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Intervention Strategies Used in Sport Injury Prevention Studies: A Systematic Review Identifying Studies Applying the Haddon Matrix

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Abstract

Background Prevention of sport injuries is crucial to maximise the health and societal benefits of a physically active lifestyle. To strengthen the translation and implementation of the available evidence base on effective preventive measures, a range of potentially relevant strategies should be considered.

Objective Our aim was to identify and categorise intervention strategies for the prevention of acute sport injuries evaluated in the scientific literature, applying the Haddon matrix, and identify potential knowledge gaps.

Methods Five electronic databases were searched (PubMed, EMBASE, SPORTDiscus, CINAHL, Cochrane) for studies that evaluated the effect of interventions on the occurrence of acute sport injuries. Studies were required to include a control group/condition, prospective data collection, and a quantitative injury outcome measure.

Results A total of 155 studies were included, mostly randomised controlled trials (43%). The majority of studies (55%) focussed on strategies requiring a behavioural change on the part of athletes. Studies predominantly evaluated the preventive effect of various training programmes targeted at the ‘pre-event’ phase ($n = 73$) and the use of equipment to avoid injury in the ‘event phase’ ($n = 29$). A limited number of studies evaluated the preventive effect of strategies geared at rules and regulations ($n = 14$), and contextual modifications ($n = 18$). Studies specifically aimed at preventing re-injuries were a minority ($n = 8$), and were mostly related to ankle sprains ($n = 5$).
Conclusions Valuable insight into the extent of the evidence base of sport injury prevention studies was obtained for 20 potential intervention strategies. This approach can be used to monitor potential gaps in the knowledge base on sport injury prevention.

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Key Points

A modified version of the Haddon matrix, representing 20 possible intervention strategies, is a useful tool to identify possible intervention strategies for sport injury prevention.

Studies in the area of rule and regulation changes, education, and psychological/cognitive skills training are underrepresented. These provide new opportunities for sport injury prevention research.

Non(randomised) controlled trials have been used extensively in sport injury prevention studies, and are valid options to evaluate the effect of intervention strategies when the use of a control group is not feasible, for instance, in the case of rule modifications and policy interventions.

1 Introduction

Both a physically active lifestyle and sport participation are recommended because of their inherent health benefits [1–4]. However, they also carry a risk of sustaining injuries. These injuries form a significant public health problem at an individual and societal level, including (temporary) physical inactivity and direct and indirect costs related to medical treatment and work absenteeism. As such, the prevention of sport injuries is important to maintain and increase a physically active lifestyle and sports participation, and to maximise the related health and societal benefits [5].

Numerous studies and systematic reviews have evaluated the effects of preventive interventions on the risk of sport injuries [6–12], and, as such, these provide an evidence base for implementation efforts [13]. Differences have been found in the type of preventive measure or intervention under study by injury type and sport [8–10]. Most studies have used a randomised controlled trial (RCT) design [11]. RCTs are considered the optimal study design to establish a cause–effect relationship and, as such, to establish the effect of an intervention [14–16]. Other study designs have also been used in sport injury prevention studies [11], as RCTs are not always feasible in a real-world sport setting due to ethical or practical reasons [14, 15]. This is especially true for evaluating contextual, policy-level interventions (such as legislation or regulation changes) and for interventions that have become common practice. When evaluating such interventions, time trend analyses (e.g. pretest–posttest designs) are considered adequate study designs [14, 15].

Despite this wide base of knowledge on sport injury prevention, large-scale implementation of effective preventive interventions in real-world sport settings is still a major challenge [17–19]. Actual injury prevention in daily practice requires large-scale adoption and the correct use of evidence-based preventive interventions by the target population [13]. The majority of the available evidence on sport injury prevention appears to focus on the behaviours and actions of individual athletes, including evaluating the use of personal protective equipment (PPE) and specific training programmes to reduce the risk of injuries [7, 11, 20]. Implementation of such measures requires a behavioural change on the part of an athlete [21, 22]. This may be a challenging task, since intervention strategies that predominantly target behavioural modifications in individuals are found to be less effective in injury prevention than those based on contextual modifications, such as regulations, enforcement methods, and environmental and product modifications [7, 22–24]. Moreover, in the sport injury context, injury prevention requires more than just a change in athlete behaviours, but also relies on broad support and behaviour change from sporting federations, coaches, allied health staff and others [25]. Therefore, a range of potentially relevant strategies should be considered to support and strengthen sport injury prevention efforts.

