Overuse injuries in Swedish elite athletics

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# Overuse injuries in Swedish elite athletics

## Incidence, occurrence, athlete availability, and risk factors

Andreas Lundberg Zachrisson

GÖTEBORGS UNIVERSITET

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# Preface

First, I would like to thank Gothenburg Athletics Association for the funding of this thesis.

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Andreas Lundberg Zachrisson, Billdal

# Abstract

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The overall aim of this thesis was to explore three aspects of overuse injuries in elite Swedish athletics. The thesis is compiled of four papers, of which the first one is a study protocol. Paper II (n=58) aimed to gain knowledge about overuse injury characteristics, and Paper III (n=59) aimed to estimate the seasonal distribution of overuse injuries and the consequences for athletes. Paper IV (n=96) evaluated potential risk factors and their relation to overuse injury.

Athletes were followed prospectively during one Swedish athletics season. Injuries were diagnosed and recorded with the help of medical professionals. At enrollment, all athletes conducted a baseline screening consisting of a clinical examination, running analysis and strength tests. Male and female Swedish elite athletics athletes were recruited in Gothenburg from four event groups: middle/long distance runners, sprinters, jumpers, and throwers. All athletes were asked to fill out and submit training documentation on a monthly basis during the season.

Paper II aimed to describe the incidence proportion, injury onset, injury location, and injury severity of overuse injuries during a Swedish athletics season. The overall incidence proportion for the cohort was 72.4%, with 64.8% of all injuries being categorized as injuries with a gradual onset caused by overuse and 35.2% of all injuries with a sudden onset caused by overuse. Ninety percent of recorded injuries during the study period were located at the lower extremities. The majority of injuries were located at the thigh/hip, followed by the foot/shank. Most injuries sustained by the cohort

were severe, with 53.5% of injuries leading to a total or partial time-loss from training and competition of at least 28 days.

In paper III, the results showed that the majority of injuries occurred in October followed by December and April. The overall incidence rate per 1000 hours of athletics training was 1.81 for the cohort, and a moderate athlete availability of 78% for the season with a large individual variability. In paper IV certain risk factors were identified. More specifically, athletes with an injury at the thigh/hip show a slower knee flexion velocity compared with athletes not injured at the thigh/hip.

In conclusion, Swedish elite athletics athletes suffer from a high incidence of overuse injuries that most likely affect their potential to perform at a high level during the season. The majority of injuries are sustained at the beginning of the season during the first conditioning phase. Thus, to decrease the number of injuries, future research should focus on further investigating the athletes' training volume and training intensity and the possible association to overuse injury.

# Svensk sammanfattning

Det övergripande målet med avhandlingen var att undersöka tre aspekter av överbelastningsskador inom Svensk elitfriidrott. Avhandlingen består av fyra delarbeten varav delarbete I är ett studieprotokoll. I delarbete II (n=58) var målet att tillskansa kunskap om överbelastningsskadors egenskaper, och i delarbete III (n=59) var målet att uppskatta säsongsfördelningen av överbelastningsskador samt möjliga konsekvenser för friidrottarna. Delarbete IV (n=96) utvärderade potentiella riskfaktorer och deras förhållande till överbelastningsskador. Friidrottarna följdes prospektivt under en Svensk friidrottssäsong. Alla skador diagnostiserades och registrerades med hjälp av en fysioterapeut och en läkare. Vid inskrivning i projektet genomgick alla deltagare en screening som bestod av en klinisk undersökning, löpanalys och styrketest. Både manliga och kvinnliga Svenska elitfriidrottare rekryterades i Göteborg från fyra stycken grengrupper: medel/långdistans, sprint, hopp och kast. Alla deltagare uppmanades att fylla i och skicka in träningsdokumentation på månadsbasis under säsongen.

I delarbete II beskrevs skadeincidensen, skadeuppkomst, lokalisering av skador samt hur allvarliga skadorna var. Skadeincidensen var 72.4% under en Svensk friidrottssäsong. Av dessa skador kategoriserades 64.8% som överbelastningsskador med en gradvis skadeuppkomst, och 35.2% med en plötslig skadeuppkomst. Nittio procent av alla skador registrerades i de nedre extremiteterna. En majoritet av skadorna drabbade låren eller höfterna samt fötterna och underbenen. De flesta skador klassades som allvarliga (53.5%) och resulterade i hel eller delvis frånvaro från träning och tävling i minst 28 dagar för friidrottarna. I delarbete III visade resultaten att de flesta skador inträffade i oktober, december och april. Under säsongen rapporterades en skadeincidens av 1.81 skador per 1000 timmars exponering för friidrott, samt en måttlig tillgänglighet för idrottare på 78 % för en säsong med en stor variabilitet på individnivå. I delarbete IV visade det sig att gruppering av skador verkar öka effektstorleken för vissa riskfaktorer. Friidrottare med en överbelastningsskada vid låret/höften hade en långsammare knäflexion jämfört med friidrottare som inte hade någon skada vid höften/låret.

Sammanfattningsvis har Svenska elitfriidrottare en hög incidens av överbelastningsskador som troligtvis även påverkar deras förmåga att prestera på en hög nivå under säsongen. En majoritet av skadorna sker under uppbyggnadsfasen under den första delen av säsongen. För att minska antalet skador bör framtida forskning fokusera på att fortsatt undersöka friidrottarnas träningsvolym samt träningsintensitet och dess möjliga koppling till att drabbas av en överbelastningsskada.

# Table of Contents

# List of tables and figures

# List of papers

This thesis is based on the following original papers, which will be referred to by their corresponding Roman numerals throughout the thesis:

I Lundberg Zachrisson, A., Desai, P., Karlsson, J., Johanesson, E., Grau, S. (2018). Overuse injuries in Swedish elite athletics - a study protocol for a prospective multifactorial cohort study. *BMC Musculoskeletal Disorders,* 19, (1), 1-12. doi:10.1186/ s12891-018-2296-z

II Lundberg Zachrisson, A., Desai, P., Karlsson, J., Grau, S. (2020) Occurrence of overuse injuries in elite Swedish athletics - a prospective cohort study over one athletics season. *Translational Sports Medicine,* 3, (6), 649-656. doi.org/10.1002/ tsm2.178

III Lundberg Zachrisson, A., Ivarsson, A., Desai, P., Karlsson, J., Grau, S. (2020). Athlete availability and incidence of overuse injuries over an athletics season in a cohort of elite Swedish athletics athletes - a prospective study. *Injury Epidemiology,* 7, (16), 1-10. doi.org/10.1186/s40621-020-00239-0

IV Lundberg Zachrisson, A., Ivarsson, A., Desai, P., Karlsson, J., Grau, S. Risk factors for overuse injuries in a cohort of Swedish elite track and field athletes. Manuscript submitted.

# Abbreviations

| | |
|---|---|
| BMI | Body mass index |
| DOMS | Delayed onset muscle soreness |
| GFIF | Gothenburg Athletics Association |
| Km | Kilometer |
| MVC | Maximum voluntary contraction |
| Nm | Newton meter |
| OI | Overuse injury |
| QTM | Qualisys Track Manager |
| ROM | Range of motion |
| WA | World Athletics |

# Background

## Definition of athletics and track and field

The sport *athletics* is the umbrella term for a group of events that includes competitive running, jumping, throwing, and walking. It comprises track and field events, cross country running, road running, and race walking. Track and field events encompass jumping, throwing, and running competitions that take place in a stadium that has a running track. In the USA and Canada, the term *athletics* refers to sport in general, and instead *track and field* is used as a broader term to include marathon and race walking. In this thesis, *athletics* is defined according to the umbrella term.

## Athletics in an international context

WA consists of 215 member nations that are divided into six continental area associations according to geographical location: Asian Athletics Association, Confederation of African Athletics, South American Athletics Confederation, North American, Central American and Caribbean Athletic Association, European Athletics Association, and Oceania Athletics Association. The sport is governed by WA (formerly International Association of Athletics Federations) with its headquarter in Monaco [1].

As a sport, athletics has developed substantially over the last decades. Since 1983, the World Athletics Championships have been held every two years at different locations worldwide. At the same time, the amount of half marathons and marathons around the world and the number of participants in these competitions have increased substantially [2]. This development has led to a large marketing potential and increasing global reach for the sport. As a parallel development, there has been a considerable increase of prize money for the top international athletes. In addition to the World Athletics Championships, the European Athletics Championships are held every two years and the summer Olympic Games every four years. Further, indoor world and continental championships take place on a regular basis. Apart from the major championships, an international tour circuit (Diamond League) takes place annually and comprises 14 invitational athletics competitions in Africa, Asia, Europe, and the USA.

## Athletics in a Swedish context

In Sweden, athletics is governed by the Swedish Athletics Association. The Swedish Athletics Association is divided into 23 district associations and together they represent approximately 1000 registered member clubs across the country. In 2019, it was reported that roughly 4100 people between 15 and 25 years of age had participated in at least one outdoor athletics competition. Sweden has an annual national indoor championship at the end of February and a national outdoor championship in August. These national championships include both youth and senior competitions in all event groups. There is a national competition tour circuit for elite athletes during the outdoor competition phase in summer, named *Folksam Grand Prix*, with a mix of elite national and invited international athletes. *Finnkampen* concludes the Swedish outdoor competition season at the turn of the month between August and September. It is a competition between the best national athletes from Sweden and Finland. There are also regional cross-country running competitions during the conditioning phase in autumn (October through December), in which a majority of track athletes from the middle/long distance event group compete.

After the Swedish Athletics Association, athletics in Gothenburg and its surrounding municipalities is governed by GFIF. GFIF consists of 16 member clubs that are responsible for the sporting activities hosted by the association. Athletes belonging to a member club from the Gothenburg area have been responsible for approximately 20% of all top six placements during the Swedish Senior National Championships from 2015 and onwards (Johan Wettergren, national running coach, personal communication). The cohort of athletes in Gothenburg consists of athletes competing both nationally and internationally. GFIF hosts the world's largest half marathon (60 000 participants), *Göteborgsvarvet* held in May each year, that also serves as the competition for the Swedish national championship for the half marathon. Gothenburg is also the location of one elite athletics school that offers a national athletics education (Swedish: Nationell idrottsutbildning, NIU) and has a national intake (Swedish: Riksidrottsgymnasium, RIG). In Sweden there are six RIG-schools and twenty NIU-schools with athletics as an elective specialization. Around 40 athletes divided into three grades between the ages of 16 and 19 make up the elite section. The school recruits both male and female athletes from all event groups according to different performance criteria decided by the employed teachers (coaches).

## Characteristics of athletics

Historically, athletics dates back to ancient Greece. Modern-day athletics is divided into twelve different event groups: sprints, middle/long distance running, hurdles, road running, jumps, throws, combined events, race walks, relays, cross country running, mountain running, and ultra-running. Further division is made to distinguish the events that take place on a running track, such as sprints and middle/long distance running. Each event group consists of a number of different specific events divided by, for example, running distance. Men and women compete separately, except for mixed relays. The relatively low cost to participate in the sport and its simplicity makes athletics available to most people.

The athletics season generally consists of different conditioning and competition phases (indoor and outdoor). The athletics season usually finishes at the end of August (pending the schedule of major championships), and most athletes take a resting period in September before starting the conditioning phase for the upcoming season. An athlete has one or more coaches and plans the training and the periodization of the training around the season's competition phases.
Many athletes and training groups arrange training camps in warm weather countries during the athletics season, especially athletes living in colder climates that make year-round outdoor training at home difficult. For middle/long distance runners, most training camps are located at high altitudes (e.g. South Africa) to take advantage of the thin air that allows the bone marrow to form more red blood cells.
Athletics as a sport is characterized by a high training frequency, where elite athletes train approximately two times a day on five days a week, and between 12 and 20 hours per week in total, regardless of event group and

event. Middle/long distance runners, sprinters, and jumpers are characterized by a lean physique [3]. The training consists of different basic contents, such as strength training, endurance training, speed training, flexibility training, and technique training. The training contents vary in frequency, depending on the event group and event. Further variation in training depends on the point in time of the athletics season (conditioning or competition phase) where training volume, training duration, training intensity, and training density show different characteristics [4]. Finally, training content can vary due to different coaching philosophies.

Elite athletics athletes seem to be prone to injuries due to the high training volume [5, 6]. Before focusing on previous research on injuries and injury development in athletics, explanations will be given for common terms and definitions used in sports injury research.

## Terms and definitions

### Onset and injury type

In the past, injuries were recorded as either being acute or overuse. An acute injury was defined as a sudden injury usually associated with a traumatic onset, such as a fall or a ligament tear due to a collision. An OI was defined as being caused by repeated micro-trauma without a single identifiable causal event [6]. This definition was based on a consensus statement on injury definitions and data collection procedures in football (soccer) [7]. Later, and in another consensus statement, a decision was made to record injuries according to their onset (sudden or gradual onset) [8]. Sudden onset injuries were subsequently defined as either traumatic injuries (previously named acute injuries) or OI, while gradual onset injuries were defined as OI.

### Injury definition

There is a consensus among researchers and practitioners that overuse is the main cause of injuries in athletics [6, 8]. In a consensus statement on injury definitions and data collection procedures for athletics, an athletics injury was defined as:

> A physical complaint or observable damage to body tissue produced by the transfer of energy experienced or sustained by an athlete during participation in athletics training or competition, regardless of whether it received medical attention or its consequences with respect to impairments in connection with competition or training [8].

In the same statement, an OI was described as:

> A condition to which no identifiable single external transfer of energy can be associated. Multiple accumulative bouts of energy transfer could result in this kind of injury [8].

## Injury incidence

Injury incidence measures describe the occurrence of new (overuse) injuries in athletics during a specified period (e.g. one athletics season). There are three common types of incidence measures: incident cases, incidence proportion, and incidence rate.

Incident cases are the number of athletes with new injuries over a certain period, e.g. pre-season. Incidence proportion is the number of athletes with new injuries during a follow-up period (e.g. one athletic season) in relation to the number of non-injured athletes. It is expressed as a percent value. The cumulative incidence proportion without censoring are athletes with new injuries divided by all athletes at risk at the start of follow-up over a certain period. The incidence rate is the number of new injuries divided by the total of athletic exposure hours, expressed as for example, 1000 athlete-hours. Incidence-based measures are recommended to be used in studies on injury etiology, in prevention studies, and in treatment studies [9].

