REVIEW

Strategies to prevent injury in adolescent sport: a systematic review

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This systematic review set out to identify randomised controlled trials and controlled intervention studies that evaluated the effectiveness of preventive strategies in adolescent sport and to draw conclusions on the strength of the evidence. A literature search in seven databases (Medline, SportDiscus, EMBASE, CINAHL, PEDro, Cochrane Review and DARE) was carried out using four keywords: adolescent, sport, injury and prevention (expanded to capture any relevant literature). Assessment of 154 papers found 12 studies eligible for inclusion. It can be concluded that injury prevention strategies that focus on preseason conditioning, functional training, education, balance and sport-specific skills, which should be continued throughout the sporting season, are effective. The evidence for the effectiveness of protective equipment in injury prevention is inconclusive and requires further assessment.

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Sport is the main cause of injury in adolescents.[1 2] Young people are at particular risk of sports injury because of high levels of exposure at a time of major physiological change.[3 4] Prevention of injury is important for several reasons not least the initial impact on health and long-term outcome—that is, early development of osteoarthritis.[5]

Although most sports injuries are not severe enough to require hospitalisation, they are frequent and have a major economic impact through direct medical costs, treatment and rehabilitation, and indirect costs, including parents taking time off to care for injured offspring.[2 6] In addition, injury prevents future involvement in physical activity, and about 8% of adolescents drop out of recreational sporting activities annually because of injury.[7] There are long-term public health consequences associated with inactivity in terms of cardiovascular disease, obesity, etc, but injury may also interfere with the potential benefits of greater self-esteem, relaxation, socialisation, teamwork and fitness associated with sport participation at this age.[8]

Injury prevention generally focuses on modifiable risk factors: extrinsic factors, such as equipment, playing surface, rule changes and playing time, or intrinsic factors, such as fitness, flexibility and balance. This is based on adult research, but is now supported by studies of sports injury prevention in children and adolescents.

There are few systematic reviews of sports injury prevention in adolescents,[6] and none focusing specifically on the adolescent age group. The aim of this review is to examine prevention strategies in adolescent sport, focusing specifically on sports that are available in schools. The specific objectives of this systematic review are:

- (*a*) To identify randomised controlled trials and controlled intervention studies that evaluate the effectiveness of preventive strategies in adolescent sport.
- (*b*) To make conclusions on the strength of the evidence supporting methods used to prevent injury.

METHODS

Search strategy and selection of studies

Relevant studies were identified using a computer-based literature search in seven databases (Medline 1966–January 2006, SportDiscus, EMBASE (1974–January 2006), CINAHL (1982–January 2006), PEDro and Cochrane Databases: Cochrane Review and DARE) using four keywords: adolescent, sport, injury and prevention. These keywords were expanded to capture any relevant literature:

- (1) Adolescent OR youth OR (high+school+student) OR school age OR school+pupil
- (2) Injury
  - (a) wounds AND injuries exp.
  - (b) sport$ injur$ OR athletic$ injur$
  - (c) sprain$ OR strain$ OR twist$ OR tear$ OR pull OR break$ OR fracture$ OR
  - (d) soft tissue injur$ Or acute injury
  - (e) chronic injur$ OR overuse injury OR cumulative trauma OR repetitive trauma OR tendonitis OR tendinopathy
  - (f) concussion OR head injury
  - (g) major trauma OR catastrophic injury OR death
- (3) Sport
  - (a) explode sports
  - (b) sport$ OR exercise OR athletic$ OR physical education OR school games
  - (c) hockey OR rugby OR football OR soccer OR swim$ OR tennis OR squash OR badminton OR basketball OR netball OR Gaelic football OR GAA OR camogie OR hurley OR hurling

Abbreviations: ACL, anterior cruciate ligament; NNT, number needed to treat

- (4) Prevention

  - (a) primary+prevention
  - (b) protective+equipment OR protective device OR safety device OR taping OR brace$
  - (c) supervision OR rule enforcement OR rule change$ OR competition+rules
  - (d) sport$+facilities OR sport$+grounds
  - (e) size+matching OR age-matching
  - (f) warm-up OR warm-down OR pre-season+preparation OR pre-season+training OR resistance+training OR weight+training OR strength+training. The Cochrane Filter was applied.

In the first stage of selection, the titles and abstracts of all studies were assessed for the criteria below. Full text articles were retrieved for potentially relevant studies where no abstract was available, where the cohort age was unclear from the abstract, and where the abstract suggested selection. There was no blinding to study author, place of publication or results. Hand searches of study bibliography identified a further 62 potentially relevant publications that were subsequently retrieved and assessed. The primary reviewer (LA) assessed the content of all full text articles, making the final inclusion/exclusion decisions on the basis of criteria described below.

Selection criteria

Types of study

Randomised controlled trials, non-randomised intervention studies and cohort studies, published in English, were considered.

Types of participants

Adolescents (12–18 years) involved in supervised physical education and sport. This includes the usual range of school sports in Ireland (athletics, hockey, rugby, football, swimming, tennis, squash, badminton, basketball, handball, netball, gaelic football, camogie, hurling and lacrosse). It excludes sports that only a minority have the opportunity to experience—for example, equestrian sport, water sports, snow boarding, skiing, ice hockey, skating and motorised sport. It excludes unsupervised sports—for example, roller-blade and skate sports—and "extreme sport" activities. Both acute (fractures, soft-tissue injuries, concussion, head injuries, major trauma, death) and chronic injuries were included. Studies that included both adult and adolescent participants were included if the adolescent age group could be identified and studied separately.