An overview of sport injury prevention studies categorised by their intervention strategy, i.e. geared at the individual versus geared at the context, is as yet lacking. A useful and valid tool for the categorisation of intervention strategies for the prevention of acute injuries is the Haddon matrix [24, 26]. This matrix, originating from traffic safety research, has previously been successfully applied to sport injury prevention. An early example of its use to identify possible sport injury prevention strategies is the study by Bahr et al. [27] for the prevention of ankle sprains in volleyball. A recent review on snow sport injuries also used the Haddon matrix as its conceptual framework [28].

The aim of this systematic review was to identify intervention strategies for the prevention of sport injuries evaluated in the scientific literature, and to identify potential intervention strategies not yet evaluated (i.e. to identify potential knowledge gaps), making use of the Haddon matrix. The review was restricted to the prevention of acute sport injuries. The specific objectives of this review were to (1) provide a categorisation of sport injury prevention studies by intervention strategy using the Haddon matrix; (2) assess differences in intervention strategies evaluated in studies aimed at the prevention of different injury types and sports; and (3) categorise the number of sport injury prevention studies by study design and intervention strategy. Such an evidence-based overview can facilitate future sport injury prevention efforts by

identifying possible strategies to choose from, given an injury problem and context.

2 Methods

2.1 Definitions

For the purpose of this review, sport injury prevention studies were defined as studies evaluating the efficacy or effectiveness of interventions aiming to prevent the occurrence of injuries within a real-world sport setting [25]. Acute sport injuries were defined as traumatic injuries (i.e. caused by a single, specific and identifiable onset), in contrast to overuse injuries (i.e. a gradual onset) [29] and systemic injuries (e.g. heat stress, organ failure, sudden cardiovascular death).

2.2 Literature Search

A systematic computerised search was performed to identify relevant studies published up to 31 December 2015, using five electronic databases: PubMed, EMBASE, SPORTDiscus, CINAHL and Cochrane Central Register of Controlled Trials. The search terms used were a combination of database-specific thesaurus terms and free-text terms in the title and abstract related to (a) the problem (*injur* AND sport*/athlet*/exercis**), (b) the intervention (*prevent* AND injur**), and (c) the study design, using standard Cochrane scripts (terms were used to identify clinical trials, cohort, epidemiological and evaluation studies, and systematic reviews). The search was limited to humans and English-language publications. The reference lists of relevant recent systematic reviews (i.e. published since 2010) that appeared in the search were screened for additional studies. No publication date restrictions were used.

2.2.1 Inclusion Criteria

Studies were considered for inclusion if they met all of the following criteria: (a) they evaluated the effect of a preventive measure or intervention on the occurrence of acute injuries in sports; (b) the study subjects were able-bodied, healthy and physically active at the time of injury (all ages, male and female); (c) data were registered prospectively; (d) the study design included a control group or control condition (e.g. pre-interrupted data serving as control condition in pretest–posttest design, or interrupted time series); (e) the study results contained a quantitative injury measure as an outcome; and (f) the article concerned original research, published in a peer-reviewed journal.

2.2.2 Exclusion Criteria

Studies that evaluated the effect of a preventive measure or intervention on overuse injuries were excluded. However, studies targeting both acute and overuse injuries [or all injuries in specific body region(s)] were included in the review, but data extraction was restricted to acute injuries only. Injury prevention studies related to commuting (e.g. cycling), dance, performing arts (e.g. ballet and circus), and leisure time physical activity next to sports (e.g. play) [30] were excluded from this review. Injury prevention studies evaluating the effect of interventions outside an everyday sport setting (i.e. military training studies, laboratory-based studies, and modelling studies) were excluded. Studies that reported on intermediary behaviour (e.g. protective equipment use) or determinants of preventive behaviour (e.g. individuals' knowledge or attitudes) as an outcome measure, rather than reporting on a quantitative injury measure as an outcome, were not included either. If several exclusion criteria applied to a study, only one was noted.

2.2.3 Study Selection

All identified studies were screened for relevance in two steps. First, all studies were evaluated for inclusion based on title and abstract. In the case of uncertainty, full-text articles were retrieved. To become familiarised with the inclusion assessment, two reviewers (IV and EALMV) independently screened a random selection of 215 studies in two rounds. Out of the first 106 studies screened, there was initial disagreement on 16 studies; the next 109 studies screened resulted in disagreement on one study. Based on this high level of agreement, it was decided that the remaining studies only needed to be evaluated for inclusion based on title and abstract by one reviewer (IV). As a second step, two authors independently evaluated full-text articles for final inclusion (IV and EALMV). Any disagreement in the selection of potentially relevant studies was resolved by consensus.