## Injury prevalence

Injury prevalence measures describe the availability of an athlete (e.g. weekly) within a specified period (e.g. one athletics season). There are two common types of prevalence measures: prevalent cases and prevalence proportion.

Prevalent cases are the number of athletes with injuries at a certain time point (e.g. per week over one athletic season). Prevalence proportion is the proportion of athletes with injuries at a certain time point (named point prevalence proportion). Prevalence proportion is calculated by dividing the number of injured athletes by the total number of all athletes at a given time point and expressed in percent.

Prevalence-based measures can be used in surveillance studies to identify the availability of athletes, and medical treatment [9].

### Injury occurrence

Injury occurrence describes the time point of an injury during an athletics season. Injury occurrence has so far been reported according to whether injuries occurred during athletics training or during competition [6, 10-13], or at the beginning, in the middle, or at the end of the season [5, 14].

### Injury severity

Injury severity describes the duration of an athlete's absence from regular training and competition due to an injury. Injury severity is counted from the first day of injury until the athlete returns to normal training. The most commonly used method of calculating this is the use of subjective cutoffs (e.g. 1-7 days, 8-28 days) [8]. Another method used is the average number of days absent per month [13], and a further way of measuring an athlete's time-loss from training and competition is to use athlete or training availability [15]. It is a measurement of an athlete's ability to participate in unrestricted training or competition.

### Injury location

Injury locations are often reported according to anatomical locations. So far varying injury locations, (e.g. ankle/foot or foot/shank) have been reported. A consensus statement has been published to rectify this [8].

### Risk factors

A risk factor is described as the reason why a particular athlete may be at risk of sustaining an injury in a given situation [16]. Risk factors are commonly divided into extrinsic (externally related) and intrinsic factors (internally related) [17, 18]. Risk factors in sport have been linked to four overarching areas: biomechanics (e.g. running pattern, strength), training, clinical, and psychological.

The following section will present what previous literature has reported regarding injuries in athletics.

## Injury research

### Research on injury onset

Bennell et al. (1996) published a study on musculoskeletal injuries in track and field. In the study, 98% of all recorded injuries were diagnosed by a medical professional. The onset diagnoses were specified among the different event groups [5]. Sprinters and hurdlers had an even divide of 50% of acute and overuse injuries. In middle distance running, a large majority (75%) of the injuries were caused by overuse, while 25% had acute onset injuries. For athletes competing in jumping events, 55% of injuries were caused by overuse and 45% were acute.
Zemper (2005) conducted a systematic review of studies on injuries to youth athletes (≤18 years old) in athletics and found that only one study reported injury onset [19]. The study found that 26.8% of all injuries were acute and 73.2% of all injuries had a gradual onset.
A Swedish retrospective study from 2012 by Jacobsson et al. aimed to ascertain the one-year retrospective and current prevalence of injury in elite athletics athletes. They found that the main cause of injury was gradual onset inflammation and pain with a 1-year prevalence of 20.9% and a point prevalence of 23.2%. For sudden onset injuries, the 1-year prevalence was 16.5% and the point prevalence was 8.5% [20]. A Swedish prospective cohort study from 2013 by Jacobsson et al., that estimated the incidence of musculoskeletal injuries, observed the onset of injuries over a 52-week period in Swedish elite athletics athletes [6]. Athletes were asked to self-report the onset of their injuries via an online questionnaire. After 52 weeks, they found that 96% of the recorded injuries were caused by overuse, 55% were considered to be gradual onset, and 41% sudden onset [6].

### Summary of injury onset research

A limited number of studies have reported injury onset in athletics. There is a consensus that the most common injury onset is a gradual onset caused by overuse. There are inconsistent numbers reported on percentage of injury onset due to different onset definitions, and there is a mixture of study designs using self-reported injuries and injuries reported by a medical professional.

## Research on injury incidence

Ahuja et al. (1984) conducted a study on injuries in elite Indian athletics athletes. A total of 317 injuries were reported from a population of 140 athletes, however no data on the number of injured athletes were presented [21]. In a study using a cohort of Swedish adult sprinters and distance runners belonging to a track and field club, Lysholm et al. (1987) found that 39 out of 60 sprinters and runners were injured during the data collection period of one year, resulting in an incidence proportion of 65% [13]. D'Souza (1994) conducted a one-year survey to collect data on track and field athletics injuries with a cohort of athletes from the United Kingdom (UK) who performed at different levels of competition. They found that 90 of 147 athletes sustained at least one injury during the athletics season, leading to an incidence of 61.2% [14]. Bennell et al. (1996) conducted an Australian study with Victorian track and field athletes ranging in age from 17-26 years and found that 72 of 95 athletes were injured during the season. This was reported as an incidence rate of 76% [5]. More recently, Jacobsson et al. (2013) prospectively estimated the incidence of musculoskeletal injuries among Swedish male and female elite youth and adult athletes. After one year, 199 of 292 athletes had sustained at least one injury during the 52-week data collection period, leading to an incidence proportion of 68% [6]. Data collected from adult high-level competition, World Championships and the summer Olympics display a cumulative injury incidence close to 10% per event occasion [10-12, 22]

## Summary of injury incidence research

There appears to be a high incidence of injuries in athletics with a majority of studies reporting an injury incidence of over 60%. There are wide variations in injury incidence among the different studies, which can be attributed to different injury diagnoses (self-reporting vs. medical professional reporting), different injury definitions, or different populations (sub-elite vs. elite, different events, and sex). This was also confirmed by Zemper (2005) [19].

### Research on injury prevalence

One Swedish athletics study from 2012 looked at the one-year retrospective injury prevalence and current prevalence of injury in athletics [20]. The cohort consisted of youth (16 years of age and older) and adult athletics athletes who were ranked in the national top 10 in their respective event group. The one-year retrospective injury prevalence for 278 athletes was 42.8%, while the point prevalence was 35.4%. Another study on youth (aged 16 to 19 years) athletics athletes from Ireland found an average weekly prevalence for all athletes of 27% for all health problems including illnesses, acute injuries, and OI [23].

### Summary on injury prevalence research

A limited number of studies have reported information regarding injury prevalence for athletics athletes. Research results indicate that the injury prevalence is between 27% and 42.8%. However, comparisons between studies are difficult to make due to the different study designs and measurement periods.

### Research on injury location

During a fourteen-month training camp for Indian elite athletics athletes, Ahuja et al. (1984) found that the majority of injuries were located at the lower extremities (59.2%), with the knee (27%), ankle (23%), and foot (16%) being the most common injury locations [21]. In a cohort study of 60 Swedish runners from 1987, Lysholm et al. found that most of the 55 reported injuries for sprinters and distance runners were at the leg and ankle (18) followed by the thigh (10) [13]. D'Souza (1994) conducted a one-year survey on a cohort of track and field athletes from the United Kingdom. Sprinters sustained a majority of injuries at the back and foot, and middle/long distance runners sustained injuries that were located at the back, hip, knee, and shin. Jumpers sustained injuries located at the ankle, knee, and thigh, while the remaining injuries sustained by throwers were predominately injuries to the back and ankle [14]. In 1996, Bennell et al. evaluated the incidence, distribution, and types of musculoskeletal

injuries in an Australian cohort of track and field athletes. Sprinters mostly sustained thigh injuries, with the hamstring the most common location, middle and distance runners sustained mostly leg (tibia) injuries, while jumpers mostly sustained thigh and back injuries [5]. During the Penn Relay Carnival Competition, the most common injuries (and locations) were a rupture of the Achilles tendon along with fractures of the foot and ankle. No further data regarding injury location were presented [24].
In a systematic review of studies with athletics athletes under 18 years of age from 2005, Zemper found that 64% to 87% of all reported injuries were found at the lower extremities [19]. Rebella et al. (2008) conducted a prospective cohort study observing 140 high school athletics athletes in the United States, and found that the lower extremities were responsible for 71.5% of all injuries, with the most common injury type being ligament sprains [25]. Jacobsson et al. (2012) conducted a retrospective study with Swedish elite adult and youth track and field athletes. The majority of athletes in this study reported injuries in the lower extremities at the knee, lower leg, ankle, foot, and toe, with the most common injury being to the Achilles tendon [20]. In 2013, Jacobsson et al. also conducted a study with a cohort of 199 elite Swedish athletics athletes. In the cohort, 77% of all injuries occurred at the lower extremity; the most common locations were the Achilles tendon, ankle, foot, and toe (28%), followed by the hip, groin, and thigh (24%), and the knee and lower leg (24%) [6]. Roos et al. (2015) conducted a descriptive epidemiology study of 16 sports from the National Collegiate Athletic Association's Injury Surveillance System and 14 sports from High School Reporting Information Online which included athletics. The lower extremity was the most commonly injured body site among athletes regardless of sport [26].

Aside from longer observation periods, such as a year, previous studies have analyzed the frequency and characteristics of sports injuries during major championships. At the 2007 IAAF World Athletics Championships, 80% of all recorded injuries affected the lower extremities, with the thigh being the most common injury location [10]. The same results were observed two years later at the 2009 IAAF World Athletics Championships [12].

### Summary of injury location research

There is a consensus that most injuries in athletics occur at the lower extremities. There are inconsistent or unclear results about injury distribution with regard to anatomical location. This is due to the different injury location categorization (regional vs. diagnosis), different populations (events, sex), and the type of injury reporting (self-reporting vs. medical professional reporting).

### Research on injury severity

An older study by Lysholm et al. (1987) observed a cohort of Swedish sprinters and distance runners, and they reported an average of 1.6 to 1.9 days of involuntary rest per month due to injury during the season [13]. In Australian track and field athletes, Bennell et al. (1996) found that injuries generally restricted athletes to alternative training (e.g. swimming or cross-trainer) for 3.1 weeks (±3.9), with a return to full training occurring 9.0 weeks (±8.5) post-injury, regardless of event [5].
In a systematic review of studies with athletics athletes under 18 years of age, Zemper (2005) found that two studies reported that boys and girls had similar injury patterns. 14% of the boys' injuries and 19% of the girls' injuries led to time-loss from training for more than 10 days, and 30% of the boys' injuries and 40% of the girls' injuries led to time-loss from training for more than 5 days [27]. A more recent and larger study by Knowles et al. from 2006 showed a different pattern, with 50% of injuries in boys and only 33% of injuries in girls lasting one week or longer [28].
Edouard et al. (2010) conducted a retrospective study using questionnaires focused on French high-level track and field throwing events, and found that 40% of recorded injuries required a time-loss of over 28 days [29]. Another recent study in a Swedish elite athletics cohort by Jacobsson et al. (2013) found that there were no differences in injury severity with regard to event group. Irrespective of event group, most reported injuries (51%) led to an absence from normal training for more than three weeks [6].

### Summary of injury severity research

There is a consensus that the majority of reported injuries induce a time-loss of at least one week. There are unclear results about the severity of injuries beyond one week, as different severity categories have been used (days vs. weeks or different length categories of absent weeks). To make severity categories comparable, a recent consensus statement included suggestions for defining severity categories [8].

### Research on injury occurrence and athlete availability

In a cohort of Swedish elite athletes, Jacobsson et al. (2013) found that the majority of injuries (73%) occurred during training and 18% of injuries occurred during competition. The remaining injuries (9%) had no information registered for occurrence and were recorded as missing data [6]. For Swedish athletics sprinters, two out of 12 injuries occurred during competition; the rest of the recorded injuries were training-related. No information was presented for the distance runners who took part in the study [13]. In 1994, D'Souza published a study on a cohort of UK athletes, where it was found that most injuries occurred during training (63.3%), followed by competition (20%). It was further observed that most injuries occurred at the beginning of the season compared to the middle, and the end [14].

More recently, Jacobsson et al. (2013) estimated injury patterns in Swedish elite athletics athletes and found that most injuries were sustained by athletes in March, April, and May [6]. However, no further information was reported. Raysmith et al. (2016) conducted a study with Australian athletics athletes with the objective to investigate the impact of training modification on achieving performance goals. It was found that the likelihood of achieving a performance goal increased sevenfold in those athletes who completed >80% of the planned training weeks, and that training availability accounted for 86% of successful seasons [15].

### Summary of injury occurrence and athlete availability research

A limited number of studies have reported information regarding injury occurrence for athletics athletes. Research results indicate that training, and not competition, appears to be the most common trigger for injury, and that most injuries occur at the beginning of the season. However, there is no information available regarding specific time points of injury during this initial phase of the season. There is currently, to the author's knowledge, no other published research on athlete availability for athletics.

## Risk factors associated with injury in athletics

There have been various attempts at establishing risk factors that are associated with the onset of injury in athletics. A consensus has been established that a previous injury is a risk factor for sustaining a new serious injury, as identified for example by Jacobsson et al. (2013) [6]. A review on running-related OI found that one likely risk factor was the occurrence of previous injuries [30]. Similarly, it was found that a pre-participation injury complaint was a risk factor for injury prior to a major championship in athletics [31]. Incurring a subsequent injury (secondary) while recovering from a primary injury was found to be common among Swedish youth and adult athletics athletes [32]. An observational cohort study over 17 years with 367 elite athletics athletes found a statistically significantly higher frequency of hamstring injuries in athletes having experienced a previous ankle ligament injury [33]. In contrast, there seems to be a consensus that event group does not indicate a higher risk of injury, as several studies were unsuccessful in finding such an association [5, 6, 20].

Inconsistent results have been reported for sex and training as risk factors. A Swedish retrospective study on elite athletes found female youth athletes to be at a higher risk for injuries than male youth athletes, but no differences could be found between female and male adults [20]. A similar Swedish study, however, found that there was a higher injury rate among male athletes than among female athletes [6], while two international studies concluded that sex had no impact on injuries [5, 34]. There are conflicting findings on the impact of training volume, including hours spent training. One Swedish study focusing on elite athletes found an increased risk of injury with an increased training volume [6], as did a review on risk factors for OI in runners [30], while a study in the UK saw no relationship between training hours and injury incidence [14]. An Australian study found that elite youth athletes aged 13-14 who sustained an injury trained at a higher intensity, completed more high-intensity training sessions, and had a higher yearly training load than non-injured athletes [35].

