Injuries, risk factors and prevention initiatives in youth sport

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Background: Sports injuries in young athletes are a public health issue which deserves special attention. Effective prevention can be achieved with training programmes originating from the field of physical therapy and medicine.

Sources of data: A systematic literature search on injury prevention in youth sport was performed in the MEDLINE database.

Areas of agreement: For prevention programmes to reduce sports injuries, critical factors must be considered, such as training content, duration and frequency, as well as athlete compliance.

Areas of controversy: Home-based programmes could be inferior to supervised training, but are efficient if compliance is high. So far prevention programmes have focused on team sports and their efficiency in individual sports remains to be proven.

Growing points: Active prevention programmes focusing specifically on the upper extremity are scarce. Initiatives enhancing the awareness of trainers, athletes and therapists about risk factors and systematic prevention measures should be encouraged.

Keywords: sports injuries/young athlete/prevention strategies/compliance/risk factors
Introduction

Promotion of a physically active lifestyle is encouraged worldwide, particularly with regard to the many health benefits.\(^1\) In children and adolescents, regular sports practice facilitates the development of fundamental movement skills,\(^2\) helps prevent obesity and its long-term consequences\(^3\) and has long-lasting benefits on bone health.\(^4\) Unfortunately, increased intensity and volume of sport practice lead to a higher rate of acute and overuse injuries. For the young athlete, the consequences of sports injuries could be numerous, ranging from re-injury to career-ending.\(^5\) Long-term impacts of sports injuries are frequently found in adulthood, such as an accelerated development of osteoarthritis.\(^6\)

In addition to the potentially long-term outcomes of sports injuries on later life, the related healthcare costs constitute a substantial economic burden. In a recent study, Cumps et al.\(^7\) showed that the ensuing total direct medical costs of sports injuries in Flandren (i.e. rehabilitation, medical care, hospitalization, medication, bandages, transport, crutches) amounted to 15 027 423.00\(\text{€}\), which represents 0.07–0.08\% of the total budget spent on health care. In the USA, the estimated total hospital charges for sports injury hospitalizations among 5–18-year-olds were $485 million over a period of 4 years, with a steady increase each year.\(^8\) The highest medical costs are mostly found for knee injuries, especially for anterior cruciate ligament (ACL) injuries.\(^7,8\) The costs for one ACL surgery plus rehabilitation were estimated to up to $17 000. Gianotti et al.\(^9\) analysed knee ligament injuries in New Zealand and found that the mean treatment costs were $885 for nonsurgical knee injuries, $11 157 for ACL surgeries and $15 663 for other knee ligament surgeries. The socio-economic impact should also be viewed under the light of indirect costs of sports injuries, such as absence from work and long-term health consequences, which add to the direct costs.\(^7\)

Reduction of only a moderate proportion of all sports injuries is of significance for the young athletes’ health and could have a long-term economic impact regarding health-care costs.\(^10\) It is therefore important to convince medical doctors, physical therapists, trainers and coaches, as well as the athletes themselves, of the necessity to implement active prevention measures into their therapy and training programmes, thus decreasing the (re-)injury rate and enhancing athletic performance. Indeed, recent scientific literature based on a systematic injury prevention approach suggests that well-designed programmes do have positive effects, provided that a number of conditions are fulfilled.

Van Mechelen et al.\(^11\) proposed a general four-step model (Fig. 1) for sports injury surveillance. The first step comprises the description and
The extent of the injury problem. In a second phase, the aetiology and mechanisms of sports injury are being investigated. A third stage concerns the introduction of preventive measures, which will then be assessed regarding their effectiveness by repeating step 1. The purpose of this paper is to review the state-of-the-art knowledge on injury prevention in child and youth (≤19 years) sports based on that model. In the first part, the incidence and frequency of particular sports injuries will be briefly recalled, highlighting the specificities of the young age group related to biological maturation. The second part will discuss intrinsic risk factors of that population, with special emphasis on those which are modifiable and can be targeted by intervention. In the last part, active prevention programmes will be critically presented regarding their implementation, characteristics and efficiency. This analysis will make it possible for practitioners of different areas to draw relevant recommendations for their work.

**Search strategy and methods**

A systematic search of relevant publications was performed for the section on active prevention strategies via the MEDLINE database (1966–May 2009). The keywords used were adolescent OR youth AND sports injury AND prevention, yielding a total of 1953 hits. Additional searches were performed in the authors’ personal databases. Relevant papers were selected on the basis of the following criteria:

- exclusive focus on organized sports;
- separate results for young athletes under the age of 19 years;
- longitudinal studies: only prospective designs;
- major focus on intrinsic risk factor;
Injuries in youth sport

Before investigating the effectiveness of prevention measures, it is mandatory to get a global overview of the injury problem. This is, however, a difficult task for any person confronted with the considerable amount of literature that has accumulated in recent years. It appears that the sports injury issue can be addressed from multiple points of views (Fig. 3). Most studies\textsuperscript{12–24} have focused on one specific sport discipline highlighting injuries related to the inherent characteristics of the sport in question. Other investigations\textsuperscript{25–28} have addressed a particular body region or injury type, which again only provides a rather limited view of the sports injury problem. The aim of this section is therefore to briefly summon up the main acute and chronic injuries related to youth sports to present a general picture, taking into account the specificity of this population, the sport-specific context and the anatomical location. Previous reports have shown rates of injury per 1000 exposure hours between 0.5 and 34.4, with highest rates for boys in ice hockey (5–34.4 injuries/1000 h), rugby (3.4–13.3 injuries/1000 h) and soccer (2.3–7.9 injuries/1000 h), and for girls in soccer (2.5–10.6 injuries/1000 h), basketball (3.6–4.1 injuries/1000 h) and gymnastics (0.5–4.1 injuries/1000 h).\textsuperscript{5,29} For a more detailed analysis of injury

\begin{figure}
\centering
\includegraphics[width=\textwidth]{flow-chart.png}
\caption{Flow-chart illustrating the search strategy used for investigations dealing with active prevention strategies.}
\end{figure}
incidence rates in different sport disciplines, the reader is kindly referred to some excellent reviews that have been recently published.5,29–31