2.3 Methodological Quality Assessment

All relevant studies were categorised by study design following the system used in evidence-based practice to indicate the strength of evidence based on the study results [31]. As the primary aim of this systematic review was to categorise studies by intervention strategy used, and not to assess the effect of a preventive intervention, risk of bias in individual studies was not assessed. A similar approach has been used in previous systematic reviews on the prevention of sports injuries [7, 11].

2.4 Data Extraction

One reviewer (IV) extracted data from the included studies, describing study design, characteristics of study participants, sport, injury (causation, location and type), preventive intervention, study outcome, and intervention strategy (Table 1). A standardised form was used for data extraction. The primary aim of each individual sport injury prevention study was used as a starting point for the categorisation of the extracted data. The categorisation of extracted data was checked for consistency.

2.4.1 Intervention Strategy

The included studies were categorised by their intervention strategy, applying a modified version of the original Haddon matrix. The original Haddon matrix identified nine potential intervention strategies to prevent injuries, based on two dimensions (3×3 matrix): (1) three levels for intervention targets (i.e. 1 = host, 2 = agent, 3 = physical and sociocultural environment) and (2) the time window or time frame in which an injury occurs (i.e. 1 = pre-event, 2 = event, 3 = post-event) [24, 26].

For the purpose of this review, the original Haddon matrix was modified for sport injury prevention. The first dimension (i.e. intervention target) was expanded from

three to four levels. The host was interpreted as the athlete; the agent as the sport activity subdivided into rules and regulations of the sport, and sport equipment; and the environment was interpreted as the physical, sociocultural and policy setting or context within which the sports injury occurs [24, 27]. Interventions targeting the agent are aimed at reducing the amount of energy created or transferred. The second dimension (i.e. time window) comprised the three levels of the original Haddon matrix. In accordance with the purpose of this review, the post-event phase was restricted to interventions specifically targeted at the prevention of recurrent injuries. Next, a category was added to both dimensions of the original Haddon matrix to categorise studies evaluating the effect of multi-component or multiple interventions. As such, a total of 20 potential intervention strategies for sport injury prevention were distinguished, based on two dimensions (5×4 matrix; Table 2).

3 Results

3.1 Literature Search

The search strategy initially yielded 16,314 articles, of which 226 studies were considered relevant after title and

Table 1 Data extracted from the included studies

Item	Categories
Study design	Randomised controlled trial; controlled trial; prospective cohort study; pretest–posttest design; interrupted time series
Target population	General sport population; athletes with a previous injury (or reduced function/residual symptoms)
Age	Children (<18 years); adults (18–65 years); elderly (65+ years); all
Sex	Male; female; both
Sport	Sport activity targeted in the intervention under study
Preventive intervention	Training (strength, plyometrics, endurance, agility, flexibility, stretching, balance/coordination, sport-specific skills/technique, other); education; rules and regulations (rule change, enforcement); equipment (personal protective equipment, brace, tape, footwear/orthotics, sport devices); context (physical, sociocultural, policy); multi-component intervention
Intervention target ^a	Athlete; rules and regulations; equipment; sport setting or context; multiple
Time window ^a	Pre-event; event; post-event; multiple
Injury causation ^b	Acute (traumatic onset); overuse (gradual onset)
Injury location (body region) ^b	Head/face, neck/cervical spine (head/neck); shoulder/clavicle, arm/elbow, wrist, hand/fingers (upper limb); back, abdomen, pelvis (trunk); groin, thigh/hamstring, knee, lower leg/Achilles tendon, ankle, foot/toes (lower limb); other
Injury type (structure involved) ^b	Fracture (bone); dislocation/subluxation, sprain (joint-ligament); strain, tendinopathy (muscle–tendon); abrasion, laceration, contusion (skin); concussion, structural brain injury, spinal cord injury (central and peripheral nervous systems); dental injury; organ injury (blunt trauma); other
Study outcome	Significant change; not significant change in main injury outcome(s) (following the study outcome and the level of statistical significance set by the original researchers)

^a Adapted from the Haddon matrix [24, 26]

^b Based on the Orchard Sports Injury Classification System (OSICS): sprain = stretch and/or tear of a ligament; strain = stretch and/or tear of a musculotendinous structure) [29]

Table 2 Definitions used for the modified Haddon matrix with regard to the prevention of acute sport injuries [24, 27]