Other factors shown to be related to an increased injury risk are increasing age, greater overall flexibility, lack of supervision by coach, lower bone density in females, and a greater prevalence of menstrual disturbances [6, 36, 37]. A study from the United Kingdom found that the level of competition had a significant relationship to the incidence of injuries. Athletes competing at the highest level had an injury incidence of 33.3%, while athletes competing at the lowest level had an injury incidence of 70.8% [14]. In Swedish elite athletics, psychological factors, such as self-blame and hyperactivity, were found to be related to OI in elite athletics athletes [38].

### Summary of risk factors associated with injury in athletics

There is a consensus that previous injury is a risk factor in developing an injury in athletics, and that event group is not. Inconsistent results were found for sex (adult vs. youth and competition level) and training risk (different variables to describe training load). It is unclear whether age, competition level, psychological factors, clinical, or biomechanical factors contribute to an increased risk of injury in athletics.

Several studies on recreational runners indicate different training, biomechanical, and clinical risk factors associated with injury [39-47]. It is unclear whether this is transferable to elite athletics athletes.

## Consequences of injuries

The high incidence and the severe nature of the injuries incurred by athletes competing in athletics is clear. Despite this, very little information is available regarding the consequences for the athletes who incur injuries. The time-loss from training and competition reported in previous studies indicates that many athletes miss a substantial part of the season. An Australian study determined that a lack of training due to injury has a direct effect on performance. The likelihood of achieving a performance goal increased sevenfold among the athletes who completed >80% of their planned training weeks during the season [15], and the same has been seen among youth athletes [48].

Even though a majority of athletes suffer from injury during the season and miss training sessions, both of which affect athlete performance, this has been sparsely discussed in research. Other consequences from being injured could be the inability to qualify for competitions, such as major championships, which could result in cancelled or decreased sponsorship(s) due to a lack of exposure, meaning a monetary loss for the athlete. Injuries also lead to economical costs for the athletes and the healthcare system [49].

Therefore, many athletes refrain from seeking treatment, and train in a constant state of pain. This affects their psychological well-being in a negative way, which can lead to an early retirement from the sport [50, 51].

## Perspectives of sports injury research

An early model on the etiology of sports injuries was proposed by Meeuwisse in 1994, suggesting a linear, causal pathway to injury [52]. The framework consisted of the idea that intrinsic factors (e.g. age, sex) through interactions with extrinsic risk factors (e.g. training errors, running shoes) would increase the risk of injury in predisposed athletes. The idea was that these risk factors would influence how much of an injury-related mechanism an athlete could tolerate. The framework was later revised in 2007, as the previous version included a start and end point for injuries, which does not reflect the true onset of sports injuries [53]. Further changes were also made to take into account that the same factors and mechanisms may have different outcomes for different athletes. More recent research suggests a framework moving from risk factors to identifying risk patterns and looking deeper into the complex nature of causation [54-56]. Instead of trying to find ‘causes’, researchers should focus on ‘relationships’. Another more recent framework was based on structure-specific capacity. Structure-specific capacity is the musculoskeletal system's ability to withstand load without sustaining injury [57]. The framework is divided into four structure-specific parts; the capacity when entering a running session, the cumulative load per running session, reduction in the capacity during a running session, and exceeding the capacity [58]. The argument put forward is that a better understanding of the cause of running-related injury will be possible by looking at all four steps, as well as the number of strides, magnitude of load, distribution of load, and load capacity.

Further models and frameworks have been published with regard to injury risk management in sports. An early injury risk model using a four step method was developed and presented in 1992 by van Mechelen et al. [17]. Step one is to establish the extent of the problem using epidemiology data, and step two to establish the cause and mechanism of injury. Step three introduces preventative measures, and step four is to assess intervention efficacy by repeating step one. Similarly, the Translating Research into Injury Prevention Practice (TRIPP) model proposed by Finch in 2006 uses a step-wise method, where the first step is to surveille injury, step two is to establish etiology and mechanisms of injury, and step three is to develop preventive measures [59]. The main point that Finch raises is that only research that is adopted by the participants, coaches, and sporting bodies will prevent injuries.

There have been suggestions to establish a more precise definition of the term *overuse injury* for use in injury surveillance [60]. This reasoning was further developed by Bahr in 2009, who presented a new methodology for recording overuse symptoms in sport, including recommendations for prospective study designs and using valid and sensitive scoring instruments to properly record injuries [61].
In the last few years, the importance of recording OI, or overuse symptoms, has been highlighted by a number of researchers [62, 63].
In 2013, Clarsen et al. presented a new methodology to identify overuse symptoms, as OI previously may have been substantially underestimated due to the use of different and inconsistent time-loss injury definitions [64]. The new method includes an expanded and remodeled weekly questionnaire to monitor and register health problems among athletes. This method was compared to a time-loss definition for team sports, where injuries were registered by the team coach or physiotherapist during scheduled training sessions. However, road cyclists and cross-country skiers, who usually train individually, used an online questionnaire where they could indicate if they had felt any pain that had restricted them in their training. A time-loss definition with a short injury duration (e.g. time-loss of 24 hours and changes made to normal training) in conjunction with using a medical professional to diagnose injuries should eliminate this problem.

Further suggestions to decrease the incidence of OI have been to increase mileage gradually in increments of 10 percent or less each week, and to find easily administered tests that can predict the level of risk that occurs at various levels of training intensity, duration, and frequency [65, 66]. These models, in part, have been used in athletics research. Recommendations have been published regarding how to collect injury data in athletics [8], and injury preventive guidelines have been implemented in conjunction with major championships to decrease the incidence of injuries [11]. However, most research that has utilized these models has focused on recreational running. In athletics, the focus has mainly been on descriptive studies looking at the incidence, location, and severity of injuries. Certain specific topics have been researched, such as the recovery time for posterior thigh muscle injuries and bone stress injuries using different rehabilitation protocols, and the overrepresentation of hamstring injuries [34, 67-69].
However, as these models point out, the reason that athletes sustain injuries is most likely a combination of risk factors that lead to an injury. One framework questioned whether non-training variables, such as biomechanical or anthropometrical variables, themselves can lead to injury [70].

In athletics research, certain methodological issues have also hindered establishing a consensus on how to proceed with injury research.

## Methodological issues in previous studies

A limited number of findings in athletics studies are consistent, and there are still major hindrances to adequately compare studies. Summarized below are the most common methodological issues in the current literature on athletics.

### Study design

The most common methodological issue in previous research is the use of different study designs (retrospective vs. prospective) and the quality of information that can be derived from them. In the past, most researchers used a retrospective study design, which does not allot a causal (or even temporal) relationship between a risk factor and injury, as the risk factor could be affected by the injury. Information on risk factors from retrospective studies should therefore be treated with care. Prospective studies are seen as necessary to clarify cause-and-effect relationships and to determine interrelationships between different risk factors (e.g. biomechanical or clinical) that can lead to an injury [41, 45, 71].

Previous research has used varying study periods to collect data, ranging from a specific part of the athletics season (e.g. half a season) up to 14 months, with one study defining the athletics season as 30 weeks, from December until July the following year [23]. Until now, no published study has used only the athletics season, removing the resting period, as the period for data collection, meaning it is difficult to interpret how many injuries occur during an actual season. One reason for the differing data collection periods may be the potential difficulty to collecting data over a longer period due to limited access to athletes.

**Injury definitions**

In previously published studies, injury definitions have ranged from subjective injury interpretations by the participating athletes [14] to more specific injury definitions, such as:

> Overuse injuries, if caused by repeated micro-trauma without a single identifiable causal event, and as a traumatic injury, if resulting from a specific identifiable event [6].

The impact of using different injury definitions has been researched in sports in general [72, 73], and in more specific contexts such as football [74] and running [75]. It has been established that minor changes in injury definitions can cause major differences in the final results of a study, meaning that the number of injuries recorded could change from low to high. A consensus statement was published in 2014 to standardize the way injury data in athletics was collected, defined, and categorized. However, the consensus statement still recommends self-reporting of injuries when medical professionals are unavailable [8]. Therefore, a major methodological issue that can lead to bias remains.

## Categorization of injuries

While most studies have not categorized injuries further than placing all injuries in a general 'injury' category, it is important to distinguish between the onsets of injuries to be able to develop preventive guidelines for athletes. Even though the frequency of traumatic (acute) injuries in athletics is sparse, a majority of studies have given acute injuries equal consideration as OI. Studies have shown that OI are responsible for a majority of all injuries sustained by athletics athletes [6, 11]. This clearly indicates that the main focus should be on OI and identifying the injury onset connected to overuse. Medical professionals should, if possible, be responsible for physical examinations and categorizing injuries, establishing a clear diagnosis, and ensuring data is recorded as correctly as possible. OI are difficult to diagnose, because the symptoms are often diffuse and change over time. An appropriate diagnosis followed by treatment by a medical professional is therefore recommended [76, 77].

In the past, injuries have been recorded as being either acute or overuse. An acute injury was a sudden injury usually associated with traumatic onset, such as a fall or a ligament tear due to a collision. An OI was defined as being caused by repeated micro-trauma without a single identifiable causal event. Nevertheless, a sudden injury could be an OI, leading to an incorrect categorization of type of injury. To avoid mislabeling, a consensus statement recommended recording injuries according to their onset (sudden or gradual onset) [8]. Sudden onset injuries were either traumatic injuries (previously named acute injuries) or OI, while gradual onset injuries were defined as OI.

## Self-reporting of injuries

The most common method used for collecting data on injuries is to have athletes submit an online questionnaire answering questions regarding the past week's training and competition. This method is usually described as athletes self-reporting potential injuries. This method has been researched in several different sports and settings with poor results [78-81]. Two older athletics studies used medical professionals to assist with diagnosing injuries. However, they used periods of differing lengths to collect injury data, and also used different injury definitions and methodologies, which makes it difficult to compare them to present day athletics and athletics research [5, 21].

The consensus seems to be that it is difficult for athletes to recall exact details of their injuries, or they only remember certain parts, such as the injury location but not the correct diagnosis [82]. The use of self-reporting might lead to injuries being unrecorded and thus underestimated, falsely reported and thus overestimated or misinterpreted by the athlete after a doctor's medical diagnosis. As injury data is crucial in athletics research, self-reporting of injuries should be kept to a minimum to avoid bias.

**Study population**

The majority of published athletics studies use varying definitions and terminology to describe the competitive level of their study cohorts (e.g. collegiate, sub-elite). This together with inherent national differences in ranking systems and national team qualification makes it difficult to establish a universal definition of elite level in athletics. However, finding a consensus for a universal definition of "elite athletes" for athletics would make it easier to compare studies in the future. For example, such a universal definition could state that you are an elite athlete in athletics if you compete at a national level regardless of national affiliation or if you are an athlete that receives a salary or monetary compensation from your club or national federation.

**Training documentation**

In general, only a limited number of studies have documented training information from athletics athletes. It has mostly been limited to documenting training volume by quantifying the number of training hours and/or training sessions in a retrospective or prospective study design. Jacobsson et al. (2013) prospectively documented information from Swedish elite athletics athletes regarding the type of training (e.g. strength training) and compared it to the incidence of injuries [6]. However, they did not document additional details about the type of training conducted. This means, for example, when strength training was documented, there was no information regarding training volume (e.g. kilograms or sets/repetitions of individual exercises). The same method was used by Lysholm et al. (1987) [13].

There is generally insufficient evidence regarding the relationship between training risks and developing OI in both recreational and elite athletics. One main reason for this deficit is that single training variables and their relationship to OI were investigated, neglecting possible modifying or confounding effects of the different training variables. A recent study suggests using structure-specific load capacity to describe training load, as it comprises a more accurate quantification of training exposure [58]. However, this method was developed to describe training load in running and thus cannot be used generally in athletics. Therefore, structure-specific training documentation needs to be developed for all event groups.

## Summary of introduction

The consequences of being injured as an elite athlete in athletics are manifold. Injuries can lead to a performance decrease, inability to qualify for competitions, loss of sponsorships leading to income loss, which all can have an adverse effect on the athletes' well-being.

The current reported results in athletics research can be divided into three categories; results with a consensus, results that are inconsistent, and results that are unclear. A consensus means that multiple studies have reported the same results, inconsistent means that multiple studies have reported different results, and results deemed unclear are due to the limited number of studies (or no studies) published.

There is a consensus that the most common injury onset for athletics injuries is a gradual onset caused by overuse, and that the majority of injuries are located at the lower extremities. Most injuries sustained by athletes lead to total or partial time-loss from training and competition of at least one week. Furthermore, there is a consensus that a previous injury is a risk factor for sustaining further injuries, while being a member of a specific event group is not a risk factor.

There are inconsistent reports regarding the injury incidence, injury location distribution with regard to anatomical region, the percentage values on injury onset, and whether sex and training are risk factors.

Unclear results have been reported for injury severity beyond one week, and whether age, competition level, psychological factors, and clinical and biomechanical factors are risk factors for sustaining an injury.
These shortcomings are due to a number of methodological issues including varying study designs (retrospective vs. prospective), different use of injury definitions, different categorization of injuries, self-reporting of injuries, varying study populations, and use of very basic training documentation.

Therefore, there is a need for additional research to ascertain the injury incidence, location, severity, and onset of overuse injuries in elite athletics with the help of medical professionals. Further, the injury occurrence, athlete availability, and clinical and biomechanical risk factors need to be established in elite athletics.

# Aim

The overall aim of this thesis was to explore three aspects of OI among elite Swedish athletics. The first aspect was to gain knowledge about OI characteristics. The second aspect was to examine the seasonal distribution of injuries, and the consequences for athletes. The third aspect explored potential risk factors and their relation to OI.

This was investigated using one study protocol and in three original research articles.

**Specific aims of the dissertation papers**

**Paper I: Study Protocol**

*Overuse injuries in Swedish elite athletics - a study protocol for a prospective multifactorial cohort study*

This paper describes the design of the conducted prospective cohort study which investigated injury characteristics (incidence, onset, location, and severity), injury occurrence, athlete availability, as well as potential risk factors (clinical, biomechanical, training, and anthropometrical) for developing OI in elite Swedish athletics. The paper outlines three hypotheses, of which #1 is investigated in Paper II, #2 in Paper IV, and #3 in Paper III.