Types of intervention

Studies examining the effect of any preventive intervention—for example, protective equipment, specialist coaching, conditioning or neuromuscular training—were included. Control interventions included no intervention or other interventions.

Types of outcome measured

Injury was the outcome measured and defined as:

- (1) Injury rate (per participant, per 1000 exposures or per 1000 exposure hours).
- (2) Injury severity (time missed from sport participation, training practice or match because of injury).
- (3) Where possible, individual study effect estimates were calculated—that is, risk ratios (RR) each with 95% CI.[9]

Note that recording of injury by participants or observers was acceptable for inclusion purposes.

Validity assessment

The two authors (LA and CB) independently assessed the methodological quality of each study. We were not blinded to the identity of authors, institutions and journals. Agreement was reached by consensus regarding the methodological quality of all studies. As no validated tools exist to evaluate or rate studies that are not randomised controlled trials, we developed a quality assessment key to score the studies (table 1). This key was based on keys used by the Cochrane Collaboration Injuries Group and the Cochrane Collaboration Bone, Joint and Muscular Trauma Group. We piloted the key independently, modified it by consensus, and used it to score all included studies. For the purposes of this review, studies were rated for quality by application of a system described by MacKay *et al*[6] whereby a score for overall quality was converted into a percentage value—that is, 0–49% is poor, 50–89% moderate, and >90% good (table 2).

Data extraction

We (LA, CB) independently extracted data on the study characteristics, study population, interventions, analyses and outcome. Studies were first assessed for homogeneity with respect to the nature of the intervention, control group, and the type and timing of outcomes and follow-up.

Table 1 Study quality score key

Study reference:	Score
How was allocation to the intervention group done?	
2 = random	
1 = cluster random	
0 = historical comparison/volunteer or convenience group	
Was the assigned intervention concealed before allocation?	
2 = adequate	
1 = unclear	
0 = inadequate/impossible	
Were the outcomes of participants who withdrew described and included in the analysis (intention to treat/effect of compliance)?	
2 = withdrawals well described and accounted for in analysis	
1 = withdrawals described and analysis not possible	
0 = no mention, inadequate mention, or obvious differences and no adjustment	
Were the outcome assessors blinded to treatment status?	
2 = effective action taken to blind assessors	
1 = small or moderate chance of unblinding of assessors	
0 = not mentioned or not possible	
Were the inclusion and exclusion criteria (age, previous injury, sport) clearly defined?	
2 = clearly defined	
1 = inadequately defined	
0 = not defined	
Were the intervention and control group comparable at entry?	
2 = good comparability of groups, or confounding adjusted for in analysis	
1 = confounding small; mentioned but not adjusted for	
0 = large potential for confounding, or not discussed	
Were the interventions clearly defined?	
2 = clearly defined interventions are applied	
1 = clearly defined interventions are applied but the application is not standardised	
0 = intervention and/or application are poorly or not defined	
Were the outcome measures used clearly defined? (injury: self-reported injury/medically confirmed/severity defined)	
2 = clearly defined	
1 = adequately defined/recorded	
0 = not adequately defined/recorded	
Was the surveillance period active and of clinically appropriate duration?	
2 = active surveillance and appropriate duration	
1 = active surveillance, but inadequate duration	
0 = surveillance not active or not defined	
Total score (18 = 100%)	

Table 2 Study quality scores

Study reference	Allocation to intervention group	Assigned intervention concealed before allocation	Outcomes of participants who withdrew described + included in analysis	Outcome assessors blinded	Inclusion/exclusion criteria clearly defined?	Groups comparable at entry	Interventions clearly defined	Definition outcome measures	Surveillance period active and of clinically appropriate duration	Total score	Quality rating
Emery[14]	1	0	2	0	2	0	2	1	2	10	M
Grace[13]	0	0	1	0	1	1	2	1	2	8	P
Heidt[15]	2	0	0	2	1	0	2	2	2	11	M
Hewett[19]	0	0	1	0	1	0	2	2	2	8	P
Junge[16]	1	0	1	0	1	0	2	2	2	9	M
Mandelbaum[20]	0	0	0	0	2	1	2	2	2	9	M
McIntosh[17]	1	0	0	0	1	0	2	2	2	8	P
Olsen[18]	1	0	1	2	2	2	1	2	2	13	M
Webster[12]	0	0	0	0	0	0	2	1	2	5	P
Wedderkopp[21]	1	0	0	0	2	2	1	2	2	10	M
Wedderkopp[22]	1	0	2	0	1	2	1	1	2	10	M
Yang[11]	0	0	0	0	0	1	2	1	2	6	P

M, moderate; P, poor.

Study characteristics

Tables 3–5 summarise the study characteristics.

Quantitative data synthesis

Table 6 gives quantitative data synthesis with results.

RESULTS

Trial flow

The process of study selection and explanations of exclusions at each stage are reported according to the Quality of Reporting of Meta-Analysis (QUORUM) statement flow diagram[10] (fig 1). From the initial list of citations yielded in the literature search, 154 studies were included. After review of the complete texts, 142 studies were excluded, leaving 12 eligible studies for inclusion in this review.