Dimension level	Definition
Dimension A: intervention target	
Athlete (<i>host</i>)	Interventions targeted to change individual player attitudes, knowledge or behaviours (e.g. improve physical fitness, skills and techniques)
Rules and regulations in sport (<i>agent</i>)	New or modified rules in sport (including rules regulating PPE use, and enforcement of rules) to change athletes' behaviour related to the sport activity
Sport equipment (<i>agent</i>)	New or modified PPE or sport equipment related to the sport activity (including tape, braces, footwear and shoe inserts)
Sport setting or context (<i>environment</i>)	Interventions targeted to change the physical, sociocultural and policy setting or context within which the sport injury occurs
Multi-component, or multiple interventions	Interventions that include multiple intervention targets
Dimension B: time window or time frame in which an injury occurs	
Pre-event	Interventions aimed to prevent the sport injury event from occurring in the first place, reduce the injury risk to an acceptable level before participation, or build the capacity of an athlete before the injury event
Event	Interventions aimed at being effective at the time of the injury event
Post-event	Interventions aimed to minimise the consequences of a sports injury by treatment and rehabilitation, and returning the athlete to the 'pre-event' status
Multiple time windows	Interventions that include multiple interventions, targeting different time windows in which an injury occurs (within a study)

PPE personal protective equipment

abstract screening. An additional 38 articles were identified through reference lists of relevant systematic reviews. After reading the full-text papers, a further 109 papers were excluded, including three studies exclusively targeted at the prevention of overuse injuries [32–34]. A total of 155 studies were included for analyses (Fig. 1). Of these, 88 studies targeted the prevention of acute injuries and 67 studies the prevention of all injuries, including acute injuries. Most studies used an RCT design to evaluate the preventive effect of an intervention ($n = 66$; 43%) [30, 35–99]. In addition, 23 controlled trials (CTs) (15%) [100–122], 22 prospective cohort studies (14%) [123–144], 39 studies with pretest–posttest designs (25%) [145–183], and five interrupted time series (3%) [184–188] were included.

3.1.1 Target Study Population

The majority of the included studies focussed on preventing injuries in the general sport population regardless of injury history ($n = 135$). Some studies exclusively targeted the prevention of re-injuries (i.e. athletes with a previous injury or reduced function/residual complaints; $n = 8$) [40, 47, 52, 56, 59, 69, 99, 140], or included athletes at risk based on a psychological high injury risk profile [93, 94] or reduced hip adductor strength [174] ($n = 3$). Another nine studies excluded athletes with a previous (recent) injury at the start of the study [36, 38, 39, 46, 75, 88, 105, 123, 131].

A total of 25 different sports were studied. Soccer was the most frequently studied sport ($n = 43$; 28%), followed by rugby ($n = 13$; 8%), American Football ($n = 12$; 8%), basketball ($n = 11$; 7%), and ice hockey ($n = 10$; 7%). Another 13 studies (8%) focussed on the prevention of injuries in multiple sports combined.

One-third of the included studies were targeted at male athletes only ($n = 52$; 34%). Another 22 studies only included females (14%), and 49 studies (32%) included both sexes. The focus of the included studies was on the prevention of sport injuries in children ($n = 49$; 32%), adults ($n = 40$; 26%), or people of any age ($n = 34$; 22%). For 18 studies (12%), the age of the study population could not be retrieved.

3.1.2 Body Region and Injury Type

Overall, most studies evaluated the effect of an intervention on injuries to the lower limb ($n = 73$), and/or any injury ($n = 72$). With regard to the lower limb, the majority of studies specifically targeted the prevention of ankle injuries ($n = 27$) and/or knee injuries ($n = 23$). There were 24 studies specifically aimed at preventing ankle sprains, and 13 studies aimed at preventing knee ligament injuries. A total of 25 studies aimed to prevent head/neck injuries, primarily head/face injuries ($n = 21$) including concussions ($n = 10$). A few studies specifically targeted sport injuries to the upper limb ($n = 4$) and/or trunk ($n = 6$).