**Paper II: Original research**

*Occurrence of overuse injuries in elite Swedish athletics - a prospective cohort study over one athletics season*

The aim of this paper was to describe the overall incidence proportion, injury onset, injury location, and injury severity of OI in elite Swedish athletics in a prospective cohort study.

## Paper III: Original research

*Athlete availability and incidence of overuse injuries over an athletics season in a cohort of elite Swedish athletics athletes - a prospective study*

The aim of this paper was to estimate the injury occurrence, the overall and individual athlete availability, and the incidence rate of OI per 1000 athletic hours of training in a cohort of Swedish elite athletics athletes.

## Paper IV: Original research

*Risk factors for overuse injuries in a cohort of Swedish elite track and field athletes*

The aim of this paper was to evaluate how biomechanical factors (movement patterns and strength) and clinical factors (muscle flexibility and range of motion) relate to the occurrence of OI in a cohort of elite Swedish athletics athletes, and to research whether risk factors become clearer if injuries are grouped by location.

# Materials and methods

This thesis comprises one study protocol and three original research papers that are summarized in Table 1.

Table 1. Summary of included papers.

| | Paper II | Paper III | Paper IV |
|---|---|---|---|
| **Aim** | To describe incidence proportion, injury onset, injury location, and injury severity of OI. | To estimate the injury occurrence, the overall and individual athlete availability, and the injury incidence rate of OI per 1000 athletic hours. | To evaluate how biomechanical and clinical factors relate to the occurrence of OI, and to research whether risk factors become clearer if injuries are grouped by location. |
| **Data sources** | Injury data recorded during one Swedish athletics season from October to the end of August the following year. | Injury and training data recorded during one Swedish athletics season from October to the end of August the following year. | Baseline screening data (biomechanics and clinical) and injury data from a Swedish athletics season from October to the end of August the following year. |
| **Inclusion criteria** | 18 years of age, no musculoskeletal pain at baseline, member of a Gothenburg athletics club. | 18 years of age, no musculoskeletal pain at baseline, member of a Gothenburg athletics club. | No musculoskeletal pain at baseline, member of a Gothenburg athletics club or attending an elite sports school with focus on athletics. |
| **Event groups** | Middle/long distance runners, sprinters, jumpers, and throwers. | Middle/long distance runners, sprinters, and jumpers. | Middle/long distance runners, sprinters, jumpers, and throwers. |
| **Number of athletes** | 58 | 59 | 96 |
| **Analytical method** | Descriptive. | Descriptive. | Mann Whitney U-test, Rank-Biserial Correlations. |

Inclusion criteria for the participants were discussed and agreed upon together with GFIF's elite coaches. The first criterion determined was performance, meaning only elite athletes would be included in the project. For Papers II and III, athletes had to have placed in the top six of the

Swedish national senior indoor or outdoor championships or top three in the Swedish national youth indoor or outdoor championships. The performance eligibility was initially determined to be for the competition year 2015, and was prolonged during the project to 2018 (last year of enrollment). Athletes only had to fulfil the criteria once during this period to be considered eligible for participation. Athletes had to be at least 18 years of age and be registered as a member of a Gothenburg-based athletics club. All athletes had to be healthy at enrollment, with no musculoskeletal injury or pain, as confirmed by the study's physiotherapist at the clinical examination. For Paper IV, students attending an elite sports school with focus on athletics were also eligible for inclusion, and the age and club affiliation requirements were removed.

GFIF assisted with the recruitment of athletes and compiled a list of possible eligible male and female athletes to invite. The project leader contacted all athletes on the list through e-mail or phone to inform them of the project and to invite them to partake. Additional information about the project in the form of a booklet was e-mailed to all athletes who expressed an interest to participate and to their respective coaches. The project leader, together with GFIF, also hosted an informational meeting including a project presentation for invited athletes. At this meeting, the athletes could ask questions regarding the aim and scope of the project.

The invited athletes competed in middle/long distance running, which comprises 800m up to marathon, sprinters competing in 60m up to 400m including all hurdle events, jumpers competing in pole vault, triple jump, long jump, or high jump, and throwers competing in shot put, hammer throw, discus, or javelin. The grouping of events was assembled according to GFIF's established event groups.

An initial 61 athletes enrolled in October of 2016, with additional enrollment of eligible athletes every six months until the final enrollment of athletes in October 2018. A total of 117 athletes enrolled during the project period as presented in Figure 1.

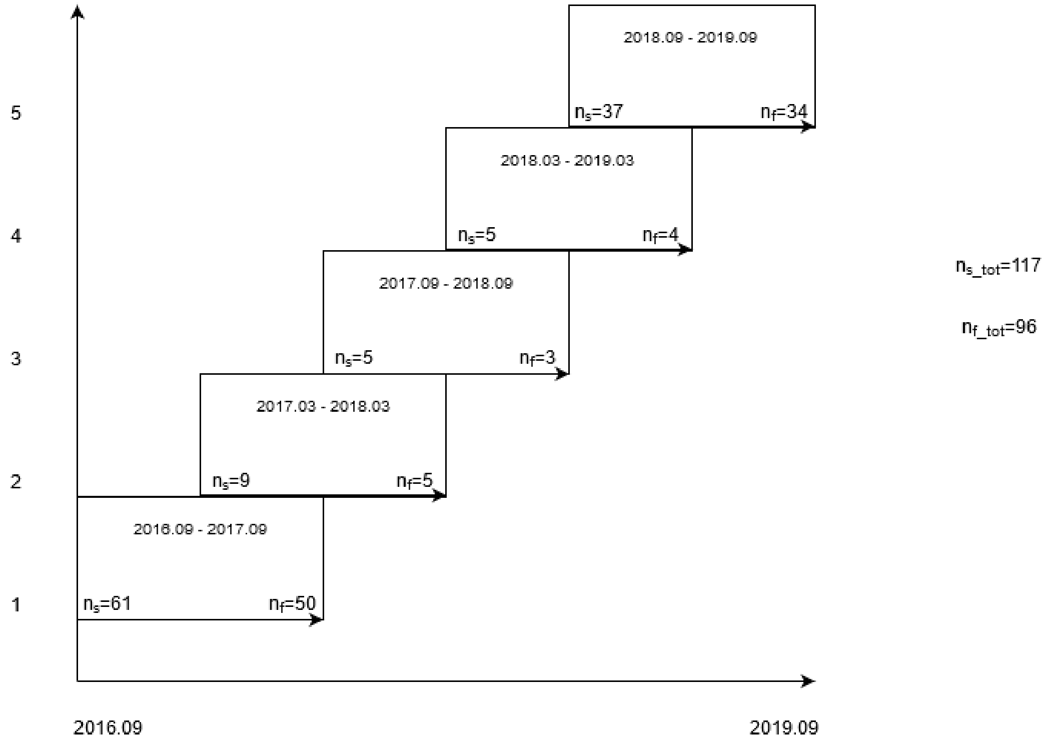


Figure 1. Enrollment of athletes between 2016 and 2019.

$n_f$ Final study population for respective test period, $n_{f\_tot}$ Final study population for the entire project, $n_s$ Number of screened athletes, $n_{s\_tot}$ Total number of screened athletes for the entire project.

## Data collection

Injury data and training data were collected prospectively over one full Swedish athletics season from the first of October until the end of August the following year, and consisted of 335 days for each respective athlete. Athletes were enrolled from October 2016 until October 2018, with the last athletes completing their season at the end of August 2019.

### Injury definition

Over the last decades, different injury definitions have been used in athletics research depending on the used study design.

The injury definition in the present thesis to identify OI was a modified definition of the consensus statement [8]:

> An injury was defined as any musculoskeletal pain felt during athletics training or competition that inflicted a non-voluntary reduction of or complete stop from athletics training for at least 24h, and was diagnosed by a trained medical professional, e.g. a physiotherapist and/or sports physician [83].

The used injury definition was modified in comparison with the injury definition stated in the consensus statement. Modifications were made with regard to an injury's impact on future training and competition (injuries had to affect training or competition) and how injuries were recorded (injury reporting by a medical professional instead of self-reporting of the athletes) [8]. The modifications were made because the effect of injuries on training or competition is an important aspect for elite athletes. Furthermore, the addition of medical professionals was imperative to be able to ascertain the injury data, and to avoid bias from self-reported injury data as seen in previous studies [78-81].

**Injury data**

Injury data was collected during one Swedish athletics season for each athlete using three different methods. The first and central method was that, at enrollment, all athletes were asked (and given contact information) to contact the project leader if they had any pain that caused them to change training content or miss a training session. The project leader then scheduled an immediate physical examination for the afflicted athlete with one of the two medical professionals working with the project. The second method was that all athletes were given access to a mobile phone application at enrollment, with which they could submit information regarding their health status; if they had trained normally or if they had felt any pain while training which had caused them to change training content (Appendix A1). This information was submitted daily by the athletes through the application. If there were any discrepancies, the project leader contacted the athlete to make sure no pain or injury was making them change training content or miss training sessions. The third and last method was that athletes could make a note in their training documentation if they had changed or missed any training sessions. The project leader checked the participating athletes' training documentation on a daily basis to see if any notes of pain or injury had been added and that no information was missing. If any of the three methods showed that an athlete had experienced pain, changed training content, or missed a scheduled training session, the athlete was scheduled for an immediate physical examination.

Using these three methods made it possible to perform an ongoing validation of the injury data that was collected during the project, and to ensure that all injury data that was added to the dataset was correct and not entered multiple times.

### Injury diagnosis

A diagnosis of each injury was made by either the project's physiotherapist or medical doctor. Athletes who reported pain that made them change training content or miss a training session were immediately referred to the project's medical professionals. During the physical examination, one of the medical professionals established a clear diagnosis of the injury using an injury report form (Appendix A2). If needed, the medical doctor could give the athletes a referral to the local hospital where he was employed so that the athlete could make an appointment for additional imaging procedures e.g. MRI or CT scan.

Injury data collected by an external medical professional (not financed or employed by the project) was collected using one of three methods: The information was collected electronically by e-mail from the medical professional who treated the athlete, the project leader met with the medical professional to collect the information in person, or the information was forwarded by the athlete's coach as was agreed upon with the athletes at enrollment [84].

### Injury location

All recorded injuries were divided into one of four different anatomical locations: foot/shank, knee, thigh/hip, and other injuries covering for example the upper body [83].

The categorization of injuries was decided upon during the physical examination by the medical professional who treated the afflicted athlete.

### Injury onset

The categorization of injury onset was based on the categorization that was included in the consensus statement on data collection procedures for epidemiological studies in athletics that was published in 2014 [8]. All injuries were categorized into sudden onset injuries caused by overuse (e.g. hamstring strain) or gradual onset injuries caused by overuse (e.g. tendinosis). Traumatic (acute) injuries (e.g. a fall during sprint) and recurrent injuries were diagnosed and recorded by the medical professionals, but not included in the data analysis [8].
The two medical professionals involved in the project were responsible for categorizing the injury onset of all injuries.

### Injury severity

Time-loss in days from training and competition was used to quantify the severity of injuries sustained by the participating athletes.
Injury severity was divided into four categories: minor (1–7 days), moderately serious (8–28 days), serious (>28 days-6 months), and long-term (>6 months) [8]. Quantification of time-loss was stopped when the injured athlete returned to full athletics training according to the training documentation that was submitted on a monthly basis. A clear definition of recovery is imperative to record injury severity accurately [85]. Injury severity was recorded by the project leader.

### Injury occurrence and athlete availability

Together with the elite coaches, based on their experience, it was decided that the Swedish athletics season should be divided into four phases to evaluate when most OI occur: conditioning phase one (October through December), indoor competition (January through February), conditioning phase two (March through May), and outdoor competition (June through August) [84]. The conditioning phases are when athletes complete most of their basic training, consisting of high volume and intensity. This training is designed and structured to prepare the athletes for the competition phases of the season. All recorded injuries were assigned to one of the phases depending on the month in which they occurred. It was also decided that this information would be used to calculate athlete availability, which is a measure of an athlete's ability to partake in training and competition during the season, for the cohort and for sex and event group [15].

### Training documentation

The training documentation used for this thesis was created together with the elite coaches from the participating event groups connected to GFIF. During the spring of 2016, several meetings were held at Friidrottens Hus in Gothenburg with coaches from the four different event groups to discuss the content and implementation of the training documentation. Pilot testing was conducted with a select few athletes during the spring and summer to ensure that the training documentation was correct (e.g. no content was missing) and easy to interpret and fill out. The training documentation was divided into categories of different types of training, such as strength training (weight training and bodyweight training), technical training, aerobic and anaerobic training. Additional information was included such as what surface the athletes trained on, type of shoes they used, and number of training sessions per day. The different categories of training were color coded to simplify the process for the athletes filling them out (Appendix A3).

## Baseline screening

At enrollment, all athletes performed a baseline screening test at the Center for Health and Performance (CHP) in Gothenburg, Sweden. The baseline screening consisted of a clinical examination, running analysis, and isometric strength tests and took approximately 90 minutes per athlete.

A decision was made together with the elite coaches on which event groups would partake in which screening tests. Eventually, all athletes conducted the clinical examination (with a minor modification for throwers) and isometric strength tests, while the running analysis was performed by middle/long distance runners, sprinters, long jumpers, and triple jumpers as seen in Table 2.

Table 2. Overview of baseline screening tests according to event group.

| | Triple jump / Long jump | High jump | Pole vault | M/L | Sprint | Throw |
|---|---|---|---|---|---|---|
| Clinical examination | X | X | X | X | X | X |
| Running analysis | X | | | X | X | |
| Strength tests | X | X | X | X | X | X |

*M/L Middle/long distance runners.*

## Clinical examination

The clinical examination consisted of measurements of passive ROM and muscle flexibility, and was performed according to the neutral-zero-method by the project's experienced physiotherapist [86].
An inertial goniometer, which is comprised of an accelerometer, gyroscope, and magnetic field sensor, was used in conjunction with the software program Mobee Fit and Mobee Med (SportMed A.G. SA, Bitburg, Germany) [87]. For passive ROM, athletes were placed in a supine position to test hip abduction, hip adduction, hip internal rotation, hip external rotation, ankle dorsiflexion, ankle plantarflexion, shoulder flexion, shoulder extension, shoulder external rotation, shoulder internal rotation, elbow flexion, and elbow extension. Hip flexion, hip extension, knee flexion, and knee extension were performed with athletes in a lateral recumbent position. Rotation of the thoracic/lumbar spine was performed in a sitting position.
For muscle flexibility, athletes were placed in a supine position for the hamstring and iliopsoas test, and in a prone position to test the rectus femoris. Each athlete performed three trials of each measurement with the maximum angular value recorded by the physiotherapist. All measurements were given in the unit of degrees.
The throwers were the only athletes who performed the upper body measurements.