Study characteristics

Injury-prevention studies fell into two groups: the effect of use of protective equipment; the effect of preseason conditioning programmes and injury-prevention strategy that continued throughout the season. Results will be discussed in these study groupings.

Outcome measures

The definition of injury varied across studies. In certain cases ''injured subjects'' could still have been actively involved in their sport; for example, Yang *et al*[11] used the definition ''any new injury that required medical attention or restricted participation on the day after the injury'', whereas Webster *et al*[12] used the definition ''any injury involving the head or face'', and Grace *et al*[13] used the simple definition ''any lower limb injury that limited participation''. In the majority of studies,[14–18] however, only subjects that missed one or more days' participation in sport were described as sustaining an injury. Two studies[19 20] focused solely on the incidence of knee injuries, with one[19] counting only knee injuries significant enough to seek care from an athletic trainer and leading to >5 days lost time from practice. Mandlebaum *et al*[20] focused on anterior cruciate ligament (ACL) injuries, using diagnostic confirmation from MRI and arthroscopy.

The methods used to collect injury data and verify the injury lacked consistency. In the majority, athletes subjectively reported their injury, by using questionnaires or by relaying information to a nominated reporter, coach, investigator, physiotherapist, nurse or doctor. Only half of the studies followed up subjective reports with a physical examination by a doctor, physiotherapist or athletic trainer,[13 16 17 19 21 22] and only one study opted to use further diagnostic imaging.[20]

Protective equipment

Four studies[11–13 17] monitored the benefits of various forms of protective equipment throughout a range of sporting environments. All of these studies achieved a poor rating on quality score (<50%). A 2-year study[13] found that hinged knee braces were not effective at reducing knee injury in high school American footballers, and were even associated with an increase in ipsilateral ankle and foot injuries. A larger study by Yang *et al*[11] using athletes from 12 different sports also found that both knee and ankle braces increased lower limb injury rates, but the use of knee pads was associated with a significant reduction. McIntosh and McCrory[17] found that headgear (scrum caps) could not reduce the incidence of concussion occurring in junior rugby union players over a single playing season, whereas the cohort study of Webster *et al*[12] on lacrosse players over two seasons found that eye goggles reduced the number of head and face injuries, particularly during competition.

Table 3 Preseason conditioning: study characteristics

Author, year, study type (setting)	Participants and recruitment	Groups/intervention (compliance)	Outcomes (follow-up period)	Comments
Hewett 1999 Prospective intervention study (USA)	1263 high school students from 43 sports teams (basketball, volleyball, soccer). Volunteer team allocation into 3 groups: 2 female and 1 male	(A) Preseason conditioning: 366 female athletes (185 volleyball, 97 soccer, 84 basketball; 15 different teams); 6 week preseason neuromuscular training programme (flexibility, plyometrics, weight training and landing mechanics); 60–90 min sessions; 3 times a week. (B) Control groups: 463 female athletes (81 volleyball, 193 soccer, 189 basketball). (C) Male controls: 434 male athletes (209 soccer, 225 basketball) (Compliance: self-reported).	Injury definition: knee ligament sprain or rupture causing player to seek care of athletic trainer and leading to at least 5 days of lost time from practice and games). Severity classification: classified by type, mechanism and treatment. (1 sporting season) Authors' conclusion: positive: neuromuscular training reduced serious knee injuries in females.	Data collection methods: injury documented by athletic trainers: (1) weekly reporting forms to monitor numbers of injuries along with game and practice injury risk exposures; (2) individual injury reporting forms to monitor injury type, mechanism + treatment. Injury verification: athletic trainer diagnosed serious injury with physician referral. ACL ruptures diagnosed with arthroscopy.
Heidt 2000 RCT (USA)	300 female soccer players (aged 14–18)	(A) Preseason conditioning: n = 42; 7 week programme consisting of sport-specific cardiovascular training, plyometric work, strength training and flexibility; 20 sessions in total (2 treadmill and 1 plyometric session a week). (B) Control: n = 258; no intervention. (Compliance: not described).	Injury definition: any injury causing the athlete to miss a game or practice. Severity classification: (1) missed 1 game/practice; (2) missed 2–3 games/practices; (3) missed 4–7 games/practices; (4) missed 2–4 weeks; (5) missed 1–2 months; (6) season-ending injury. (1 year: August–November and March–August). Authors' conclusion: positive: preseason conditioning prevents injury in female soccer players.	Data collection methods: injury information collected by school's athletic trainer (blinded). Injury verification: data recorded on injury incident report form (type, mechanism, severity, event in which occurred, type of shoe worn).

ACL, anterior cruciate ligament; RCT, randomised controlled trial.