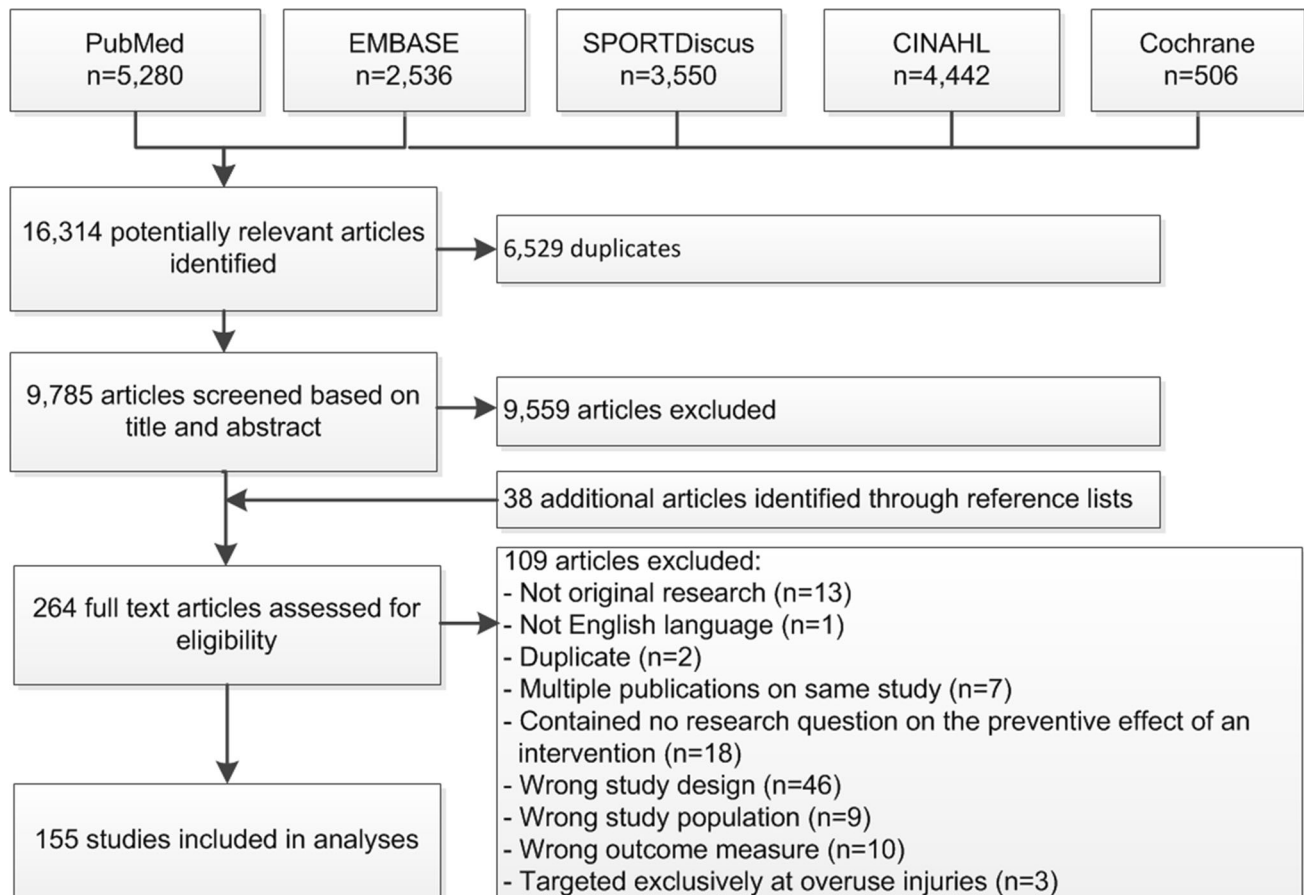


Fig. 1 Flow chart of literature search and study selection. *CINAHL* Cumulative Index to Nursing and Allied Health Literature, *Cochrane* Cochrane Central Register of Controlled Trials

3.2 Intervention Strategies

3.2.1 Preventive Interventions Under Study

Most studies ($n = 70$; 45%) focussed on the preventive effect of a variety of training programmes, including warm-up programmes and the FIFA 11/11+ programme, aimed at improving general physical fitness and/or skills of athletes. The focus of 33 studies (21%) was on the preventive effect of sport equipment, including PPE, and brace or tape. Another 14 studies evaluated the preventive effect of rules and regulations in sport (9%), including rule modifications ($n = 4$), stricter rule enforcement by referees ($n = 2$), and (new/existing) rules related to mandatory PPE use ($n = 8$). The effect of education was evaluated in 12 studies (8%), other context-related interventions in 12 studies (8%), and multi-component interventions/multiple interventions in 14 studies (9%).

3.2.2 Strategies Used in Sport Injury Prevention Studies

The majority of intervention strategies targeted the preventive behaviour of athletes in the pre-event phase ($n = 79$; 51%).

These strategies most often concerned training programmes to improve physical fitness ($n = 58$); training components frequently included were strength training (58%), balance/coordination training (45%), stretching (31%), and plyometrics (30%). Another six training programmes (9%) in the pre-event phase were aimed at improving psychological and/or cognitive skills [86, 93, 94, 106, 121, 122].