## Running analysis

Three-dimensional kinematics were used to conduct a running analysis. Athletes were given time to familiarize themselves with the laboratory setting and to perform short trial runs on the treadmill. A majority of the athletes had experience running on a treadmill prior to the screening test. Each athlete was fitted with thirty-two retroreflective spherical markers (passive markers) according to International Sports Biomechanics (ISB) guidelines [88, 89]. All measurements were conducted using the QTM software with the Qualisys 3D motion capture system (Qualisys AB, Gothenburg, Sweden) at a sampling frequency of 400 Hz. The system was set up with sixteen infrared light cameras to identify the retroreflective markers that were worn by the athletes. Each athlete began in a neutral standing position that was recorded before the athlete began to run on the treadmill. All athletes ran on the treadmill (Rodby, RL 2500E x 700) at a controlled running speed of 18km/h in the same model of standardized neutral running shoes. Each recorded capture lasted 30 seconds, however all athletes ran for longer intervals to ensure that they could find their natural running style and rhythm on the treadmill before any data was recorded. The following movement variables were evaluated during stance: hip adduction range of motion, initial knee flexion angle, knee flexion range of motion, knee flexion velocity, ankle eversion range of motion, ankle eversion velocity, and initial ankle flexion angle.

All motions of the hip, knee, and ankle joints were calculated relative to the neutral standing position. Averages from ten consecutive strides were calculated using a script (MATLAB ver. R2019b).

The running analysis was performed by middle/long distance runners, sprinters, long jumpers, and triple jumpers. The project leader was the sole test leader for all running analyses.

### Isometric strength tests

Isometric strength devices (David Health Solutions Ltd., Helsinki, Finland) were used to measure strength for the trunk and the lower extremity muscles, as they have previously shown good validity [90]. All measurements were performed using a standardized test protocol (Appendix A4). Each athlete completed a warm-up consisting of dynamic exercises followed by isometric sub-maximal contractions.

Each trial had a time limit of five seconds for the athletes to reach their maximal torque through a MVC. Every athlete was allowed two trials for each measurement, and a third if the difference exceeded 10% between the first and second trial. The highest value was noted by the test leader.

Vocal encouragement was used by the test leader to ensure that the athletes reached their maximal strength potential.
The following maximal isometric strength measurements were tested: trunk extension (30°), trunk flexion (0°), trunk rotation (±30°), hip abduction (15°), hip adduction (15°), knee extension (60°), and knee flexion (30°).
Strength balance ratios were calculated for trunk flexion:extension, trunk rotation right:left, hip abduction:adduction, knee extension left:right, knee flexion left:right, and knee flexion:extension.

## Statistical analyses

### Paper II

All participating athletes were divided according to the four different event groups: middle/long distance running, sprinting, jumping, and throwing. Injury incidence proportion, injury severity, and injury location data were analyzed using descriptive statistics for the eleven-month study period. Incidence proportion, expressed in percentage, was calculated by dividing the number of athletes with new injuries by the total number of participating athletes. Mean and standard deviation were used to display the study population. Confidence interval (95% CI) was calculated for the overall incidence proportion, as well as for the respective event group, except for throwers due to the low sample size (n=3).
All data were analyzed using SPSS Statistics (version 25, IBM Inc).

### Paper III

Participating athletes belonged to one of three event groups: middle/long distance running, sprinting, or jumping. The overall study population was presented descriptively with mean values and standard deviation for age, height, weight, BMI, and weekly training hours. The total and average monthly training sessions of injuries during an athletics season were presented with standard deviation for the average number of training sessions per event group, and with 95% confidence intervals for athlete availability and incidence rate.
To be able to calculate the monthly incidence rates, it was necessary to define what constitutes an exposed athlete. The definition from Timpka

et al. (2014) and Knowles et al. (2006) was used where an exposed athlete was defined as an athlete that was injury-free and could participate in training or competition without restrictions [8, 91].

First, a quantification of the exact number of exposed athletes for each month had to be made. Athletes with carry-over injuries from the last month into the next month (e.g. 10 days) had to be determined, as they were then also exposed athletes in the following month but not for the whole month. Therefore, the number of injury days in the following month for athletes with carry-over injuries was divided by the number of days for that month (=number of unexposed athletes per month and event group). This value was then subtracted from the total number of athletes for each event group (=number of exposed athletes). The number of new injuries for each month and event group was then divided by the number of exposed athletes per event group to estimate the monthly incidence rates in percentage (%). An exception was made for the first month at the beginning of the project (October), as there were no carry-over injury days from September, since all athletes had to be injury-free at enrollment. For the month of October, the number of new injuries was divided by the number of exposed athletes per event group [84].

A two-step procedure was used to calculate athlete availability: In the first step, the total number of healthy days for each athlete was converted to healthy weeks (seven days were one week). In a second step, one hundred was divided by the length of the study (47.5 weeks) and then multiplied by the number of healthy weeks for each individual athlete (athlete availability in %). Athlete availability was calculated for each athlete individually, as well as for the overall cohort, between sex, and event groups. This was a modification of previous models that have been used to determine incidence and severity [15, 92].

The incidence rate per 1000 athletic-hours of training was calculated by dividing the number of injuries per athlete by the yearly hours of athletics training, and then multiplying by 1000 [93].

All data were analyzed using SPSS Statistics (version 25, IBM Inc).

## Paper IV

Rank-Biserial Correlation effect sizes with accompanying 95% confidence intervals were calculated according to previous recommendations [94]. To

interpret the effect sizes, the recommendations from McGrath et al. (2006) were followed using three categories: small ($r$ = .10), medium ($r$ = .24), and large ($r$ = .37) [95]. A two-step analysis was conducted. In the first step, the differences in all study variables between injured and non-injured athletes (without any specification of injury location) were investigated by conducting the Mann Whitney U-test. Study variables with at least a small effect size ($r$ = .10) were selected for further analysis. Even though only one side (left or right) showed an effect size, both sides for the same variable were selected for further analysis. In a second step, differences were examined between injured and non-injured athletes with regard to specific injury locations. For the Mann Whitney U-test, a $p$-value <.05 was considered to indicate statistically significant results. Only differences for thigh/hip and foot/shank OI were investigated due to the low number of OI for the upper-body and knee.
All data was analyzed using JASP Statistics (JASP Version 0.14).

## Ethical considerations

This thesis follows the Swedish published guidelines for ethical research that include rules and recommendations to protect participants from harm and preserve individuals' privacy [96]. As the athletes were recruited from a specific region it could be argued that it is easier to identify specific individuals. However, the results from the different papers are presented at group level for the full cohort or for the different event groups, and not on an individual level. Furthermore, enrollment was conducted over a three-year period, making it impossible to identify individuals.
Prior to enrollment, athletes were sent an information booklet explaining the project and baseline test screening in detail. At any given time during their participation, athletes could contact the project leader and end their participation without having to state a reason for doing so. At enrollment, all athletes were given a personal coded identification number to ensure their anonymity. All athletes provided written informed consent prior to their participation and screening (Appendix A5). All personal information, including personal identification numbers and data, is stored on an internal server with limited access for the duration of the project. The project was approved by the Regional Ethical Committee in Gothenburg (dnr. 2016/723–16).

# Results

Table 3. Overview of the study populations for each paper.

| | **Paper II** | **Paper III** | **Paper IV** |
|---|---|---|---|
| | Overall (n=58) | Overall (n=59) | Overall (n=96) |
| **Age (years)** | 21.7 (2.9) | 21.6 (2.8) | 19.9 (3.3) |
| **Height (m)** | 1.77 (0.1) | 1.77 (0.08) | 1.78 (0.1) |
| **Weight (kg)** | 68.2 (10.1) | 67.2 (9.3) | 68.2 (10.4) |
| **BMI (kg/m$^2$)** | 21.5 (1.9) | 21.2 (1.7) | 21.5 (2.2) |
| **Male (n)** | 28 | 29 | 52 |
| **Female (n)** | 30 | 30 | 44 |
| **M/L (n)** | 23 | 23 | 33 |
| **Sprint (n)** | 23 | 23 | 30 |
| **Jump (n)** | 9 | 13 | 27 |
| **Throw (n)** | 3 | 0 | 6 |

*Mean values for age, height, weight, and BMI. Standard deviation in parentheses. M/L Middle/long distance runners, n number.*

## Paper II

The incidence proportion was 72.4% (95% CI: 61%, 84%), with a total of 71 recorded injuries over one Swedish athletics season. Among the four event groups, middle/long distance runners had the highest incidence proportion at 87%. Most injuries were severe, with 38% of all injuries being moderately serious (time-loss of 8-28 days), and 36.6% serious (time-loss of >28 days-6 months) (Table 4). No clear differences were seen between the event groups. Of the recorded injuries, 64.8% were classified as having a gradual onset caused by overuse and 35.2% were classified as having a sudden onset caused by overuse.

Table 4. Incidence proportion and injury severity.

| Incidence proportion (%) | Female | Male | All | |
|---|---|---|---|---|
| All events (n=58) | 70.0 | 75.0 | 72.4 | |
| M/L (n=23) | 84.6 | 90.0 | 87.0 | |
| Sprint (n=23) | 71.4 | 56.3 | 61.0 | |
| Jumping (n=9) | 62.5 | 100 | 66.6 | |
| Throwing (n=3) | 50.0 | 100 | 66.6 | |
| **Injury severity (%)** | **1-7 days** | **8-28 days** | **28 days to 6 months** | **>6 months** |
| All events (n=71) | 8.5 | 38 | 36.6 | 16.9 |
| M/L (n=33) | 12.1 | 39.4 | 27.3 | 21.2 |
| Sprint (n=24) | 0 | 50 | 45.8 | 4.2 |
| Jumping (n=11) | 9.1 | 18.2 | 45.5 | 27.3 |
| Throwing (n=3) | 33.3 | 0 | 33.3 | 33.3 |

*Overall incidence proportion (top) and injury severity (bottom) in % per event group. M/L Middle/long distance runners. Modified table from Lundberg Zachrisson et al. (2020) [97].*

The most common injury location for the cohort was the thigh/hip followed by the foot/shank. The most common injury was at the hamstring followed by the Achilles tendon (Table 5).

Table 5. Specific injury locations for the four injury groups.

| Foot/shank (n=27) | | Thigh/hip (n=29) | | Knee (n=7) | | Other (n=8) | |
|---|---|---|---|---|---|---|---|
| AT | 8 | Hamstring | 16 | Pop. F. | 2 | LS | 7 |
| Calf | 7 | Quadriceps | 7 | Meniscus | 2 | TS | 1 |
| Metatarsals | 5 | Adductor | 3 | PTI | 2 | | |
| Peroneus | 3 | Iliopsoas | 1 | ITBI | 1 | | |
| PF | 2 | ITB | 1 | | | | |
| Shin | 1 | Hip joint | 1 | | | | |
| Tib. P. | 1 | | | | | | |

*AT Achilles tendon, PF Plantar fascia, Tib. P. Tibialis Posterior, ITB Iliotibial band, Pop. F. Popliteal Fossa, PTI Patella tendon insertion, ITBI Iliotibial band insertion, LS Lumbar Spine, TS Thoracic Spine.*

## Paper III

The cohort of athletes (n=59) conducted the highest number of training sessions in October with 1719 sessions, followed by April with 1687 sessions. Middle/long distance runners had the highest average number of training sessions among the event groups over a full athletics season. For the overall cohort, most injuries occurred in the first month of the season, October (13). Middle/long distance runners suffered most injuries in October (6), sprinters in October (4), December (4), and April (4), and jumpers in October (3) and December (3). Overall, most training sessions and injuries occurred in the first conditioning phase that runs from October through December [84].

The incidence rate was 1.81 injuries per 1000 athletics hours of training. Middle/long distance runners had the highest incidence rate (2.38).

The overall athlete availability was 78.0% for the whole cohort of athletes. Sprinters had the lowest athlete availability (71.4%), followed by jumpers (77.3%), and middle/long distance runners (82.7%). Female athletes (76.5%) had a lower athlete availability than male athletes (79.7%). There was a large individual variability of athlete availability throughout the season in all event groups, as seen in Figure 2.

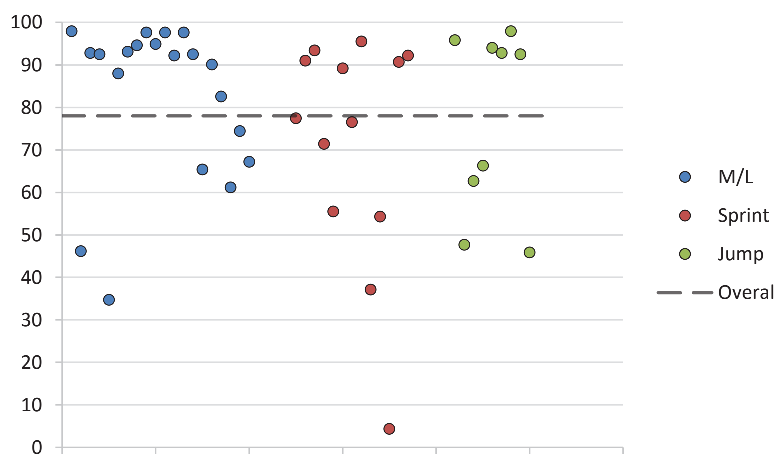


Figure 2. Distribution of athlete availability (%) at an individual level and for the overall cohort.

*M/L* Middle/long distance runners. Modified figure from Zachrisson et al. (2020) [84].

The overall incidence rate for all athletes was highest in October, at 22.0%, and lowest in November and July. The injury incidence rate according to event group was highest for middle/long distance runners in October, at 26.1%, for sprinters in April, at 19.0%, and for jumpers in October, at 21.4%, as seen in Figure 3 [84].