Table 4 Preventive strategies continued throughout the playing season: summary of study characteristics

Author, year, study type (setting)	Participants and recruitment	Groups/intervention (compliance)	Outcomes (follow-up period)	Comments
Emery 2005 Cluster RCT (Canada)	120 subjects (aged 14–19; with no history of musculoskeletal injury or medical condition). Computer-generated random recruitment of schools and students (2 males and 2 females from PE programme roster in grades 10–12)	(A) Balance training (n = 60 players): physiotherapist taught each participant a home-based, proprioceptive balance training programme; performed 20 min/day for 6/52, then weekly for remainder of 6/12 period. (B) No intervention (n = 60 players). (Self-reported compliance: daily record sheet with weekly phone call over 6/52 training period).	Injury definition: any injury requiring medical attention or loss of 1 or more days of sporting activity or both. Severity classification: classified by area and type (sprain, fracture, etc) of injury. (6 months). Authors' conclusion: positive: wobble board reduced self-reported injury	Data collection methods: injury report forms; completed by subject and by any attending medical professional. The physiotherapist made biweekly phone calls to all participants to ensure all eligible injuries reported.
Wedderkopp 1999 Cluster RCT (Denmark)	237 female handball players (aged 16–18; playing at elite, intermediate, recreational levels). Randomised for intervention. Controlled for age, practice time, playing level, floor composition and injury incidence in previous season (self-reported, assessed with survey).	(A) Intervention protocol (11 teams; n = 111 players): various functional activities followed by use of ankle disc for 10–15 min at all practice sessions. (B) Control (11 teams; n = 126 players): subjects continued to practice as usual. (Compliance: not reported).	Injury definition: any injury causing the player to miss the next game or practice, or to play with considerable discomfort. Severity classification: absence from practice/games. Minor: <1 week. Moderate: 1 week but <1 month. Major: >1 month. (August–May 1996; 10 months). Authors' conclusion: positive: intervention group reduced injury.	Data collection methods: coaches documented injury incidence and severity by questionnaire. Injury verification: club physiotherapist and doctor.
Wedderkopp 2003 Cluster RCT (Denmark)	163 female European handball players (aged 14–16; playing at elite, intermediate and recreational levels). Randomised by team (8 to each group).	(A) Functional training and ankle disk (n = 77 players): performed for 10–15 min at each training session plus strength activities. (B) Functional training only (n = 8 teams; 86 players) (Compliance: not reported)	Injury definition: any injury causing the player to miss the next game or practice, or to play with considerable discomfort. Severity classification: absence from practice/games. Minor: 1 week. Moderate: >1 week but <1 month. Major: >1 month. (1 season). Authors' conclusion: positive: ankle disc reduced traumatic injury when added to functional strength training.	Data collection methods: investigators contacted coaches at least once a week. Injury verification: injured players contacted and interviewed by doctor. Examined if in doubt.
Olsen 2005 Cluster RCT (Norway)	1837 youth handball players (aged 15–17; 1586 female, 251 male); 123 volunteer clubs. Block randomisation to intervention or control group. Clubs matched by region, playing level, sex and numbers of players.	(A) Technical, balance and strengthening exercises (61 clubs; 958 players; 808 female, 150 male): structured 20 min group programme (warm-up, technical, balance and strengthening exercises). Performed before first 15 training sessions, then weekly for rest of season. (full details on each facet of warm-up described). (B) Control (59 clubs; 879 players; 778 female, 101 male): subjects advised to continue training as usual. (Compliance reported by coach of each team).	Injury definition: classified as acute or overuse injury to knee or ankle. Severity classification: absence from practice/games. Slight: 0 days. Minor: 1–7 days. Moderate: 8–21 days. Major: >21 days. (1 league season 8 months). Authors' conclusion: positive: an injury prevention protocol can prevent injuries in youth handball.	Data collection methods: injury and exposure reported by physiotherapists (blinded to group allocation) each month. Injury data confirmed by coaches at end of season.

Table 4 Continued

Author, year, study type (setting)	Participants and recruitment	Groups/intervention (compliance)	Outcomes (follow-up period)	Comments
Junge, 2002 Prospective intervention study (Switzerland)	Male soccer; age 14–19; 14 teams (3 high skill + 4 low skill level amateur youth teams in each group). Group allocation by geographic location (2 regions).	(A) Intervention group: general education and supervision of coaches + players. (Preventative intervention included: warm-up, cool-down, taping, rehabilitation, fair play and flexibility/stability exercises). (B) Control: subjects trained and played soccer as usual. (Physiotherapists delivered the primary intervention. Amount of training and matches was recorded for each player by coaches.)	Injury definition: any physical complaint caused by soccer that lasted for more than 2 weeks or resulted in absence from a subsequent match or training session. Severity classification. Mild: absence up to 1 week or complaints for >2 weeks. Moderate: absence for >1 week but <4 weeks. Severe: absence for at least 4 weeks or severe tissue damage, eg, fracture/dislocation (1 year). Incidence of injury per 1000 h. Authors' conclusion: positive: injury prevention intervention reduced injury.	Data collection methods/injury verification: doctors visited participants weekly to perform an interview and physical examination of injury. Type, severity and location of injury also documented.
Mandelbaum 2005 Prospective intervention study (USA)	1041 female competitive youth soccer players (age 14–18). Non-randomised teams volunteered for inclusion.	(A) Injury prevention protocol (n = 1041 (2000); n = 844 (2001); all female): warm-up, stretching and strengthening, plyometric activities, and soccer-specific agility drills. (B) Control (n = 1905 (2000); n = 1913 (2001)): continued traditional warm-up. Age and skill matched controls. (Compliance form for each team completed by coach with a spot check on last week of season).	Injury definition: study focused on non-contact ACL injuries. Severity classification. (2 years 2000–2001). Authors' conclusion: positive: a neuromuscular training programme led to a significant reduction in ACL injuries in female soccer players.	Data collection methods: injuries reported by coach on a weekly injury report form to project coordinator. If knee injury occurred, player was given a "knee injury questionnaire" to complete within 10 days and return to project coordinator. Injury verification: confirmed by doctor and MRI or arthroscopy.