A total of 29 studies evaluated the effect of sport equipment use (i.e. PPE, tape, brace and footwear) in the event phase (19%). Few injury prevention studies were found on the effect of strategies targeted at rules and regulations ($n = 14$) or contextual modifications ($n = 18$). These strategies were primarily implemented at an (inter)national level (71% and 61%, respectively). Very few studies targeted the use of sport equipment in the pre-event phase ($n = 2$), athletes in the event phase (one study on teaching falling, landing and recovery skills in Australian Football players) [118], or strategies in the post-event phase ($n = 8$). Interventions in the post-event phase primarily aimed to prevent recurrent ankle sprains ($n = 5$), with the main focus on training programmes (Table 3).

Table 3 Studies of the prevention of acute sport injuries, categorised by preventive intervention and intervention strategy following the modified Haddon matrix ($n = 155$ studies)

Intervention target		Time window			
		Pre-event ($n = 98$; 63%)	Event ($n = 44$; 28%)	Post-event ($n = 8$; 5%)	Multiple time windows ($n = 5$; 3%)
Athlete ($n = 85$; 55%)	<p>Training programme to improve^a:</p> <ul style="list-style-type: none"> Physical fitness ($n = 49$)^b <ul style="list-style-type: none"> FIFA 11/11 + ($n = 9$) [53, 64, 72, 76, 81, 90, 91, 107, 156] Psychological/cognitive skills ($n = 6$) [86, 93, 94, 106, 121, 122] <p>Education ($n = 6$):</p> <ul style="list-style-type: none"> Increase risk awareness ($n = 2$) [35, 180] Varied information on injury preventive behaviour ($n = 4$) [41, 61, 110, 175] <p>Multi-component ($n = 9$) [30, 43, 108, 111, 147, 153, 157, 162, 168]</p>	<p>Training programme to improve falling, landing and recovery skills ($n = 1$) [118]</p>	<p>Balance training ($n = 4$) [40, 56, 59, 99]</p> <p>Balance and strength training ($n = 1$) [47]</p>	None	
Rules and regulations (sport activity) ($n = 14$; 9%)	<p>New or modified rules of sport ($n = 2$) [154, 166]</p> <p>New law ($n = 1$) [145]</p> <p>Strict enforcement of rules/penalising ($n = 2$) [148, 151]</p>	<p>Mandatory use of PPE ($n = 8$) [125, 133, 134, 169, 172, 183, 184, 187]</p>	None	Modify the rules of sport ($n = 1$) [188]	
Equipment (sport activity) ($n = 33$; 21%)	<p>Introduction of carving skis ($n = 1$) [150]</p> <p>Use of (appropriate) footwear ($n = 1$) [62]</p>	<p>Use of (appropriate):</p> <ul style="list-style-type: none"> PPE ($n = 14$) [48, 57, 65, 68, 75, 83, 87, 104, 114, 120, 124, 141, 143, 177] Tape ($n = 2$) [50, 115] Brace ($n = 9$) [58, 67, 74, 95, 97, 123, 132, 138, 139] Footwear/orthotics ($n = 2$) [37, 131] Multiple (tape, brace, PPE) ($n = 2$) [137, 142] 	Use of thermal pants ($n = 1$) [140]	Use of braces ($n = 1$) [82]	
Context (environment) ($n = 18$; 12%)	<p>Coaching education ($n = 4$) [149, 155, 163, 186]</p> <p>Referee education ($n = 1$) [96]</p> <p>Changing safety culture (fair play programme) ($n = 1$) [130]</p> <p>Policy change^c ($n = 5$) [135, 158, 159, 161, 185]</p>	<p>Policy for mandatory use of:</p> <ul style="list-style-type: none"> Braces by coaches ($n = 2$) [127, 171] PPE/sport equipment by league ($n = 1$) [136] PPE by school ($n = 1$) [178] <p>Use of breakaway bases in softball ($n = 1$) [109]</p>	<p>Rehabilitation programme, including return to play criteria ($n = 1$) [52]</p>	Coaching education/concussion side-line management tool ($n = 1$) [182]	

Table 3 continued

Intervention target	Time window		
	Pre-event (<i>n</i> = 98; 63%)	Event (<i>n</i> = 44; 28%)	Post-event (<i>n</i> = 8; 5%)
Multiple time windows (<i>n</i> = 5; 3%)			
Multi-component/multiple interventions (<i>n</i> = 5; 3%)	Education (fair play), and new policy on cancelling games (<i>n</i> = 1) [160]	Rule change, use of (appropriate) PPE and brace (<i>n</i> = 1) [164]	Training programme (balance/strength)/use of braces (<i>n</i> = 1) [69]
			Training programme (balance/strength)/use of braces (<i>n</i> = 1) [77]
			Education/fair play/mandatory PPE use/supervision (<i>n</i> = 1) [119]
<i>PPE</i> personal protective equipment			
^a Including warming-up programmes			
^b [36, 38, 39, 42, 44–46, 49, 51, 54, 55, 60, 63, 66, 70, 71, 73, 78–80, 84, 85, 88, 89, 92, 98, 100–103, 105, 112, 113, 116, 117, 126, 128, 129, 144, 146, 152, 165, 167, 170, 173, 174, 176, 179, 181]			
^c Allowing body checking in ice hockey at a younger age			