When analysing different studies on sports injury prevention, some methodological issues arise, the most important being the way of reporting injuries (e.g. absolute number of injuries, injury proportion or injury incidence) as well as injury definition.32 The latter may explain part of the sometimes large variations in the reported injury rates.33 The time of sports practice has been frequently used in the literature with minor distinctions,33,34 such that some caution is warranted when interpreting the results presented here (Tables 1 and 2). Recently, consensus statements on injury definitions and data collection procedures have been published for soccer35 and rugby.36

**Epidemiology of acute injuries**

The main acute injuries in youth sports are sprains, strains, fractures, dislocations and contusions. Overall, sprains account for 27–48% of all injuries in the young athlete,19–21,37 with the ankle and knee being the two most common anatomical locations for sprains.20 Ankle and knee sprain rates are particularly high in sports involving sharp cutting manoeuvres, running and pivoting movements, stopping and starting movements or jumps and landings on one foot. Typically, disciplines such as tennis, volleyball, handball, basketball and soccer are especially concerned here.18,23,37,38 In youth soccer, ankle sprain incidence reaches up to 1.50/1000 h.39 These results are comparable to the 1.56 ankle sprains/1000 h found in youth basketball.40 Considering knee sprains, higher incidences were found for females compared with males, both in soccer39 (0.72/1000 h versus 0.14/1000 h) and in
basketball\textsuperscript{41} (0.09/1000 h versus 0.02/1000 h). Finger injuries, especially finger sprains, are frequent in team ball sports such as netball\textsuperscript{42} (15%), basketball\textsuperscript{16} (4.9%) and handball\textsuperscript{21} (10–18%). Strains are very common in adolescent soccer, where they account for 17–53% of all injuries.\textsuperscript{17,20,34,37} The groin region seems to be most often concerned (0.57 strains/1000 h), followed by the thigh region (0.36 strains/1000 h) and the calf and back regions (both 0.21 strains/1000 h).\textsuperscript{39} For some sports, concussions are relatively frequent. For soccer, the incidence found was 0.36 concussions/1000 h,\textsuperscript{39} whereas for ice hockey, it was \( \sim 0.74 \) concussions/1000 h,\textsuperscript{15} thus representing the most common specific injury type (18% of all injuries).

Fractures were found to represent between 2% and 37% of all injuries related to soccer,\textsuperscript{17,20,34,37,43,44} mostly at the wrist, foot and ankle region.\textsuperscript{20} A similar large proportion was found in basketball (17–36%),\textsuperscript{43} volleyball (7–21%)\textsuperscript{43} and gymnastics (2–40%).\textsuperscript{12,19,43} Dislocations accounted for 29–39% of all injuries in basketball,\textsuperscript{43} for 14–35% in volleyball,\textsuperscript{43} for 1–35% in gymnastics\textsuperscript{19,43} and for 0.3–30% in soccer.\textsuperscript{17,20,43} In the young athlete, dislocations are often recurrent and can lead to post-traumatic instability.\textsuperscript{26,45} Contusions are also relatively frequent, especially in team sports and gymnastics (up to over 50%).\textsuperscript{43}

Epidemiology of chronic injuries

Overuse injuries are due to repetitive stress on a biological tissue, which leads to microtrauma in this specific body region. In adolescent soccer, overuse injuries account for 10–34% of all reported injuries.\textsuperscript{20,22,37,39,46} In youth basketball, 38% overuse injuries were reported,\textsuperscript{16} whereas in youth handball, they represented 7–21% of total injury number.\textsuperscript{21,24} Many overuse injuries in adolescents are due to traction apophysitis.\textsuperscript{47}

Some chronic injuries are specifically associated with children and adolescents. Concerning the upper extremity, the main overuse injuries are the little leaguer’s shoulder, the rotator cuff tendinopathy and the little leaguer’s elbow. The former is a stress fracture of the proximal epiphysial plate,\textsuperscript{45} which is specific to young overhead sports athletes with open growth plates, involved in sports such as baseball, volleyball and tennis.\textsuperscript{48} Shoulder impingement and rotator cuff tendinopathies are frequent in swimmers due to excessive internal shoulder rotation. Rotator cuff tendinopathy also occurs as a result of chronic repetitive hitting and overhead serving in young tennis players.\textsuperscript{49} Little leaguer’s elbow is a traction apophysitis of the flexor/pronator muscles origin on
the medial epicondyle and can be found in young baseball players, performing excessive throwing training.\textsuperscript{50}