ACL, anterior cruciate ligament; RCT, randomised controlled trial.

Table 5 Protective equipment: summary of study characteristics

Author, year, study type (setting)	Participants and recruitment	Groups/intervention (compliance)	Outcomes (follow-up period)	Comments
Yang 2005 Cluster cohort study (USA)	Random selection; 100 schools; stratified according to size and region; 19 728 athlete seasons (1 104 354 athlete exposures); grades 9–12; from 6 male sports and 6 female sports in each school (sport selected using systematic sampling).	(A) Protective equipment: any self-reported use of discretionary protective equipment not required by sports rules. (B) Control: self-reported non-use of discretionary protective equipment. (Self-reported compliance: questionnaire).	Injury definition: any new injury sustained between hip and toe that required medical attention or restricted participation on the day after the injury. Severity classification: (1) ''no time lost to participation''; (2) mild injury, <1 week lost; (3) moderate injury, <3 weeks lost; (4) serious injury, lost more than 3 weeks. (3 year period). Authors' conclusion: inconclusive: use of lower limb discretionary equipment has variable effect on injury rate and severity,	Data collection methods: 4 questionnaires, administered during the season by trained member of school staff. Injury verification: not described.
McIntosh 2001 Pilot prospective intervention study, cluster randomisation (Australia)	294 male rugby union players (age under 15 A grade) from 6 schools (schools volunteered to participate in study). Randomisation by teams (total of 16 teams) to intervention and control groups.	(A) Headgear: 1179 exposures with headgear (9 teams). (B) Control: 357 exposures without headgear (7 teams). (Participation and headgear use documented by recording officer at each school. Checked at random by investigators).	Injury definition: a traumatic event that resulted in the player missing game playing or training time. Authors' conclusion: negative: current headgear does not provide significant protection against concussion in junior level rugby union.	Data collection methods: nominated ''recording officer'' for each team documented details of head injury for each game. Injury verification: team medical officers contacted to verify diagnosis.
Webster 1999 Prospective cohort study (USA)	700 high school lacrosse players (all female aged 13–18)	(A) Goggles: 51 376 exposures. (B) No goggles: 77 947 exposures. Note: allocation to groups based on voluntary use.	Injury definition: all reported injuries involving eyes, face, scalp, skull, ears and jaw to trainer, coach, nurse or other officials. Severity classification: according to injury site, mechanism, type and severity. (no details provided). Authors' conclusion: positive: the use of protective eyewear is beneficial in preventing injury in women's lacrosse.	Data collection methods: collected by coaches + athletic trainers, nurse and other officials on data reporting forms. Follow-up information requested 2–4 weeks after initial report to assess seriousness of injury. Injury verification: not described
Grace 1988 Prospective cohort study (matched pair) (USA)	580 (694) male high school varsity + junior varsity footballers.	(A) Knee brace: 330 athletes in knee braces (247 single hinged brace, 83 single-upright double hinged brace). (B) Control: 250 non-braced players matched for height, weight and playing position.	Injury definition: mild, less than 1 day of participation lost; minor (grade 1), loss of <7 days; moderate (grade II), 7–20 days lost; major (grade III), ⩾21 days lost. (2 year study period). Authors' conclusion: negative: braces did not reduce incidence of knee injuries, and were associated with increased injuries of ankle and foot on same side as knee injury.	Data collection methods: injuries of lower extremity + treatment documented during the season by school's full time athletic trainer. Injury verification: injuries diagnosed and managed by school doctors (voluntary).

Table 6 Summary of study results

First author	Sample size	Outcome measured	Injuries in intervention group (A)	Injuries in control group (B)	Injury reduction (RR (95% CI))	Absolute risk reduction	NNT
Emery	114	Self-reported injury	2	10	0.2 (0.03 to 0.72)	−0.19 (19%)	5
Jung	194	Injury per player per year	0.76	1.18	0.73	−0.195 (19%)	6
		Injury per 1000 h exposure	6.71	8.48			
Mandlebaum	2943	ACL injury rate per	0.05	0.47	0.255	−0.18 (18%)	6
	2757	athlete/1000 exposures/year	0.13	0.51			
Olsen	1837	Number (%) of injured players (all injuries)	95 (9.9%)	167 (19%)	0.49 (0.36 to 0.68)	−0.1 (10%)	10
		Number of acute knee/ankle injuries	85	156	0.51 (0.39 to 0.66)		
		Number of overuse injuries	18	39	0.43 (0.25 to 0.75)		
		Knee and ankle injuries per 1000 player hours	0.9	1.8	0.53 (0.35 to 0.81)		
Wedderkopp (1999)	137	Number of injuries	14	66	0.198	−0.26 (26%)	4
		Injuries per 1000 h practice	0.34	1.17			
		Injuries per 1000 h game	4.68	23.38			
Wedderkopp (2003)	163	Incidence of traumatic injury/1000 h practice	0.2	0.6	0.42 when using ankle disc compared with no ankle disc training	−0.11 (11%)	9
		Incidence of traumatic injury/1000 h match	2.4	6.9			
Hewett	1263	Number of serious knee injuries	2/366	10/463	0.25 (0.06 to 1.15)	−0.015 (1.5%)	66 (note these data reflect serious injuries; most were season ending)
		Knee injury per 1000 exposures	0.12	0.43			
		Non-contact injuries per 1000 exposures	0	0.35			
Heidt	300	Total number of injured subjects	6/42	87/258	0.42 (0.2 to 0.9)	−0.20 (20%)	5
		Total number of injuries	7/42 (16%)	91/258 (35%)		−0.19 (19%)	
Grace	580	Number of knee injuries (diagnosed by doctor)	42/330	11/250	2.88	+ 0.083 (+8.3%) *	Higher injury rate in intervention group
MacIntosh	294	Number of concussions (diagnosed by doctor)	7/1179	2/357	1.05	+ 0.0003 (+0.03%)*	Higher injury rate in intervention group
Webster	700	Number of injuries per 1000 game exposures	1.25	2.4	0.52	Insufficient data	Insufficient data
Yang	1 104 354 athlete exposures (19,728 athletes)	Lower extremity injury	Unable to calculate	Unable to calculate	0.91 (0.72 to 1.15) when use of all protective equipment compared with control	9%	Insufficient data