3.2.3 Study Outcome

The majority of the interventions under study focussed on changing the behaviour and actions of individual athletes to reduce the risk of injuries, such as specific training programmes in the pre-event phase, and the use of protective equipment (i.e. PPE, brace and tape) in the event phase (Table 4). Based on the study outcomes reported in the original studies, the evidence base for these intervention strategies was relatively low, with 25–75% of the studies reporting a statistically significant change in injury risk. In contrast, the evidence base for strategies less often studied (e.g. changes of rules and regulations in sport, post-event strategies) was relatively high, with 75% or more studies reporting a significant effect (Table 4).

3.3 Study Design

Differences in study design used in individual studies were distinctive when categorised by Haddon's intervention target (Fig. 2). RCTs (70%) and CTs (74%) were most often used to evaluate the effect of interventions targeted at the athlete. Non-randomised prospective cohort studies were used mostly to evaluate the preventive effect of sport equipment (50%); pretest–posttest designs were used mostly to evaluate the effect of strategies targeted at the athlete (46%), contextual modifications (23%), and rules and regulations in sport (21%).

3.4 Intervention Strategies for Specific Injury Targets

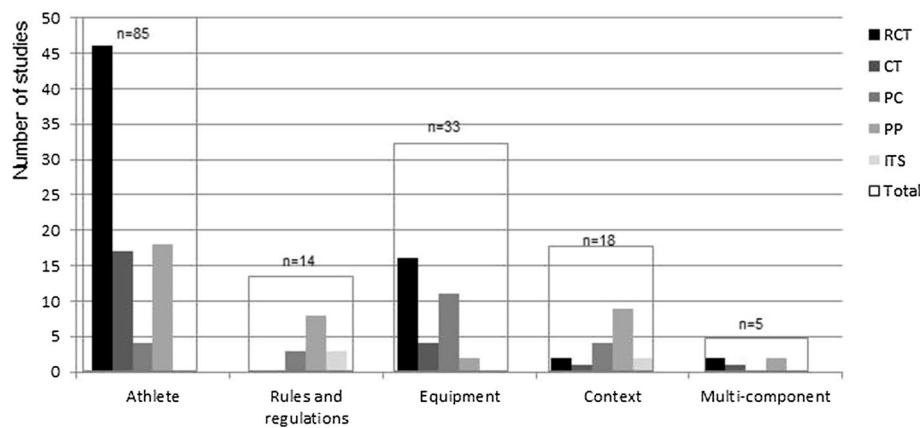
Soccer and rugby were the sports most often targeted in the studies included. In contrast to rugby, the emphasis of prevention studies in soccer was on changing athletes' behaviour in the pre-event phase (Fig. 3), mostly through training programmes (two and 29 studies, respectively).

Pre-event phase studies frequently focussed on the prevention of ankle (*n* = 8) and knee sprains (*n* = 9), whereas event phase studies had relatively few focussing on the prevention of knee sprains (*n* = 2; Fig. 3). In the event phase, both studies of knee sprain prevention concerned knee bracing [67, 123]; the studies of ankle sprain prevention (*n* = 8) targeted the effect of braces [58, 67, 95, 138], tape [115], shoe design [37, 131], or a combination of these interventions [50]. No studies were found on the effect of changes of rules and regulations or contextual modification to prevent ankle or knee sprains. No evidence was available on the effect of changing athletes' behaviour (e.g. through education) on the occurrence of concussions in sports. The focus was on the effect of (mandatory) PPE use (*n* = 9; Fig. 3).