Regarding the lower extremity, a common cause for anterior knee pain in young athletes is the Osgood–Schlatter lesion, a traction apophysitis of the tibial tuberosity. It is mostly found in children who are in a growth spurt and engaged in cutting and jumping sports, such as soccer, basketball, gymnastics and volleyball.\textsuperscript{48,50,51} In elite junior figure skating, the Osgood–Schlatter disease was found in 9\% of all the girls and 14\% of all the boys.\textsuperscript{14} Kujala et al.\textsuperscript{27} showed that 21\% of the active student population suffered from Osgood–Schlatter and that the knee pain caused complete cessation of training for an average of 3.2 months over a 5-year period. At the ankle, Sever’s disease is frequent in young athletes participating in basketball, soccer, track and other running activities.\textsuperscript{48} This calcaneal apophysitis affects the insertion of the Achilles tendon and the plantar fascia\textsuperscript{50} and is secondary to repetitive microtrauma or overuse of the heel. Sever’s disease is the second most common osteochondrosis found in the younger athlete after the Osgood–Schlatter lesion. Investigating young soccer players aged 9–19 years, Price et al.\textsuperscript{52} reported that Osgood–Schlatter’s and Sever’s disease accounted for 5\% of all injuries. In the age group of 11–13 years, these two conditions accounted even for 14\% of all injuries. Another specific chronic injury at the knee joint in adolescence is the Sinding–Larsen–Johansson disease, a tensile stress that affects the proximal attachment of the patella tendon.\textsuperscript{51}

Stress fractures also belong to the overuse injury category. Owing to mechanical overloading the balance between osteoclastic resorption and bone formation is disrupted. In tennis, stress fractures are often found at the lower extremity, more precisely at the foot, where the fifth metatarsal, the metatarsal diaphysis and navicular neck are most often concerned.\textsuperscript{49} In gymnastics, most stress fractures were found at the spine (42\%), followed by the lower extremity (35\%) and the upper extremity (23\%).\textsuperscript{13} Stress fractures at the lumbosacral spine are also called spondylolysis. They are often secondary to repetitive hyperextension of the spine, as found in gymnastics, ballet, volleyball, diving and serving in tennis.\textsuperscript{45} In basketball, stress fractures of the lower limb were found to be the third most frequent diagnosis (5.4\%) after lateral ankle sprains and patellar tendinitis.\textsuperscript{16} In elite junior skating, all stress fractures were located at the lower limb, except one that was found at the lumbar spine.\textsuperscript{14} Stress fractures were the most frequent overuse injury in female skaters with 19.8\%,\textsuperscript{14} whereas in male skaters they amounted to 13.2\%, the third most frequent diagnosis of overuse injuries. Generally, female athletes could potentially be more prone to stress fractures than males,\textsuperscript{13,14,47} an aspect that will be further addressed below.
Long-term consequences of sports injuries

The immediate outcome of a serious acute or chronic injury is the interruption of sports practice. A severe injury immobilizes the athlete up to several months and may require surgery or/and intensive and prolonged rehabilitation. On a long-term basis, the consequences of a sports injury may include decreased sports participation in later life, as well as loss of function and chronic pain, as discussed below. However, the literature on long-term consequences of injuries in youth sports is scarce, most investigations having focused on the adult population. Furthermore, only few types of injuries have been followed up on a long-term basis, which precludes any detailed analysis in relation to the different types of injuries specific to the younger population.

The injury type that has received most attention is the knee sprain, resulting in ACL or meniscus tears. Gonarthrosis, as diagnosed by radiography, is significantly increased after all knee injuries compared with the uninjured joint of the same patient. Half of the patients with a diagnosed ACL or meniscus lesion have osteoarthritis with associated pain and functional impairment 10–20 years after the diagnosis. In operatively treated handball players, the rate of return to sport at pre-injury levels was relatively good (58%), but the re-injury rate was as high as 22%, with half of the players reporting pain, instability or reduced range of motion 6–11 years after their ACL injury. A recent study showed that on an average 11.5 years after ACL reconstruction, 14–27% of the patients suffered severe loss of function and some 16% declared having rigorously modified their lifestyle. Among a group of non-operated children (average age 10.1 years) with ACL injury, 35% had not returned to their pre-injury activity level after an average of 3.9 years.

The consequences of ankle sprains and shoulder dislocations have also been investigated on a long-term basis, but not as frequently as knee injuries. In a group of young patients (mean age 20 years) followed up 2.5 years after inversion ankle injury without surgery, 74% were found to have persisting symptoms such as pain, perceived instability, weakness or swelling, and 16% were unable to return to their original sport. No relation was found between age, sex and type of sport with respect to long-term consequences in that study. Another 5-year follow-up of the functional outcome after surgery of chronic ankle instability revealed that only half of the patients regained their pre-injury ankle function. A major long-term risk after anterior shoulder dislocation is chronic instability. Re-dislocation rate after primary traumatic dislocation ranges from 14% to 67% after 12 and 5 years follow-up, respectively, often associated with functional impairment.
From the preceding discussion, it appears that the long-term consequences of a severe injury can be substantial. Although most results presented above stem from the young adult population, it is likely that they also apply to children and adolescents. It should be noted, however, that the literature lacks systematic long-term prospective follow-ups of sports injuries in the younger population. Furthermore, concerning chronic injuries in youth sports, long-term impacts on later life do not seem to have been investigated and could represent a fruitful area for future research.

Intrinsic risk factors

The second step of van Mechelen’s sequence of prevention consists in the description of the aetiology and mechanisms of injury (cf. Fig. 1), which are population-specific. Risk factors that could increase the potential for sports injuries may be qualified as extrinsic (environment-dependent) or intrinsic (athlete-dependent). Extrinsic factors that influence sports injury risk include sports context, protective equipment, rules and regulations, playing surface and coaching education and training. They will not be further developed here, because our main focus is on intrinsic risk factors. Some intrinsic risk factors cannot be changed and will only be addressed briefly hereafter. Others are potentially modifiable, which is of specific interest in the injury prevention context. The identification of intrinsic factors which could be potentially altered forms the basis for designing effective prevention programmes.