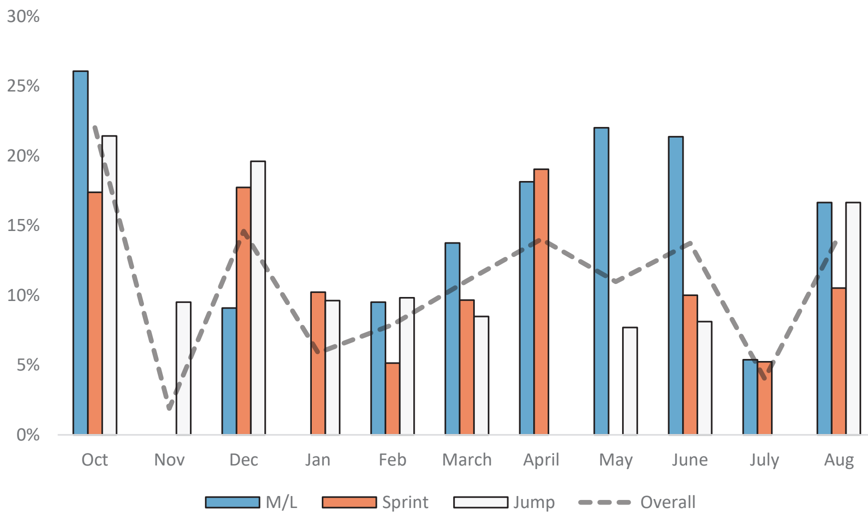


Figure 3. Overall and event-specific monthly injury incidence rate (%).

*M/L* Middle/long distance runners. Also published in Zachrisson et al. (2020) [84].

Middle/long distance runners conducted most training sessions in January. Sprinters conducted most of their training sessions in October, and Jumpers conducted most of their training sessions in December (Figure 4-6). The number of training sessions for the different event groups generally did not vary much during the season and does not seem to have a direct association to the injury incidence rate.

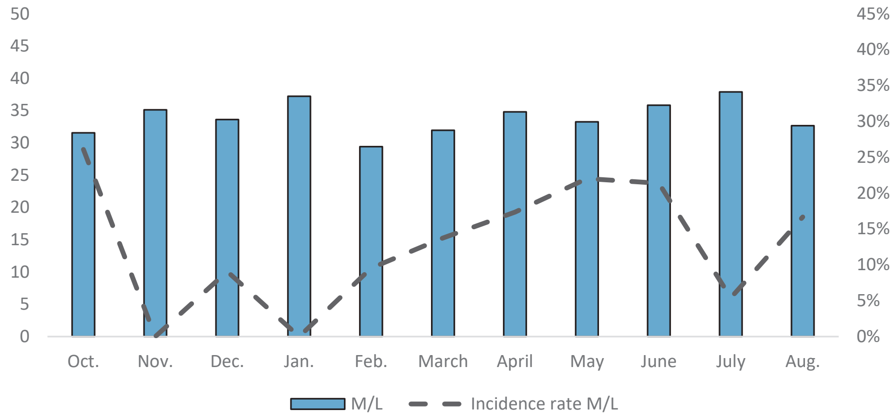


Figure 4. Monthly average number of training sessions (y-axis, left) and monthly injury incidence (%) (y-axis, right).

*M/L* Middle/long distance runners. Also published in Zachrisson et al. (2020) [84].

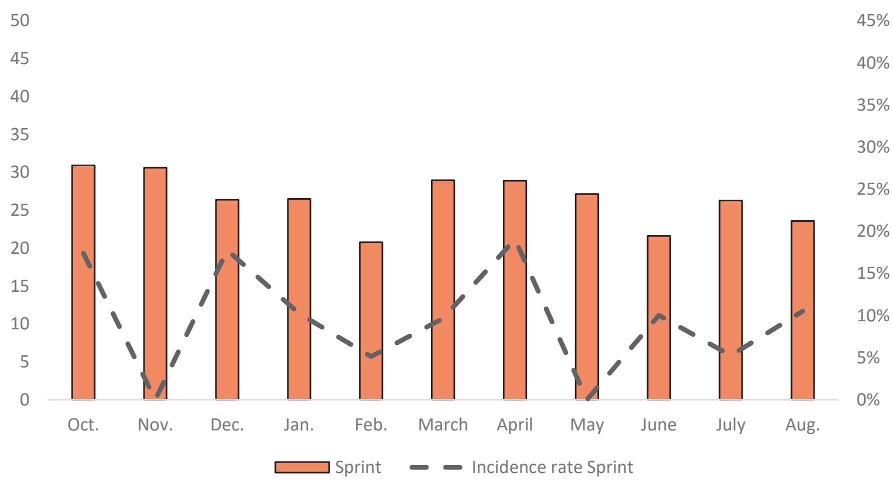


Figure 5. Monthly average number of training sessions (y-axis, left) and monthly injury incidence (%) (y-axis, right).

Also published in Zachrisson et al. (2020) [84].

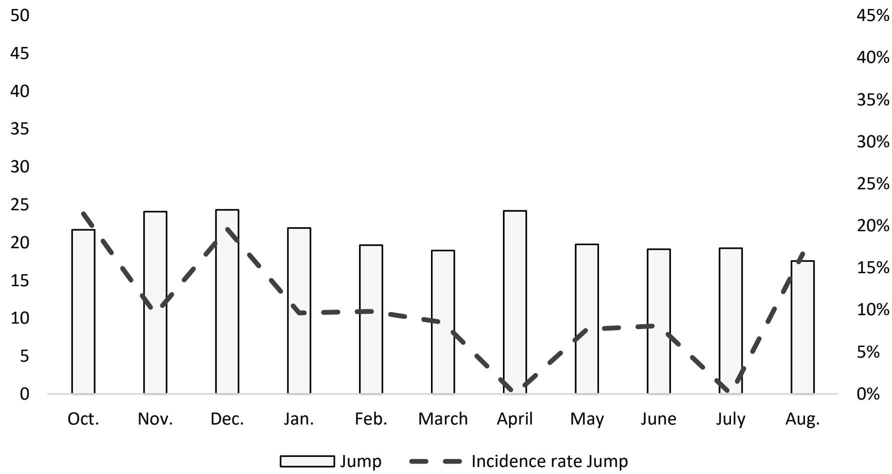


Figure 6. Monthly average number of training sessions (y-axis, left) and monthly injury incidence (%) (y-axis, right).

Also published in Zachrisson et al. (2020) [84].

## Paper IV

Most OI were found at the foot/shank, with OI at the thigh/hip being the second most common location. A small number of upper-body and knee OI were also registered during the study period, however they were not included for analysis. As not all athletes performed all tests, a different number of participants were included for each screening procedure, as seen in Figure 7.

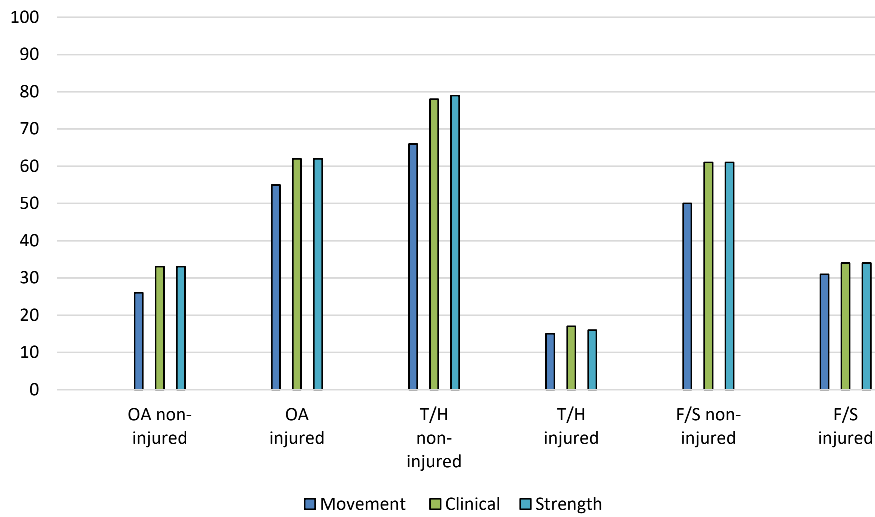


Figure 7. Number of injured and non-injured athletes for the three screening tests.

OA Overall, T/H Thigh/hip, F/S Foot/shank.

Small effect sizes were seen for certain biomechanical and clinical variables in the first analyses looking at potential differences between injured athletes (regardless of injury location) and non-injured athletes. The following variables were chosen for further analysis based on their Rank-Biserial Correlation: hip adduction range of motion, knee flexion velocity, ankle eversion, ankle eversion velocity, rectus femoris flexibility, iliopsoas flexibility, hip abduction:hip adduction strength ratio, and hamstring:quadriceps strength ratio.

When comparing thigh/hip injured athletes to thigh/hip non-injured athletes, larger effect sizes were seen for knee flexion velocity for both the left and right sides. Further, larger effect sizes were seen for hip adduction range of motion (both sides) and iliopsoas flexibility (both sides), but these variables were considered not to be practically relevant due to the small differences between injured and non-injured athletes. Knee flexion velocity for the right side increased from no effect size to a medium effect size, while knee flexion velocity for the left side increased from a small to a large effect size (Table 6). Reduced effect sizes were seen for all variables when comparing the foot/shank injured athletes to the non-foot/shank injured athletes. A few exceptions were seen; the hamstring:quadriceps strength ratio for the right side, ankle eversion for the left side, and ankle eversion velocity for both sides. However, these increases in effect size were negligible and not statistically significant (Table 6).

Table 6. Movement, clinical and strength variables in injured and non-injured athletes.

| | | T/H INJ. vs T/H NON-INJ. | | F/S INJ. vs F/S NON-INJ. | |
|---|---|---|---|---|---|
| | | *p* | *r* | *p* | *r* |
| **Movement** | **$HAD_{ROM\_R}$ [°]** | .16 | .24 | .60 | -.07 |
| | **$HAD_{ROM\_L}$ [°]** | .13 | .25 | .54 | -.08 |
| | **$KF_{VEL\_R}$ [°/s]** | .08 | .29 | .84 | -.03 |
| | **$KF_{VEL\_L}$ [°/s]** | .03* | .37 | .91 | -.02 |
| | **$AEV_{\_R}$ [°]** | .70 | -.07 | .74 | .05 |
| | **$AEV_{\_L}$ [°]** | .53 | -.11 | .38 | .12 |
| | **$AEV_{VEL\_R}$ [°/s]** | .88 | -.03 | .45 | .10 |
| | **$AEV_{VEL\_L}$ [°/s]** | .64 | -.08 | .30 | .14 |
| **Clinical** | **$RF_{FLEX\_R}$ [°]** | .30 | .16 | .63 | -.06 |
| | **$RF_{FLEX\_L}$ [°]** | .82 | .04 | .81 | -.03 |
| | **$IL_{FLEX\_R}$ [°]** | .17 | -.21 | .78 | .04 |
| | **$IL_{FLEX\_L}$ [°]** | .15 | -.23 | .68 | -.05 |
| **Strength** | **HAB:HAD [Nm/kg]** | .25 | .15 | .39 | .11 |
| | **$H:Q_{\_R}$ [Nm/kg]** | .62 | .08 | .39 | -.11 |
| | **$H:Q_{\_L}$ [Nm/kg]** | .84 | .03 | .60 | -.07 |

*$HAD_{ROM}$ Hip adduction range of motion, $KF_{VEL}$ Knee flexion velocity, AEV Ankle eversion, $AEV_{VEL}$ Ankle eversion velocity, $RF_{FLEX}$ Rectus femoris flexibility, $IL_{FLEX}$ Iliopsoas flexibility, HAB:HAD Hip abduction:adduction strength ratio, H:Q Hamstring:quadriceps strength ratio, T/H INJ Thigh/hip injured, T/H NON-INJ Thigh/hip non-injured, F/S INJ Foot/shank injured, F/S NON-INJ Foot/shank non-injured R Right side, L Left side, * indicates $p \leq 0.05$, r Rank-Biserial Correlation. Modified table from manuscript Zachrisson et al. (2021).*

Athletes with thigh/hip injuries had a slower knee flexion velocity, and lower HAB:HAD strength ratio than athletes without thigh/hip injuries (Table 7).