ACL, anterior cruciate ligament; NNT, number needed to treat; RR, relative risk.
*+ indicates increased risk in intervention group.

In summary, there is limited evidence that eye goggles and knee pads can reduce the incidence of head and face (RR = 0.52)[12] and knee (RR = 0.44)[11] injuries, respectively, and there is currently no evidence to suggest that headgear (RR = 1.05)[17] and knee braces (RR = 2.24)[13] have a positive effect on injury prevention.

Preseason conditioning

Hewett *et al*[19] used a preseason conditioning strategy to develop flexibility, strength, power and landing mechanics. Using a sample of female soccer, volleyball and basketball players, he found that 6 weeks of this preventive intervention (three sessions a week) decreased the number of serious knee injuries over the next sporting season. Although this study used a large sample size (n = 1263), it scored poorly on the quality scale (<50%), and subjects entered into either the intervention or control group on a voluntary basis. Moreover, the effect of this strategy on other lower limb injuries is not clear.

Heidt *et al*[15] carried out a similar study, but used a randomised controlled study design with moderate quality (11/18), using a smaller group of female soccer players. The study randomised subjects to either a 7-week conditioning programme designed to improve sports-specific cardiovascular fitness, lower limb strength, flexibility and power or to a control group receiving no preseason intervention. A 1-year (two seasons) follow-up showed that the injury rate of the conditioning group was significantly lower than that of the control group.

In summary, there is poor evidence from one cohort study and moderate evidence from one randomised controlled study that 6 weeks of preseason conditioning can significantly reduce injury rate in female athletes (RR = 0.25[19], RR = 0.42[15]).

Injury prevention strategies throughout the playing season

Proprioceptive training

Three studies[14 21 22] using cluster randomisation and scoring moderately (10/18) on the quality scoring scale examined the effectiveness of various balance-training protocols. Emery *et al*[14] found that a home-based proprioceptive balance-training