Non-modifiable risk factors

The risk factor most consistently associated with a greater injury risk is previous injury. Considering all injuries, soccer players with a history of injury had a 1.739 to 3.044 times greater risk to sustain a new injury. When specifically looking at ankle sprains in youth soccer, Tyler et al. found an even greater relative risk of 6.5 associated with previous injury. Across different sport disciplines, McHugh et al. reported that the association between previous injury and injury occurrence was significant, but only for male athletes.

The young athlete is particularly vulnerable to sports injuries because of the physical and physiological processes of growth. Body areas especially affected in adolescents compared with adults are the bone tissue and the muscle-tendon units. The muscle-tendon units elongate secondarily in response to bone growth leading to tightness of the
muscles, especially those muscles which cross two joints, such as the rectus femoris and gastrocnemius.\textsuperscript{47} Even if the metaphysis of long bones is more flexible and elastic in children than in adults, resulting in greater bone deflection without fracture,\textsuperscript{45} there are two areas which are especially susceptible to fractures. First, there is the line of weakness between the epiphyseal plate and the formed bone. Second, there is the apophyseal cartilage, which is often exposed to high pulling action from the muscle-tendon unit, resulting either in acute avulsion fracture or in traction apophysitis, depending on whether the muscular traction applied is sudden and intense or chronic and repetitive.\textsuperscript{47}

Growth plates in the epiphyseal regions may be injured by repetitive physical loading and stress. These physis injuries could produce permanent injury to the cells in the zone of hypertrophy resulting in growth disturbance.\textsuperscript{64} Bailey \textit{et al.}\textsuperscript{25} demonstrated that the incidence of fracture of the distal end of the radius was highest at the time of peak velocity of growth in both sexes. Thus, they concluded that during the adolescent growth spurt, there is a discrepancy between bone growth and bone mineralization, which results in a temporary period of relative weakness of the bone. In a recent study, Sugimori \textit{et al.}\textsuperscript{28} also showed that the incidence of fractures in a large cohort of Japanese children was highest at the age of growth spurt.

Considering the influence of gender, girls seem to be more prone for some injuries than boys. For example, in figure skating, the relative number of stress fractures (with respect to the numbers of athletes) was 11\% in girls, but only 8\% in boys.\textsuperscript{14} In gymnastics, an even greater difference was found, with 30\% for girls versus 21\% for boys,\textsuperscript{13} which could reflect different practice patterns. Unfortunately, none of the two studies reported whether these differences were statistically significant, so the answer is not definite. Regarding knee injuries, especially ACL injuries, girls were found to have a significantly higher incidence than boys [0.43 injuries/1000 athlete’s exposures (AE) versus 0.09 injuries/1000 AE].\textsuperscript{65} Other studies further suggest that ankle injuries are more frequent in girls than in boys.\textsuperscript{66,67} Possible reasons for higher injury risk in girls have been put forward, such as greater joint laxity,\textsuperscript{68} lower muscle strength\textsuperscript{30,67} and poorer proprioception and coordination.\textsuperscript{38}

Finally, there are maturity-associated variations that may influence sports injury risk.\textsuperscript{64} The adolescent athlete is more susceptible to injury than the prepubescent athlete because circulating androgens promote the fast development of muscle mass and enhance movement velocity and power. These rapid changes are likely to influence self-control and risk perception. Additionally, because of the non-linear growth process, children of the same chronological age may vary considerably in biological maturity status. As a consequence, there are early and late maturity children. As classification for participation in youth sport still
relies on chronological age, great variations with respect to height and weight can be found within a team, which increases the risk of sports injuries.\textsuperscript{64}

\textit{Modifiable risk factors}

Beside the non-modifiable risk factors, some authors have pointed out specific risk factors in children and adolescents that can be modified by prevention.\textsuperscript{29–31} Potentially implicated factors are fitness level, flexibility, muscle strength, joint stability, balance, coordination, psychological and social factors.\textsuperscript{30} Concerning cardiovascular fitness, Heidt \textit{et al.}\textsuperscript{69} showed that preseason conditioning significantly lowered injury incidence in female adolescent soccer players. Regarding muscle flexibility, it has been found that inflexible muscles can produce pain on the opposite side of a joint; in competitive swimmers, tightness of the posterior shoulder muscles was associated with anterior impingement.\textsuperscript{47} Moreover, as previously discussed, inflexible muscles could cause episodes of traction apophysitis and of overuse syndromes related to excessive strain, but this hypothesis still remains to be tested.\textsuperscript{47} Flexibility deficits, which are particularly common in adolescents suffering from overuse injuries, could be improved by regular stretching exercises. Stretching following appropriate warm-up prior to athletic activity may also prevent muscular injuries as was concluded in a recent review article.\textsuperscript{70}

The high incidence of ACL injuries in females has lead Hewett \textit{et al.}\textsuperscript{38} to evaluate neuromuscular control and joint loads in 205 young female athletes participating in soccer, basketball or volleyball. They used three-dimensional kinematics and kinetics to evaluate performance during a standardized jump-landing task. Those athletes who acquired a confirmed ACL injury during the 13-month follow-up had significantly different pre-study knee posture and loading characteristics compared with the athletes who did not develop an ACL rupture. The knee abduction angle during landing was significantly greater in ACL-injured compared with uninjured players. Moreover, ACL-injured athletes had a 2.5 times greater knee abduction moment and 20\% higher ground reaction force than their uninjured counterparts. Hence, female athletes with increased dynamic valgus and high abduction loads are at increased risk for ACL injury.