Table 7. Movement, clinical, and strength variables in athletes with thigh/hip injuries and athletes without thigh/hip injuries.

| | | Group | n | p | r | M | SD | 95% CI |
|---|---|---|---|---|---|---|---|---|
| **Movement** | **$HAD_{ROM\_R}$ [°]** | Inj | 15 | .16 | .24 | 4.68 | 2.38 | -.13-1.00 |
| | | No | 66 | | | 5.80 | 2.58 | |
| | **$HAD_{ROM\_L}$ [°]** | Inj | 15 | .13 | .25 | 4.19 | 2.01 | -.14-.99 |
| | | No | 66 | | | 5.21 | 2.44 | |
| | **$KF_{VEL\_R}$ [°/s]** | Inj | 15 | .08 | .29 | 257.82 | 41.53 | -.03-.55 |
| | | No | 66 | | | 360.59 | 161.28 | |
| | **$KF_{VEL\_L}$ [°/s]** | Inj | 15 | .03* | .37 | 266.14 | 42.50 | .15-1.29 |
| | | No | 66 | | | 367.97 | 152.16 | |
| | **$AEV_{\_R}$ [°]** | Inj | 15 | .70 | -.07 | 14.86 | 5.61 | -.37-.25 |
| | | No | 66 | | | 15.78 | 7.66 | |
| | **$AEV_{\_L}$ [°]** | Inj | 15 | .53 | -.11 | 15.24 | 5.06 | -.50-.62 |
| | | No | 66 | | | 15.67 | 7.51 | |
| | **$AEV_{VEL\_R}$ [°/s]** | Inj | 15 | .88 | -.03 | 245.12 | 88.32 | -.40-.73 |
| | | No | 66 | | | 266.10 | 133.35 | |
| | **$AEV_{VEL\_L}$ [°/s]** | Inj | 15 | .64 | -.08 | 250.26 | 84.70 | -.46-.66 |
| | | No | 66 | | | 262.72 | 134.95 | |
| **Clinical** | **$RF_{FLEX\_R}$ [°]** | Inj | 17 | .30 | .16 | 140.77 | 8.48 | -.53-.53 |
| | | No | 73 | | | 140.74 | 15.62 | |
| | **$RF_{FLEX\_L}$ [°]** | Inj | 17 | .82 | .04 | 148.94 | 5.80 | -.26-.33 |
| | | No | 73 | | | 149.25 | 10.11 | |
| | **$IL_{FLEX\_R}$ [°]** | Inj | 17 | .17 | -.21 | 108.77 | 11.46 | -.65-.40 |
| | | No | 78 | | | 107.40 | 10.66 | |
| | **$IL_{FLEX\_L}$ [°]** | Inj | 17 | .15 | -.23 | 111.25 | 8.61 | -.90-.16 |
| | | No | 78 | | | 110.65 | 8.65 | |
| **Strength** | **HAB:HAD [Nm/kg]** | Inj | 16 | .25 | .15 | 0.76 | 0.08 | -.23-.85 |
| | | No | 79 | | | 0.82 | 0.21 | |
| | **$H:Q_{\_R}$ [Nm/kg]** | Inj | 17 | .62 | .08 | 0.79 | 0.15 | -.22-.37 |
| | | No | 77 | | | 0.84 | 0.16 | |
| | **$H:Q_{\_L}$ [Nm/kg]** | Inj | 17 | .84 | .03 | 0.80 | 0.12 | -.27-.33 |
| | | No | 77 | | | 0.83 | 0.15 | |

*$HAD_{ROM}$ Hip adduction range of motion, $KF_{VEL}$ Knee flexion velocity, AEV Ankle eversion, $AEV_{VEL}$ Ankle eversion velocity, $RF_{FLEX}$ Rectus femoris flexibility, $IL_{FLEX}$ Iliopsoas flexibility, HAB:HAD Hip abduction:adduction strength ratio, H:Q Hamstring:quadriceps strength ratio, R Right side, L Left side, * indicates $p \leq 0.05$, r Rank-Biserial Correlation. Modified table from manuscript Zachrisson et al (2021).*

## Summary of results

A high injury incidence proportion (72.4%) was recorded in the cohort of elite Swedish athletics athletes.
The categorization of injury onset by medical professionals resulted in 64.8% of all injuries being categorized as injuries with a gradual onset caused by overuse and 35.2% of all injuries with a sudden onset caused by overuse. Most of the reported injuries during the study period were located at the lower extremities. The majority of injuries were located at the thigh/hip, followed by the foot/shank. Most injuries sustained by the cohort were severe, with 53.5% of injuries leading to a total or partial time-loss of at least 28 days from training and competition. Most injuries occurred in October, followed by December and April. This corresponds to the first conditioning phase of the season (October through December) and the second conditioning phase (April).

The overall athlete availability during the athletics season for the cohort was 78.0%, indicating that some athletes in the Gothenburg cohort may not reach their full performance capacity during the season. Only small differences were seen for athlete availability between event groups and sex.

Athletes with OI at the thigh/hip showed a slower knee flexion velocity compared with athletes not injured at the thigh/hip, which indicates impact cushioning via knee flexion is delayed. For several of the variables the relation to OI became stronger when grouped by injury location. There is a need for larger cohort sizes in prospective studies to further sub-divide athletes according to sex, event group, and specific injury diagnosis to further identify OI etiology.

# Discussion

First, the results will be discussed and put into context with previous research, followed by a discussion on methodological considerations.

## Injury incidence

The recorded overall incidence proportion of 72.4% in the Gothenburg cohort is higher than or similar to what has been previously published in athletics research. The high incidence proportion underlines that OI is a major issue in athletics. D'Souza reported an incidence of 61.2% from a sample with track and field athletes from many different clubs within the UK [14], while Bennell et al. (1996) reported an incidence rate of 76% for the Australian track and field athletes who were evaluated during the same period [5]. However, both of these studies used a retrospective study design to collect their data.

There are two Swedish studies that implemented a prospective study design: one is the study by Lysholm et al. from 1987, which reported an incidence of 65% for a running cohort over one year [13], and the more recent study by Jacobsson et al. from 2013 which reported an incidence proportion of 68% [6].

The differences in results between studies may be attributed to the different methods of collecting injury data. D'Souza (1994) and Jacobsson et al. (2013) used self-reporting by the athletes [6, 14], in the study by Bennell et al. (1996), 98% of all athletes consulted a medical professional [5], and in Lysholm et al. (1987), all athletes were examined by a medical professional [13]. Additionally, different injury definitions were used by the respective studies, further complicating comparisons. In the study by Lysholm et al. (1987), athletes were only examined if an injury hampered training or competition for at least one week [13], while D'Souza (1994) left it up to the participating athlete to subjectively interpret what an injury was. However, in D'Souza (1994), injuries were only recorded if they lasted one week or longer [14]. For the evaluation of incidence, Bennell et al. (1996) defined an injury as:

> Any musculoskeletal pain or injury which resulted from athletics training, and which was sufficient to cause alteration to normal training in any way (mode, duration, intensity, frequency) for a period of one week or more [5].

Jacobsson et al. (2013) used a similar definition as used for the present thesis, except that they did not use medical professionals to record injuries. An injury was defined as:

> Any new musculoskeletal pain, soreness, or injury that resulted from athletic training or competition and caused changes in normal training/competition to the mode, duration, intensity, or frequency from the current or subsequent training and/or competition sessions [6].

It was decided that injuries that occurred while participating in athletics, training, or competition were to be included [6].
Nevertheless, the incidence proportion recorded for the Gothenburg cohort could be even further underestimated, as the evaluation was based on OI only, whereas the other studies included all injuries (recurring and traumatic/acute). The incidence proportion in the Gothenburg cohort is similar compared to other sports in an elite context, such as football and field hockey [98, 99].
The incidence rate per 1000 hours of athletics training for the Gothenburg cohort was relatively low at 1.81 compared to previous studies that reported an incidence rate of 2.5 to 5.8 per 1000 hours of athletics training [5, 6, 13]. The lower incidence rate in the Gothenburg cohort might be due to the exclusion of injuries that were not considered to be OI; recurrent, or traumatic/acute. A lower incidence was also seen relative to sex in contrast to previous studies [5, 6].

## Injury location

In agreement with previous studies, the majority of injuries affected the lower extremities [5, 6, 13, 14, 48, 100]. Ninety percent of injuries recorded for the cohort were injuries to the lower extremities, which is more than what was previously reported by Jacobsson et al. (2013) for Swedish elite athletics athletes [6]. The main difference compared to previous studies is how injuries were categorized, as anatomical regions have been defined in different ways making direct comparisons difficult. The number of athletes in each event group influences the results as well, as for example throwers have been observed to sustain more upper-body injuries than other event groups [6, 14]. The number of foot, shank, knee, and lumbar injuries for the entire cohort was in agreement with the results reported by Jacobsson et al. (2013) [6]. However, our cohort reported fewer injuries in the category "other" and substantially more hip and thigh injuries.

Differences in injury location were observed between the event groups. In contrast to the study by Jacobsson et al (2013), in the Gothenburg cohort middle/long distance runners had fewer knee injuries and lumbar injuries. The sprinters in the Gothenburg cohort had more hip and thigh injuries, but the same number of foot, shank, and lumbar injuries, and fewer knee injuries. For the jumpers the Gothenburg cohort had more hip and thigh injuries, the same amount of knee injuries, more lumbar injuries, but substantially fewer foot and shank injuries.

## Injury severity

More than half of the injuries sustained by the athletes in the Gothenburg cohort led to a total or partial time-loss from training and/or competition of at least 28 days. This is an increase compared to what Jacobsson et al. (2013) reported for Swedish elite athletics athletes, although the same method was used by the athletes to report their return to full training [6]. These differences could possibly be explained by the studies' different inclusion criteria based on performance (national top six and national youth top three compared to national top ten). In the Australian cohort of Victorian track and field athletes, Bennell et al. (1996) reported that for each sustained injury, athletes were restricted to cross-training (swimming, cycling, or weights) for a period of 3.1 (±3.9) weeks and did not participate in full training until 9.0 (±8.5) weeks post-injury [5]. As no further information was given, it is difficult to interpret and compare this to the results from the present thesis or the results from Jacobsson et al. (2013).

Notably, the highest injury severity in the Gothenburg cohort was observed in the jumping events, which might be explained by event-specific training loads (e.g. high eccentric loads) [101, 102], and the middle/long distance events, which might be explained by the higher training volume [4, 103].

## Injury occurrence

Most OI occurred in autumn followed by early spring, which corresponds to the conditioning phases during the Swedish athletics season. This is contrary to what Jacobsson et al. (2013) observed, as most injuries occurred in the beginning of their study in April and continuously decreased until the study ended one year later [6]. One possible explanation for these differences could be the use of self-reporting of injuries by Jacobsson et al. (2013), as athletes may have over-reported injuries at the beginning of the study and then under-reported injuries towards the end of the study. The differences may also be due to athletes in the Gothenburg cohort increasing their training volume and/or intensity too quickly in the conditioning phases [66]. This was demonstrated by Gabbett et al. (2004), who found a correlation between reduction in pre-season training loads and fewer reported injuries in rugby [104]. The results of the Gothenburg cohort supports the findings of a retrospective analysis by D'Souza (1994), and a longitudinal study of cross country runners by Rauh et al. (2000) [14, 105].

The sprinters in the Gothenburg cohort sustained most injuries in October, December, and April, which contrasts Lysholm et al. (1987), who reported most injuries in March and July. As the athletes included in the study by Lysholm et al. (1987) were mostly top or average district sprinters compared to the Gothenburg cohort's elite status, it is possible that the elite cohort sustained more OI in preparation for the coming indoor competition season compared to the district level athletes [13]. A majority of the sprinters in the Gothenburg cohort travel to training camps in April, which may further influence the number of OI, as they might increase their training load during the training camps.

## Athlete availability

An Australian athletics study by Raysmith et al. (2016) found that athlete availability during the season was related to the performance of the athletes, as the likelihood of achieving a performance goal increased seven-fold in athletes that completed >80% of planned training weeks [15]. The overall athlete availability for the Gothenburg cohort was 78%, with the three event groups just under or over the threshold of 80%. In contrast to Raysmith et al. (2016), illnesses were not included for the Gothenburg cohort meaning that the athlete availability could be overestimated [15]. On an individual level, it seems that there is an uneven distribution among the participating athletes. This could indicate that many athletes were unable to reach their full performance potential during the observed season. This was especially evident for the sprinters and jumpers, where seven out of thirteen sprinters and four out of nine jumpers were below the threshold. The relatively low individual percentages of athlete availability could be explained by the high incidence proportion and the severity of the injuries sustained by the athletes. The same negative impact on performance seen in athletics due to low athlete availability has also been reported for football and basketball (availability of team members) [106].

## Risk factors

There is only a limited number of prospective studies focusing on biomechanical risk factors such as movement, clinical and strength variables in running cohorts. To date, only studies including recreational or cross-country runners have been published [107].

Examining running-related injuries in recreational to collegiate runners, moderate evidence was found that increased peak hip adduction may be important in the development of iliotibial band syndrome in female recreational runners [108, 109]. Because peak hip adduction was not measured in the Gothenburg cohort, but hip adduction ROM was, it is not possible to compare our results to these findings. However, only small effect sizes could be seen for hip adduction ROM in the Gothenburg cohort. The lower HAB:HAD strength ratio in the thigh/hip injured group would indicate that the hip abductors were weaker compared to the hip adductors. This is in accordance with previous studies, in which weak hip abductors were discussed as a risk factor in the development of running-related injuries, especially for hip injuries [44, 110].

Limited evidence was found in a mixed-sex cohort of recreational runners that peak knee flexion is not an important factor in the development of running-related injury [46]. There was very limited evidence that peak knee flexion is reduced in male and female recreational runners who develop Achilles tendinopathy [45]. In the Gothenburg cohort, a statistically significant association between knee flexion velocity and athletes with thigh/hip injuries compared to athletes without thigh/hip injuries was found. Unfortunately, there are currently no prospective studies in athletics that have investigated knee flexion velocity.

The association between movement variables, such as ankle eversion and the risk of sustaining a running-related injury, has been described as inconsistent in previous literature, as it has been argued that this is dependent on the study population and type of injury being studied [111, 112]. The most commonly investigated variable is ankle/rearfoot eversion. In two prospective studies with collegiate cross-country runners, moderate evidence was found that peak eversion is not an important factor in the development of running-related injury [113, 114]. Moderate evidence was also found that decreased peak eversion is an important factor in the development of iliotibial band syndrome and patellofemoral pain syndrome in recreational female runners [108, 109]. Due to the small sample size in the Gothenburg cohort, it was not possible to sub-divide injuries further than the previously established more general injury location categories, and only small to no effect sizes were found for ankle eversion and ankle eversion velocity.

## Methodological considerations

### Study population

In the present thesis, the definition of the term *elite* was decided on together with the coaches. Elite was considered something connected to performance level, and it was decided that a top three placement in the youth national indoor or outdoor championships or a top six placement in the senior national indoor or outdoor championships would be considered as performing on an elite level. This is debatable, as the youth national championships consist of events with very few athletes competing and a top three placement might not be considered to fulfill the definition of elite compared to Jacobsson et al. (2013), for example, who defined elite as being ranked in the top ten for senior athletes of their respective events [6]. For the Gothenburg cohort, a majority of the athletes that placed in the top three in the youth national championships were also competing for the national team and/or also competed at the senior national championships and placed in the top six (or at least the top ten). Compared to Jacobsson et al. (2013), who used the Swedish ranking lists for recruitment, the compilation of eligible athletes from GFIF made sure that as many athletes as possible had the chance to participate.

In general, the small sample size made it difficult to conduct more specific risk factor evaluations. From a methodological standpoint, it was impossible to sub-divide athletes according to sex and/or specific event group, and the injury locations used only allowed a rough grouping of injury location. Injury location should be recorded for each diagnosis separately, as done in other prospective studies on different specific running-related injuries [45, 108].