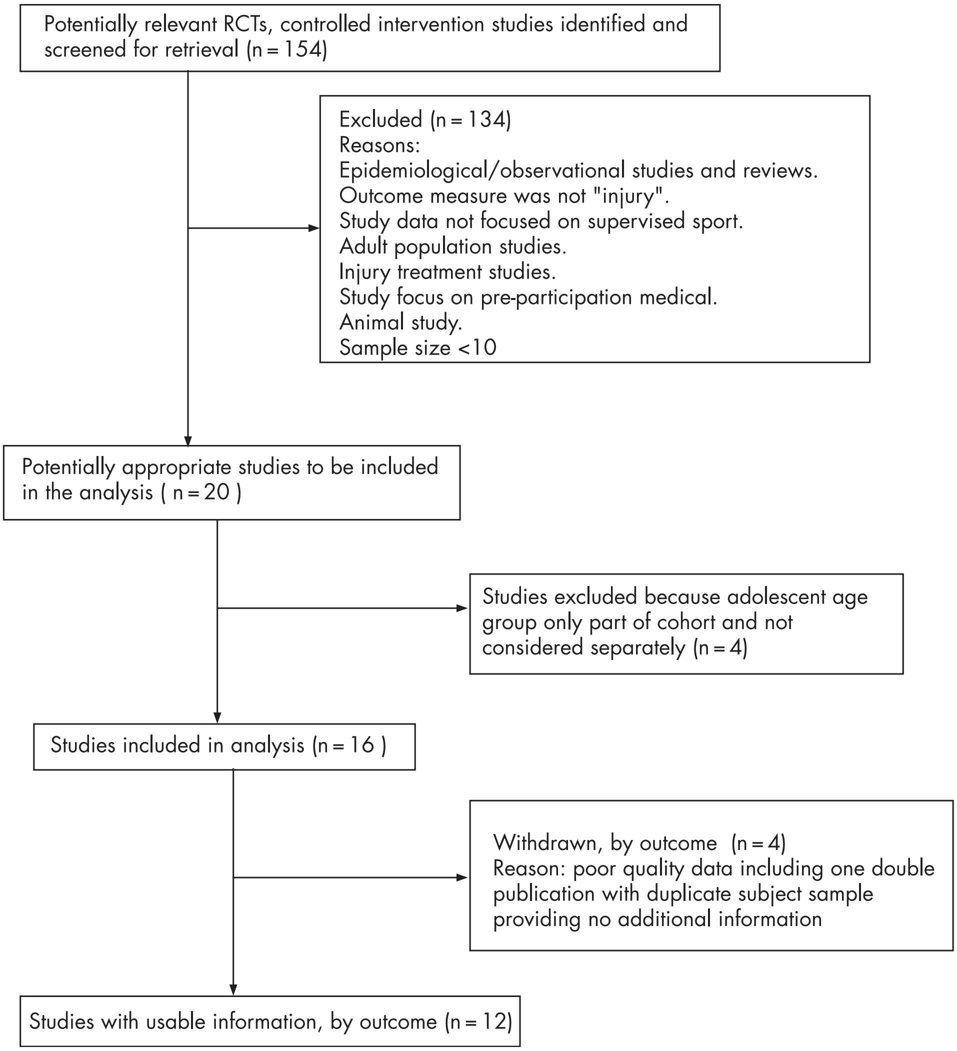

Figure 1 A systematic review of strategies to prevent injury in adolescent sport. RCT, randomised controlled trial.

programme (daily for 6 weeks, then weekly for a further 5 months) using a wobble board improved static and dynamic balance in healthy adolescents and reduced the incidence of self-reported injury over a 6-month period. Similarly, Wedderkopp *et al*[21] found that female handball players using an ankle disc in conjunction with functional strengthening at each practice session were less likely to be injured than a control group (training as normal). A follow-up study by the same group[22] using similar methods and population provided evidence that the combination of ankle disc training and functional strengthening is more effective at reducing injury incidence than functional strengthening alone.

Structured warm-up

Three trials[16 18 20] of moderate quality studied the cumulative effect of using a range of injury-preventive strategies during the playing season. Olsen *et al*[18] block-randomised handball clubs in Norway to either a control intervention (training as normal) or an intervention group that used a structured 20-min warm-up before each training session. The warm-up consisted of lower limb proprioception, strengthening exercises and technical training, with all athletes encouraged to maintain optimal lower limb alignment and control. This study, which scored highest on methodological quality rating (13/18), found that fewer knee and ankle injuries occurred in the intervention group during the one-season follow-up period. Furthermore, a prospective cohort study[20] found that a structured warm-up emphasising strengthening, stretching, plyometrics and soccer-specific agility was significantly more effective than a traditional warm-up at reducing ACL injuries in female soccer players. A more generic preventive programme (including education, warm-up, cool-down, taping, rehabilitation, flexibility and stability) delivered in the 1-year cohort study of Junge *et al*[16] was also effective in reducing male soccer injuries.

In summary, there is moderate evidence that all the reviewed injury-prevention strategies carried out throughout the playing season prevented injury (RR 0.2–0.73, table 6).

Quantitative data synthesis

Tables 1 and 2 describe the quality scoring key and study quality scores respectively. These tables illustrate that there was no good quality study scoring 16 or more, but seven moderate studies scoring between 9 and 15, and five poor quality studies scoring less than 9. There were several criteria that consistently limited the quality of studies: none of the included studies carried out allocation concealment, and only one was considered to have performed sufficient randomisation; however, six additional studies demonstrated acceptable "cluster randomisation".

We assessed the treatment effect by (1) considering preventive strategy in relation to the risk, type and severity of injuries, (2) considering the feasibility of replicating the intervention used, and (3) calculating the number needed to treat (NNT) to prevent one injury. Treatment effect in terms of NNT was calculated where there were sufficient data and is given in table 6.

DISCUSSION
Protective equipment
Headgear
Headgear is designed to attenuate the impact energy of an insult to the head. In this review, McIntosh and McCrory[17] found an increase in the rate of head injury with the use of protective headgear. It may be that the type of material used in headguards cannot withstand the high impacts associated with collision sports. Alternatively the findings may reflect the competitive nature of sport and the potential influence of protective equipment on behaviour. It has been proposed that wearing pads or headguards can cause ''risk compensation'' or ''risk homoeostasis'' whereby athletes act in a riskier manner than usual because of the sense of increased protection.[23 24] Although a recent case-controlled study (n = 674)[25] seems to refute this theory, finding no association between the use of protective equipment and risk-taking activity in children, the inclusion of younger children (8–18 years) may have led to bias.

The use of mouthguards is another commonly used preventive strategy in contact sports. Studies on adults have shown that mouthguards can prevent injury in rugby union[26 27] and other contact sports.[28] Similar studies on adolescents have been undertaken, but they failed to meet the inclusion criteria for the current review. High-quality studies are therefore required to make definitive conclusions on the effectiveness of headgear and mouthguards and their influence on risk-taking behaviour in adolescents.