Balance and coordination have been evaluated in high-school basketball players in a prospective follow-up study.\textsuperscript{40} Subjects who demonstrated poor balance (high postural sway scores) had nearly seven times as many ankle sprains as subjects who had good balance (low postural sway scores). As a result, the authors concluded that preseason balance
measurement (postural sway) could serve as a predictor of ankle sprain susceptibility. Similar conclusions were reached in another study,\textsuperscript{71} where ankle injuries were more commonly found in physical education students with decreased postural control.

Considering the influence of psychological factors on sports injuries, several studies suggest that life stress could be a significant predictor of injury.\textsuperscript{72–75} For example, major life events, such as the death of a close friend or family member, or the separation from girl/boy-friend, could increase the risk for a sports injury by up to 70%.\textsuperscript{72} Steffen \textit{et al.}\textsuperscript{72} showed that injured soccer players had undergone significantly more stressful life events than the uninjured players. Beside life stress, coping resources, personality traits and competitive anxiety could have an effect on sports injuries, as discussed in a recent review.\textsuperscript{74} Williams and Anderson\textsuperscript{76} have shown that the response to life stress is modulated by the personality of the athlete, the history of stressors and the coping resources. These factors could be easily evaluated by means of standardized questionnaires. Although athlete personality and history of stressors cannot be modified, psychological interventions could be useful in improving the athlete’s attitude and coping resources. This discussion is however beyond the scope of the present review.

**Interventions for sports injury prevention**

The previous section has described a series of intrinsic risk factors that are potentially modifiable. They are the specific focus of interventions aiming at preventing sports injuries and appear in step 3 of van Mechelen’s prevention model (Fig. 1). The efficiency of such prevention programmes must, of course, be evaluated using injury statistics from a long-term prospective follow-up (step 4 of the injury prevention model).

Basically, there are two different kinds of prevention strategies, the passive and the active. Passive strategies do not require active adaptations from the athlete during practice. Once the prevention strategy is adopted (e.g. compliance with new rules or wearing protective equipment),\textsuperscript{77,78} the athlete is automatically protected. In contrast, active strategies imply that the athlete cooperates and modifies his behaviour within the sports context. An example of an active prevention programme is the ‘11’-programme, designed by the FIFA-Medical Assessment and Research Centre (F-MARC).\textsuperscript{79} This intervention has been developed in cooperation with international experts. It promotes fair play and encompasses 10 sets of exercises which focus on core stabilization, eccentric training of thigh muscles, proprioceptive training, dynamic stabilization and plyometrics with straight leg
alignment. More recently, a revised version of this programme ('11+') has been successfully applied on young female soccer players, as will be detailed later on.

In this paper, only studies dealing with active prevention strategies are presented based on our systematic literature search (cf. introduction). Before describing different programmes in greater detail, it is worthwhile to discuss a number of issues related to the implementation of such programmes into the athlete’s training schedule.

Challenges to implement injury prevention strategies

The effectiveness of an injury prevention programme depends not only on its content but also on the success of its more or less permanent acceptance and implementation within the sports community. Great efforts are sometimes required to convince trainers and coaches to adopt a specific prevention programme over longer periods of time. Compliance to prevention training at the level of the team as well as the level of the individual athlete is critical. Therefore, the organization of large-scale randomized controlled trials demands a long preparation time and many resources.

One of the first premises for an effective prevention programme is the cooperation from trainers. The latter must be fully briefed with respect to programme duration and content, correct execution of exercises, frequency and the importance of athlete compliance. The intervention programme should be designed in such a way that it does not interfere too heavily with the usual training activities. Furthermore, additionally required material (exercise books and DVDs, balance mats, wobble boards etc.) should be made available taking into account the financial implications.

In some studies, teams are supplied with instructional videotapes at the beginning of the intervention training, demonstrating the correct execution of the prevention exercises. Sometimes the athletes are asked to control each other by watching the accomplished exercise and giving each other feedback. Regular checks from the study instructors are nevertheless needed to verify the appropriate execution of the programme, the implementation of which can take up to 1.5 months.

The success of an injury prevention programme also greatly depends on compliance of the individual athletes to the intervention, as will be discussed hereafter. Adherence can be influenced by the sport- or study-specific context, since in team sports the trainer or coach bears greater responsibility, whereas in individual sports the athlete’s own commitment is critical. Another difficulty of evaluating the role of
compliance results from the fact that some studies do not specify what kind of compliance was evaluated. Different indexes have been reported, such as the percentage of training sessions in which the programme was used (training session compliance), compliance of participants to the training sessions (participant compliance) or the percentage of teams adhering to the programme (team compliance) (Tables 1 and 2). None of these variables necessarily reflect the compliance of the individual athletes to the entire intervention programme. These aspects are of particular importance when interpreting the results of sports injury prevention initiatives. Close collaboration with the study group is also needed regarding data collection and determines, what has been termed, the ‘collecting data compliance’. The latter is also important regarding the gathering of information about sports injuries, which requires prior briefing or even training of one or several local contact persons.

Outcome of prevention initiatives

Injury prevention programmes focusing on the young athlete have been mainly tested in the context of team sports, such as soccer, basketball, handball and multiple sports. To the authors’ knowledge, no prevention programmes for individual sports have been presented in the literature. This could have practical reasons, in that implementation and high compliance are easily achieved in team sports compared with individual disciplines. Furthermore, in team sports, more athletes can be targeted at one time.