Theoretically, the sample size would have been larger if every athlete that matched the inclusion criteria had participated in the project. The first list drafted by GFIF of eligible athletes in 2015 consisted of 105 athletes. If all athletes that matched the inclusion criteria the following years had also enrolled, the sample size would have doubled.

Elite athletes outside the Gothenburg region were not included due to the logistics of the baseline screening, and because the medical professionals were located in Gothenburg. The small sample size was due to dropouts, athletes moving abroad, athletes not interested in participating, and athletes who were ending their elite career. There were also advantages to the geographical recruitment, as it made sure that all athletes had the same access to the medical professionals.

A small sample of athletes enrolled mid-season (as seen in Figure 1). However, all athletes completed the same number of months in the project, between the first of October and end of August, as that constitutes a complete Swedish athletics season.

## Training documentation

To ensure good compliance with the training documentation, event-specific training documentation sheets were developed by the head coach of each event group together with the project leader, and approved by the other coaches. The intention was to see if event-specific training content together with the intensity of training could be associated with the development of OI in elite athletics, as has been observed in other elite contexts [115]. Further, efforts were made to make it simple and quick to fill out the documentation sheets, as quantifying training load is a challenging task [116-118]. Nevertheless, compliance in documenting the training contents was poor. One possibility for this is that it may not have been clearly communicated whether the athlete or the coach should fill out the training documentation, or the coach did not communicate this to the athlete to fill it out. It is also possible that the coaches did not want to complete the training documentation, as it might have been possible to associate their training content with an athlete's injury. A majority of the coaches are not employed on a full-time basis, and only have annual contracts with a fixed salary, which might have influenced their compliance, as they might have thought it could affect their job status. The coaches that were involved at the beginning of the project did not coach all athletes that were enrolled into the project after the first enrollment. This means that their coaching and training documentation might have differed from the documentation that was developed at the beginning of the project and used throughout the project period. The inability of the athletes to correctly fill out the training documentation meant that very little event-specific training information was collected, and a low response rate in a study can influence the precision of the results [119].

**Injury data**

Even though every effort was made, not all injuries could be recorded by the project's two medical professionals. This happened for example when the athletes sustained an injury while training or competing abroad, leading to a possible lower inter-rater reliability [93]. A limited number of injuries were recorded by the athletics clubs' medical staff or the national team's medical staff and reported to the respective athletes' coaches (n=8). Although this injury data was not reported directly to the project leader by the medical staff, it can be expected that this data was correct, as both the coaches and the club's medical staff have years of experience. Most previous studies in athletics have used self-reporting of injuries by the athletes, which has been proven to be complicated for the athletes to accurately submit.
It is possible that the lowest severity level of OI (one to seven days) was not recorded. The athletes might not have reported short-term injuries to the project leader, entered the information into the mobile phone application, or noted it in the training documentation, resulting in injuries not being diagnosed by the medical professionals, and thus not added to the dataset. This problem of missing short-term OI was highlighted previously by Clarsen et al. (2013, 2014) [64, 120]. As three methods were used to collect injury data, it is unlikely that many injuries were not recorded. The project's medical professionals were very experienced, however it is possible for example that a traumatic onset hamstring strain was considered a traumatic injury and not recorded as an OI. If this was the case, the incidence proportion for the cohort would increase even more. A further underestimation of the number of injuries could have been made, as injuries were only recorded during the active athletics season (October through August

the following year). However, this is unlikely, as the majority of athletes in Sweden generally rest in September. A further underestimation of OI is possible, as OI are generally clinically diagnosed (as in this thesis), and a stress fracture can remain undiagnosed for several weeks if the athlete only undergoes further examinations when symptoms persist [121].

## Baseline screening

At the baseline screening, all athletes ran at the same speed of 18km/h, despite sprinters and jumpers running at faster speeds when competing. The first reason for choosing 18km/h was that all event groups would be able to run in a controlled manner to better replicate their natural running style. The second reason was that the sample size would have been even smaller in the different event groups if the groups had run at different speeds, making any comparisons impossible.

Isometric strength tests were chosen over dynamic isokinetic tests for the different strength variables. Performing isokinetic tests is time-consuming. Therefore, the more time-efficient isometric devices were favored instead. Additionally, isometric strength testing has also been used in previous injury sports research focused on runners [122].

Athletes conducted a body composition scan, a low dose radiological scan, and Dual-energy X-ray absorptiometry (Lunar iDXA, GE Healthcare, USA) at baseline. This information was originally included in the published study protocol [83], but the results are not included in the present thesis. Due to the small sample size (as athletes under the age of 18 did not conduct a body composition scan), it was instead decided to use the data in a methodological paper. As the overall theme of the present thesis centers on overuse injuries, a decision was made to exclude this paper from the thesis.

## Perspectives of sports injury research

Bertelsen et al. (2017) suggest four categories to improve training documentation for running-based studies: the structure-specific capacity when entering a running session, the structure-specific cumulative load per running session, reduction in the structure-specific capacity during a running session, and exceeding the structure-specific capacity [58]. The event-specific training documentation in the present thesis was designed with the coaches to capture this, but due to poor compliance this was not possible.

This thesis followed the first two recommendations of van Mechelen et al. (1992) and Finch (2006), who both suggest to establish the extent of the problem using epidemiological data in a first step, and then to establish the cause and mechanism of injury [17, 59]. It was not possible to fully establish the cause and mechanism of injury, as the low sample size did not allow to sufficiently evaluate grouped injury locations or evaluations based on diagnosis. Thus, the detected risk factors are still too inexplicit to be tested in an intervention study to finally establish cause and mechanism of injury.

Clarsen et al. (2013) suggest using injury severity measures based on sports performance limitation of training and competition, rather than on time-loss only [64]. They found that most overuse problems that were recorded did not lead to time-loss from training or competition, and could be attributed to 'normal pain' (DOMS) related to athletic participation rather than to an OI. For this thesis, injuries were recorded based on their severity as total or partial time-loss from training and/or competition, and an injury was defined as an event that hindered the athlete from completing their normal training without any changes.

The injury definition used for this thesis differs from the definition established in the consensus statement for injury and illness definitions and data collection procedures for use in epidemiological studies in athletics by Timpka et al. (2014) [8]. This is because it was decided that only injuries with an impact on future training and competition in athletics were of interest. Further, for this thesis, medical professionals recorded injuries instead of self-reporting of injuries by the athletes. It was also decided against using the comprehensive categorization of injury location from the consensus statement, as it would make any comparisons between athletes difficult due to the long list of possible injury types.

This thesis uses the definition of exposure as well as the definition of injury onset, and the recommendation on calculating incidence proportion and overall incidence rate from the consensus statement.

In addition, this thesis utilized a prospective study design as recommended by the consensus statement and Bahr (2009) [61].

# Conclusions

The present thesis contributes to athletics research by ascertaining the incidence proportion, location, severity, and onset of overuse injuries in elite athletics by using medical professionals to establish injury diagnoses. Furthermore, new information regarding injury occurrence and athlete availability, and the relation of biomechanical and clinical risk factors were established.

- There is a high overall incidence proportion (72.4%) of overuse injuries in elite Swedish athletics. Middle/long distance runners had the highest incidence proportion of the four event groups. These results show the importance of understanding causes and mechanisms for the future prevention of OI.

- A majority of injuries were located at the lower extremities (90%) with the most common injury location being the thigh/hip followed by the foot/shank. The recorded injuries manifested over time with the most common injury onset being gradual onset caused by overuse.

- Over half of the recorded injuries were so severe that they led the athletes to a total or partial time-loss of at least 28 days from training or competition, potentially having an adverse effect on both short-term and long-term performance.

- Most of the recorded injuries occurred during the first conditioning phase (October through December), and in the middle of the second conditioning phase in spring (April). This emphasizes the importance of a more thorough training plan during training phases with high training load.

- A moderate athlete availability was found for the overall cohort (78%). This indicates that many elite Swedish athletics athletes have interruptions in their training availability, which potentially leads to a decreased performance and/or missing of qualification norms.

- Knee flexion velocity could be related to the development of OI. For several of the baseline screening variables, the relation to OI became stronger when grouping injuries by injury location.

# Practical implications

Based on the results from the present thesis, the following specific practical recommendations are given to athletes and coaches:

- OI seem to be overrepresented in the first conditioning phase of Swedish athletics training, from October through December. This indicates that athletes and coaches should slowly increase the training volume and intensity to avoid early season injuries, especially if the athletes are starting after a resting period.

- Many injuries also seem too occur in the middle of the second conditioning phase in April. It is important for coaches to be careful when planning the periodization of training during the season as to avoid athlete fatigue before the start of the outdoor competition phase.

- Athletes with OI at the thigh/hip showed a slower knee flexion velocity compared with athletes not injured at the thigh/hip. This indicates the importance of strengthening the hip flexors and improving flexibility of the hip extensors to avoid OI at the thigh/hip.

# Future directions

Based on the results from the present thesis, the following specific recommendations are given for future research:

- A first step is to increase the sample size, possibly by widening the inclusion criteria to allow for more athletes to partake.

- Injuries need to be grouped according to their specific diagnosis instead of a general injury location grouping. This would further improve the detection of causes and mechanisms of the development of OI.

- Event-specific training information needs to be collected to evaluate training load for different event groups.

- The quality of detected risk factors needs to be tested in intervention studies (i.e. within training) to enable measures for the prevention of OI to be developed in the future.

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# Appendix

## Appendix A1. Questionnaire from the mobile phone application.

Have you trained today? (Yes/No)

Did you feel any pain if you trained? (Yes/No)

Did pain affect your training? (Yes, I had to stop/Yes, I had to lower the intensity/No)

How intense was the pain? (0-Absolute maximum)

Where did you feel the pain? (Hip, Hamstring, Quadriceps, Knee, Shank, Foot, Achilles, Other)

Which side? (Right/Left)

---

Have you trained today? (Yes/No)

Why did you not train today? (Planned rest/Injury/Illness)

How intense is the pain? (0-Absolute maximum)

Where did you feel the pain? (Hip, Hamstring, Quadriceps, Knee, Shank, Foot, Achilles, Other)

Which side? (Right/Left)

Have you had any treatment? (Yes, I have visited a doctor/Yes, I have visited a physiotherapist/No)

Appendix A2. Injury report form.

**REFERAL to:**

**Patient**

Name:

Social security number:

Address:

Phone:

Status/previous injuries:

Issue:

Diagnosis:

Signature Place and date (year-month-day)

# Appendix A3. Example of training documentation for the event group middle/long distance runners.

Name ____________________

Coach ____________________

| | Number of sessions | Grass | Gravel | Track | Asphalt | Treadmill | Distance shoes | Flats | Spikes | Total Distance (incl. warmup) | Whereof High Quality-km | Whereof Threshold-km | Alternative training (total) | Alternative training (quality) | Technical training (min. 10min) | Olympic weightlifting (50-70%) | Olympic weightlifting (71-85%) | Olympic weightlifting (86-100%) | Powerlifting (50-70%) | Powerlifting (71-85%) | Powerlifting (86-100%) | Supplementary strength (50-70%) | Supplementary strength (71-85%) | Supplementary strength (86-100%) | Jumps |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-may mo | | | | | | | | | | | | | | | | | | | | | | | | | |
| 02-may tu | | | | | | | | | | | | | | | | | | | | | | | | | |
| 03-may we | | | | | | | | | | | | | | | | | | | | | | | | | |
| 04-may th | | | | | | | | | | | | | | | | | | | | | | | | | |
| 05-may fr | | | | | | | | | | | | | | | | | | | | | | | | | |
| 06-may sa | | | | | | | | | | | | | | | | | | | | | | | | | |
| 07-may su | | | | | | | | | | | | | | | | | | | | | | | | | |
| 08-may mo | | | | | | | | | | | | | | | | | | | | | | | | | |
| 09-may tu | | | | | | | | | | | | | | | | | | | | | | | | | |
| 10-may we | | | | | | | | | | | | | | | | | | | | | | | | | |
| 11-may th | | | | | | | | | | | | | | | | | | | | | | | | | |
| 12-may fr | | | | | | | | | | | | | | | | | | | | | | | | | |
| 13-may sa | | | | | | | | | | | | | | | | | | | | | | | | | |
| 14-may su | | | | | | | | | | | | | | | | | | | | | | | | | |
| 15-may mo | | | | | | | | | | | | | | | | | | | | | | | | | |
| 16-may tu | | | | | | | | | | | | | | | | | | | | | | | | | |

| |
|---|
| **(Quantity)** |
| **(Mark with 'x')** |
| **(Km)** |
| **(Hours)** |
| **(Volume - Kg)** |
| **(Quantity)** |
| **(Quantity)** |

**Notes:**

# Appendix A4. Case report form – Isometric strength tests.

## MUSCULAR STRENGTH & RANGE OF MOTION - DAVID

Name [ ]

Height: [ ] m    Weight: [ ] kg

Birthdate [ ]

**KNEE**    **STRENGTH**

| | | | | | |
|---|---|---|---|---|---|
| David 200 | **Extension** at 60° | right | [ ] | N | Seat: ............... |
| | | left | [ ] | N | Foot: ............... |
| David 300 | **Flexion** at 30° | right | [ ] | N | Seat: ............... |
| | | left | [ ] | N | Foot: ............... |

**HIP**

| | | | | | |
|---|---|---|---|---|---|
| David 310 | **Abduction** at 15° | | [ ] | N | |
| David 320 | **Adduction** | | [ ] | N | |

**UPPER BODY**

| | | | | | |
|---|---|---|---|---|---|
| David 110 | **Back Extension** at 30° | | [ ] | N | Seat: ............... |
| David 130 | **Abd.Flexion** at 0° | | [ ] | N | Foot: ............... |
| David 120 | **Rotation** at -30° / 30° | right | [ ] | N | Seat: ............... |
| | | left | [ ] | N | Foot: ............... |

Appendix A5. Informed consent signed at enrollment.

# INFORMED CONSENT

## Overuse injuries in Swedish elite athletics

I: ______________________________________________

(Surname and last name)

Accept to participate in the study.

I have been informed orally about the study and have read the project's written information and had the opportunity to ask questions and get them answered.

I am aware that my participation in the study is fully voluntary and that I can cancel my participation at any time and without further explanation.

______________________________________________

Signature (Participant) Date

______________________________________________

Signature (Project leader) Date