Bracing
We found an increase in injuries associated with the use of protective external bracing, whereas kneepad use was associated with a reduction in lower limb injury.[11 13] Primarily, it must be noted that the included studies scored poorly on study quality rating, and both failed to use any form of randomisation. Brace use in all included studies was based purely on individual preference, therefore a number of other confounding factors may have contributed to the injury incidence. Indeed it has been suggested that subjects opting not to wear a brace are more likely to be risk takers, whereas ''brace users'' might be more risk adverse.[29] Other personality traits—for example, type A personality or levels of exercise dependence—can also act as a precursor to sustaining injury,[30] and although this conjecture may not explain the present results, it does highlight the importance of using adequate randomisation procedures in future studies.

Notwithstanding the methodological flaws, an increase in injury was associated with the use of protective bracing, which agrees with earlier reports.[31] Although there is some evidence from cadaver studies that knee bracing does offer protection to knee ligaments under external load,[31 32] this effect may not carry over to the high-velocity, multidirectional forces encountered during sporting activity. Others have found that bracing can lead to increased muscle fatigue,[33] and it has also been linked to decreased athletic performance,[33] factors that may cumulate to increase the injury risk.

Pragmatists argue that the potential benefits of taping and bracing are related to enhancing sensorimotor control rather than providing mechanical constraint, but the evidence to support this remains contradictory. There is some evidence to show that knee bracing can enhance sensorimotor control in subjects with a history of knee injury,[34 35] but the effect is lessened with more demanding functional tasks, and the clinical benefits of such small changes have also been questioned.[35] A review by Beynnon *et al*[36] found that the application of an elastic bandage can enhance joint positional sense in knees with an ACL tear, and a cohort study also supports the use of knee bracing in preventing re-injury during skiing.[37] Generally, however, the effects of bracing on sensorimotor control seem less definitive in healthy subjects,[38] and a systematic review[39] found no consistent evidence of effectiveness for knee bracing in reducing knee injury in adult and adolescent sports people. Further randomised studies must assess the effectiveness of bracing in preventing primary injury in adolescents.

Preseason conditioning and preventive strategies continued throughout the playing season
Conditioning programmes that include strength, flexibility, balance, and sport-specific fitness and technique training prevent lower limb injury. This benefit appears to be optimised when the preventive programme is continued throughout the playing season. This finding is consistent with adult studies that showed significant reductions in ankle sprain on introduction of preventive programmes in volleyball.[40–42] Similarly preventive programmes in football (soccer) produced a 50–75% reduction in injuries in general[43] and a significant reduction in ACL injuries.[44]

Conversely our findings do not agree with a review of the impact of stretching on sports injury risk.[45] Studies that focus on stretching alone or stretching plus warm-up and cool-down strategies—for example, a stretching protocol performed during pre-exercise warm-up—did not produce clinically meaningful reductions in risk of exercise-related injury in army recruits,[46 47] and half-time stretching exercises performed by high school footballers did not reduce the incidence of match injuries.[48] Furthermore, research on running injuries[49 50] indicates that injury incidence is not reduced by preventive strategies such as stretching, warm-up and cool-down. This could be explained by the pre-study practice of participants—that is, they were already undertaking some form of pre-exercise programme that included these aspects and therefore the intervention studied was not sufficiently different to demonstrate an effect change. An additional consideration may be that recreational and distance runners are not an equivalent population group, and caution should be exercised in extrapolating results to this setting.

It may be that the functional components of the preventive programme—that is, conditioning, proprioceptive balance training and skills training—are responsible for producing the physiological adaptations that help to prevent injury in the adolescent population.

In summary, we found that the evidence for using protective equipment—that is, bracing, taping and headgear—is inconclusive and hampered by confounding factors that are difficult to control for. There is poor evidence to support the protective effect of knee pads and eye goggles. However, there is significant and consistent evidence to support injury prevention strategies that include a combination of the following elements: preseason conditioning, functional training, education, strength, and proprioceptive balance training programmes that are continued throughout the playing season. The risk reduction is broadly similar for all strategies studied. The NNT to avoid an injury ranged from 4–10 for all injuries (table 6) to 66 for serious injury—that is, ACL injury.[19] Clearly no ''one value'' for NNT can be deemed worthwhile.[9] However, it would seem acceptable that 10 adolescents should be trained in such a way as to avoid one minor injury. Similarly a training programme that could prevent a season-threatening, if not career-threatening, injury such as an ACL rupture with a NNT of less than 100 would normally be considered acceptable. Furthermore, the intervention programmes described could easily be reproduced and applied across many sports. A significant proportion of the programmes are probably current practice in many training sessions, and adaptation to include aspects such as proprioception does not carry a major educational or financial implication.

What is already known on this topic

- Sport is the main cause of injury in adolescents.
- Adult studies have identified that injury can be prevented by using protective equipment and improving fitness, flexibility and balance.
- However, injury-prevention strategies that focus specifically on the adolescent age group have not been reviewed.

What this study adds

- There is significant and consistent evidence in the literature to support the use of injury-prevention strategies in adolescents that include preseason conditioning as well as functional training, education, strength and balance programmes that are continued throughout the playing season.
- The evidence for protective equipment in injury prevention in adolescents is inconclusive and requires further assessment.

CONCLUSION

The development and application of injury prevention strategies that focus on preseason conditioning, functional training, education, proprioceptive balance training and sport-specific skills, which should be continued throughout the sporting season, are effective. The evidence for protective equipment in injury prevention is inconclusive and requires further assessment.

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