Tables 1 and 2 summarize the main results from studies investigating the effects of different prevention programmes. In Table 1, only results with a significant positive effect on sports injuries are reported, whereas Table 2 reviews observations with no significant reduction of injuries. Regarding content, it appears that injury prevention in youth sports has mainly focused on the lower extremity and the trunk. Components which often appear in successful programmes are plyometrics, functional strength or conditioning exercises, sport-specific agility drills, activities to improve balance and body control and flexibility exercises. Great emphasis is generally placed on neuromuscular control, core stability, lower limb alignment, hip control and proper landing technique (e.g. ‘knee over toe’ position, decreased impact forces, bilateral landing). Close supervision and feedback (oral and visual via ordinary video analysis) by a proficient trainer or at least by peers seem to be of particular importance to guarantee proper execution of the exercises. This critical aspect may put home-based
Table 1. Summary of studies reporting on successful active prevention programmes.

<table>
<thead>
<tr>
<th>First author</th>
<th>Sport</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Injury definition</th>
<th>Prevention programme</th>
<th>Injuries in the control group</th>
<th>Injuries in the intervention group</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emery(^83) (CRCT)</td>
<td>Basketball</td>
<td>12–18</td>
<td>m + f</td>
<td>All injuries occurring during basketball that required medical attention and/or caused a player to be removed from that current session and/or miss a subsequent session</td>
<td>Sport-specific balance training warm-up for practice sessions</td>
<td>5 min during one basketball season (5 times/week)</td>
<td>Acute-onset injuries: 3.83/1000 player hours*, RR = 0.71 (95% CI: 0.50–0.99)</td>
<td>100% of participants for sport-specific training</td>
</tr>
<tr>
<td>Emery(^85) (CRCT)</td>
<td>Multiple</td>
<td>14–19</td>
<td>m + f</td>
<td>Any injury occurring during a sporting activity that required medical attention (i.e. visit to an emergency department or physician's office, chiropractic, physiotherapy or athletic therapy) or resulted in the loss of at least 1 day of sporting activity, or both</td>
<td>A progressive, home-based, proprioceptive balance-training using a wobble board</td>
<td>Daily training for 6 weeks and then weekly for maintenance for the rest of the 6-month study period</td>
<td>17% participants with injury, RR = 0.20 (95% CI: 0.05–0.88), OR = 0.15 (95% CI: 0.03–0.72) (multiple logistic regression)</td>
<td>43.3% (collecting data compliance)</td>
</tr>
<tr>
<td>Heidt(^69) (RCT)</td>
<td>Soccer</td>
<td>14–18</td>
<td>f</td>
<td>An injury that caused the athlete to miss a game or a practice session</td>
<td>Cardiovascular conditioning, plyometrics, sport cord drills, strength training and flexibility exercises to improve speed and agility</td>
<td>7-week training programme before the start of the season (20 sessions)</td>
<td>33.7% participants with injury</td>
<td>14.3% participants with injury*</td>
</tr>
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Table 1. Continued

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<tr>
<th>First author</th>
<th>Sport</th>
<th>Age (years)</th>
<th>Sex</th>
<th>Injury definition</th>
<th>Prevention programme</th>
<th>Injuries in the control group</th>
<th>Injuries in the intervention group</th>
<th>Compliance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hewett(^5) (CNRCT)</td>
<td>Multiple (soccer basketball volleyball)</td>
<td>14–18 f</td>
<td>A serious knee injury was defined as a knee ligament sprain or rupture that caused the player to seek care by an athletic trainer and that led to at least 5 consecutive days of lost time from practice and games</td>
<td>Neuromuscular training programme, incorporating flexibility, plyometrics and weight training to increase muscle strength and decrease landing forces</td>
<td>6-week preseason training sessions that lasted 60–90 min a day, 3 days a week, on alternating days; 1 season follow-up</td>
<td>0.43 knee injuries/1000 AE (untrained females) 0.09 knee injuries/1000 AE (male athletes)</td>
<td>0.12 knee injuries/1000 AE*</td>
<td>4 weeks: 100%; 6 weeks: 70% (participant compliance)</td>
</tr>
<tr>
<td>Junge(^6) (CNRCT)</td>
<td>Soccer</td>
<td>14–19 m</td>
<td>Any physical complaint caused by soccer that lasted for more than 2 weeks or resulted in absence from a subsequent match or training session</td>
<td>Improvement of warm-up, regular cooldown, taping of unstable ankles, adequate rehabilitation, application of the ‘11’</td>
<td>two 1-year season intervention (no other details indicated)</td>
<td>low-skill group: 11.1/1000 h</td>
<td>6.95/1000 h*</td>
<td>NR</td>
</tr>
<tr>
<td>Malliou(^7) (CRCT)</td>
<td>Soccer</td>
<td>15–18 NR</td>
<td>An injury was defined as any mishap occurring during scheduled games or practices causing an athlete to miss a subsequent game or practice session</td>
<td>Proprioceptive balance training program, which included sport-specific exercises on the ‘Biodex Stability System’, on the mini-trampoline and on the balance boards</td>
<td>20-min balance training twice a week during the competition period</td>
<td>88 lower limb injuries</td>
<td>60 lower limb injuries*</td>
<td>NR</td>
</tr>
<tr>
<td>Study</td>
<td>Sport</td>
<td>Age</td>
<td>Gender</td>
<td>Adolescent Match Frequency</td>
<td>Injury Definition</td>
<td>Injury Prevention Programme</td>
<td>Injury Rate</td>
<td>Injury Rate</td>
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<tr>
<td>Mandelbaum (non-randomized prospective cohort study)</td>
<td>Soccer</td>
<td>14–18</td>
<td>f</td>
<td>Non-contact ACL tear was confirmed by history, physical examination by a physician and MRI and/or arthroscopic procedure</td>
<td>20-min warm-up before each athletic activity during two one-season interventions</td>
<td>Season 1: 0.47 ACL injuries/1000 AE; Season 2: 0.51 ACL injuries/1000 AE</td>
<td>0.05 ACL injuries/1000 AE*, RR = 0.114 (95% CI = NI); 0.13 ACL injuries/1000 AE*, RR = 0.259 (95% CI = NI)</td>
<td>96.5 – 100% (team compliance)</td>
</tr>
<tr>
<td>McGuine (CRCT)</td>
<td>Multiple (soccer basketball)</td>
<td>16</td>
<td>m+f</td>
<td>An ankle sprain was defined as a trauma that (i) disrupted the ligaments of the ankle, (ii) occurred during a coach-directed competition, practice or conditioning session and (iii) caused the athlete to miss the rest of a practice or competition or miss the next scheduled coach-directed practice or competition</td>
<td>Balance exercises on a flat surface or on a board such as single-leg stance with eyes open and closed; performing functional sport activities such as throwing, catching and dribbling on one leg; maintaining double-leg stance while rotating the balance board</td>
<td>Progressive five-phase balance training program; phases 1 – 4: five exercise sessions/week for 4 weeks before the start of the season; in phase 5 (maintenance phase), three 10-min sessions/week</td>
<td>1.87 ankle sprains/1000 AEs</td>
<td>1.13 ankle sprains/1000 AEs; the rate of ankle sprains was significantly lower in the intervention group as shown by Kaplan–Meier survival analysis, RR = 0.56 (95% CI: 0.33–0.95)</td>
</tr>
<tr>
<td>McHugh (prospective cohort study)</td>
<td>Soccer</td>
<td>15–18</td>
<td>NR</td>
<td>An inversion ankle sprain was defined as an ankle injury with an inversion mechanism requiring the player to miss at least one game or practice</td>
<td>Single-limb balance training on a foam stability pad</td>
<td>Balance training was performed for 5 min on each leg, 5 days/week for 4 weeks in preseason and 2 times/week for 9 weeks during the season</td>
<td>2.2 ankle sprains/1000 exposures</td>
<td>0.5 ankle sprains/1000 exposures*</td>
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Table 1. Continued

