in Childhood Health, University of Southern Denmark. The authors would like to thank the participants and their parents and the participating schools, The Svendborg Project and the municipality of Svendborg. Finally, the authors wish to acknowledge the members of the CHAMPS Study-DK not listed as coauthors of this paper: T Junge and NC Møller.

Contributors NW was responsible for the overall study concept and design. HK and MH were responsible for the acquisition of the body composition data. EJ, CTR, CF and NW were responsible for the acquisition of injury data. EJ, EV, RH and NW were responsible for the analysis and interpretation of data. EJ drafted the manuscript. All authors took part in a critical revision of the manuscript. RH provided statistical expertise. NW obtained the funding.

Funding This study was supported by grants from The IMK Foundation, The Nordea Foundation, The TRYG Foundation—all private, non-profit organisations, which support research in health prevention and treatment, and TEAM Denmark, the elite sport organisation in Denmark, that provided the grant for the text messaging system.

Competing interests None.

Ethics approval Written informed consent was obtained from the child's parent, including verbal acceptance from the parent and the child prior to every clinical examination for diagnosing injuries and medical record keeping. All participation in the data collection was voluntary with the option to withdraw at any time. The study was approved by the Ethics Committee for the region of Southern Denmark (ID S20080047)

Provenance and peer review Not commissioned; externally peer reviewed.

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