<table>
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<td>Olsen⁸¹ (CRCT)</td>
<td>Handball</td>
<td>15–17</td>
<td>m + f</td>
<td>Any injury occurring during a scheduled match or training session, causing the player to require medical treatment or miss part of the next match or training session</td>
<td>Exercises with the ball, including the use of the wobble board and balance mat to improve running, cutting and landing technique as well as neuromuscular control, balance and strength</td>
<td>1.8 acute injuries/1000 player hours (0.6 in training 10.3 in match)</td>
<td>0.9 acute injuries/1000 player hours*, RR = 0.51 (95% CI: 0.39–0.66) (0.4 in training 4.7 in match*)</td>
<td>87% (team compliance)</td>
</tr>
<tr>
<td>Soligard²³ (CRCT)</td>
<td>Soccer</td>
<td>13–17</td>
<td>f</td>
<td>An injury occurred during scheduled match or training session, causing the player to be unable to fully take part in the next match or training session</td>
<td>Application of ‘11+’ 20-min programme at all training sessions and prior to matches for one 8-month season</td>
<td>4.8/1000 h</td>
<td>3.2/1000 h*, RR = 0.68 (95% CI: 0.56–0.84)</td>
<td>77% (training session compliance); 58% (participant compliance)</td>
</tr>
<tr>
<td>Wedderkopp⁹⁰ (CRCT)</td>
<td>Handball</td>
<td>16–18</td>
<td>f</td>
<td>Any injury occurring during scheduled games or practices, causing the player to either miss the next game, practice session or being unable to participate without considerable discomfort</td>
<td>Ankle disc practice and two or more functional strength activities for all major muscle groups 10–15-min programme at all training sessions for one 10-month season</td>
<td>1.17/1000 h of practice, 23.38/1000 h of match</td>
<td>0.34/1000 h of practice*, OR = 0.17 (95% CI: 0.089–0.324); 4.68/1000 h of match*</td>
<td>NR</td>
</tr>
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Any injury occurring during scheduled games or practices, causing the player to either miss the next game, practice session or being unable to participate without considerable discomfort.

Ankle disc practice and two or more functional strength activities for all major muscle groups 10–15-min programme at all training sessions for one 10-month season.

0.6/1000 h of practice, OR = 4.8 (95% CI: 1.9–11.7); 6.9/1000 h of match.

0.2/1000 h of practice*; 2.4/1000 h of match*.

NR

AE, athlete’s exposure; NR, not reported; m, male; f, female; CNRCT, cluster-non randomized controlled trial; CRCT, cluster randomized controlled trial; RCT, randomized controlled trial.

*Significantly different from the control group (p < 0.05).
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<td>Emery^83</td>
<td>Basketball</td>
<td>12–18</td>
<td>m + f</td>
<td>All injuries occurring during basketball that required medical attention and/or caused a player to be removed from that current session and/or miss a subsequent session</td>
<td>Sport-specific balance training warm-up for practice sessions</td>
<td>All injuries: 4.03/1000 player hours, RR = 0.80 (95% CI: 0.57–1.11)</td>
<td>3.3/1000 player hours, RR = 0.80 (95% CI: 0.57–1.11)</td>
<td>100% of participants for sport-specific training</td>
</tr>
<tr>
<td>Junge^86</td>
<td>Soccer</td>
<td>14–19</td>
<td>m</td>
<td>Any physical complaint caused by soccer that lasted for more than 2 weeks or resulted in absence from a subsequent match or training session</td>
<td>Improvement of warm-up, regular cooldown, taping of unstable ankles, adequate rehabilitation, application of the ‘11’</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steffen^82</td>
<td>Soccer</td>
<td>13–17</td>
<td>f</td>
<td>An injury was registered if it caused the player to be unable to fully take part in the next match or training session</td>
<td>Application of the ‘11’</td>
<td></td>
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AE, athlete's exposure; NR, not reported; m, male; f, female; CNRCT, cluster-non randomized controlled trial; CRCT, cluster randomized controlled trial; RCT, randomized controlled trial.
interventions at a disadvantage, since the quality of the execution (and the compliance—see below) cannot be easily verified. Another factor to consider is the possibility for variation and progression in the exercise set, which will avoid ceiling effects, enhance motivation among trainers and athletes and favour compliance. Indeed, the ‘11’-programme applied by Steffen et al. in a group of young soccer players did not provide the possibility for variation and progression, was characterized by a low compliance and had no significant effect on injury incidence. Similarly, Junge et al. did not find significant improvements in injury statistics with this prevention method in already skilled soccer players (cf. Table 2), only the low-skilled group had a decreased injury incidence (cf. Table 1). On the other hand, the revised ‘11+’ version including additional exercises to provide variation and progression, plus a new set of structured running exercises, reduced the risk of severe injuries, overuse injuries and injuries overall in young female soccer players.

Globally, there is a strong tendency of interventions with a high compliance to bring about significant reductions in injury incidence, whereas studies in which compliance to the programme was low showed only marginal effects. It should be noted here that a home exercise programme may be less motivating and result in poorer compliance than a supervised and structured training agenda followed in a group of peer athletes. Considering the fact that the young athlete's behaviour can be easily influenced by the environment, the attitude of the trainers and probably also of the parents may be of particular importance here. The investigation of Mandelbaum et al. had a team compliance of almost 100%, which lead to an 88% reduction in ACL injuries in female soccer players. Similarly, in the study of Olsen et al., 87% of the participating clubs applied the proposed intervention programme throughout the study period, which yielded a 50% decrease in acute injuries in young handball players. Hewett et al. found a 72% reduction in knee injuries in female athletes from team sports after a specific 6-week preseason preparation. All the girls from the intervention group followed the prevention programme for 4 weeks, and 70% of them accomplished the full training programme. McGuine and Keene reported a compliance of 91%, which lead to a 38% reduction in ankle sprains in male and female high-school basketball and soccer players. In the study of McHugh et al., 91% of the athletes followed the entire balance training. The authors observed an overall reduction in injury incidence of 77%. In contrast to the previous studies, Steffen et al. noted a low training session compliance among young soccer players (52%), despite regular contacts with the coaches during the study period and encouragements to continue the intervention programme. Accordingly,
the results did not reveal the expected training effects of reduced sports injury risk (cf. Table 2).

Given the previous findings, it appears that appropriate content and high compliance are critical, yet insufficient factors for a successful intervention. Another important aspect seems to be the frequency and duration of the prevention sessions, for which some fundamental differences can be noted (cf. Tables 1 and 2). Some programmes with significant reductions in injury statistics have encompassed an initial high volume phase of prevention exercises, i.e. 15–40 sessions of 15–20 min, performed either daily or in every practice, followed by one weekly session for maintenance.\textsuperscript{81,85} Another successful approach has been to introduce a pre-season preparation programme of 18–20 sessions over 6–7 weeks, with durations of up to 90 min.\textsuperscript{65,69} Finally, a strategy of continuous, moderate volume prevention training of 10–20 min in each practice session (e.g. during warm-up) also yielded positive results.\textsuperscript{37,80,89,90} From these results, it can be concluded that frequency and duration of preventive training sessions should guarantee certain minimal criteria. All in all, the final choice will depend on practical considerations of feasibility and acceptance by trainers and athletes.

**Conclusion**

Acute injuries and overuse syndromes in the young athlete deserve specific consideration. Detailed knowledge about injury incidence, injury type and modifiable and non-modifiable risk factors makes it possible to design pertinent prevention programmes. Their effectiveness depends on a number of characteristics related to content, compliance, duration and frequency. Practical issues regarding implementation of and adherence to these prevention exercises require special attention. The proposed programmes should be time-efficient for the trainers and motivating for the athletes.

There seem to be no systematic analyses about the effectiveness of injury prevention programmes directed to the upper extremity, despite well-described injury patterns. The latter are rather sport-specific and concern, e.g. the young overhead athlete. The reasons why this area may have raised less interest in the field of sports medicine are not clear. Attention should be drawn here to interventions aiming at decreasing muscle dysbalances and restoring appropriate ranges of motion. The modalities and efficiency of such training programmes are yet to be investigated by long-term prospective follow-ups.

Finally, it is important to take into account the education of trainers and coaches. Indeed, few coaches consider sports injuries as an issue
they can impact on. It is also regrettable that injury prevention seems to have a rather low priority and has been cited by some trainers as a reason for non-participation in injury prevention studies. This indicates the necessity to include the topic of injury prevention in the curricula of trainers and coaches. Furthermore, information and education of the parents and the young athletes themselves should be reinforced. Only an uninjured athlete is able to perform at his/her best.

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**References**