Table 4 Absolute number of studies reporting the prevention of acute sport injuries categorised by intervention strategy following the modified Haddon matrix, and the proportion of studies with a statistically significant effect

	Pre-event	Event	Post-event	Multiple	Overall
Athlete	79	1	5	-	85
Rules and regulations	5	8	-	1	14
Equipment	2	29	1	1	33
Context	11	5	1	1	18
Multiple	1	1	1	2	5
Overall	98	44	8	5	155

Colour coding indicates the proportion of studies with a statistically significant effect: white <25%; grey 25–75%; dark grey \geq 75%
 – no studies

**Fig. 2** Absolute number of studies categorised by Haddon's intervention target and study design. *RCT* randomised controlled trial, *CT* controlled trial, *PC* prospective cohort study, *PP* pretest–posttest design, *ITS* interrupted time series

4 Discussion

The primary aim of this review was to categorise sport injury prevention studies by their intervention strategy, using a modified version of the Haddon matrix. The majority of the available evidence focussed on strategies that required a behavioural change on the part of individual athletes. These studies predominantly evaluated the preventive effect of various training programmes targeted at improving athletes' level of physical fitness and/or sport-specific skills before the injury event, and the use of PPE, tape or brace aimed at being effective at the time of the injury event. This corresponds to reports in previous reviews of sport injury prevention [11].

The current review showed that research related to some specific intervention strategies is underrepresented. Only a

few studies were identified that evaluated the preventive effect of strategies geared at rules and regulations in sport, contextual modifications, and sport equipment (other than PPE, tape or brace) on the occurrence of sport injuries. The lack of studies of the preventive effect of rule modifications to prevent sport injuries has been previously identified [7, 188–190]. Studies specifically aimed at preventing re-injuries were a minority, and were mostly related to recurrent ankle sprains.

Questions can be raised as to whether the identified 'gaps' in the number of studies evaluating the various intervention strategies represent actual knowledge gaps or are unavoidable as not all intervention strategies are appropriate for all sports, injury types and/or sport settings. This is illustrated by the differences found in intervention strategies used in studies of the prevention of soccer and

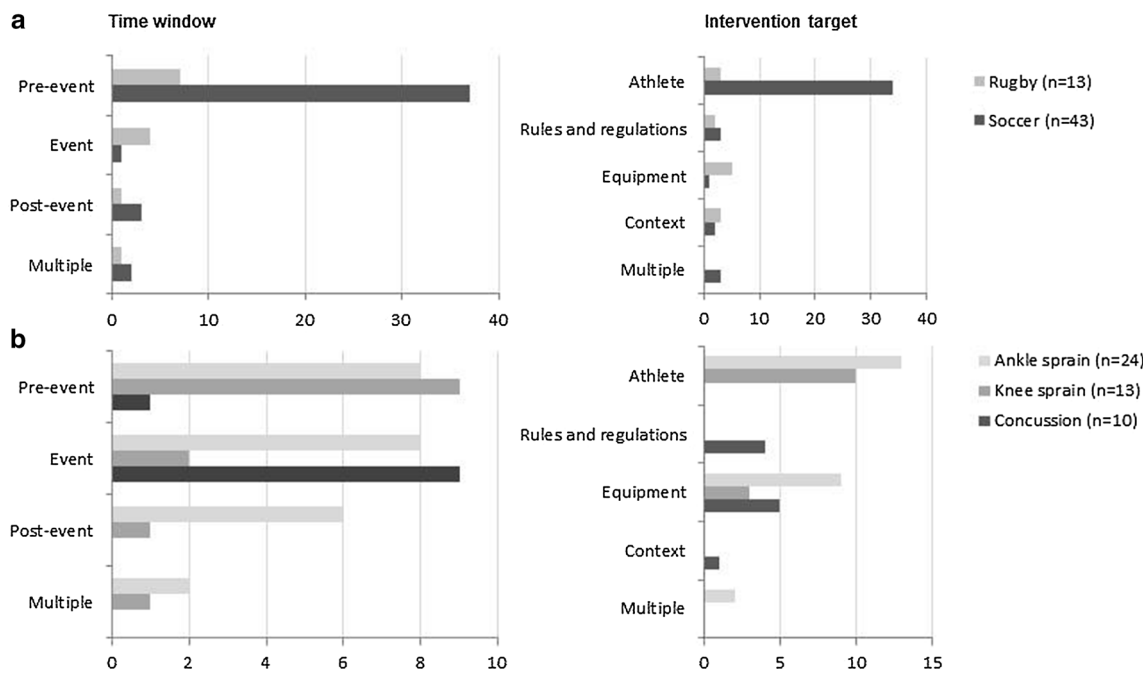


Fig. 3 Absolute number of studies targeted at the prevention of soccer or rugby injuries (a), and ankle sprains, knee sprains or concussions (b), categorised by intervention strategy used

rugby injuries. By its nature, rugby has a high injury rate due to the multiple contact situations [191]. This can explain the emphasis in rugby studies on intervention strategies related to PPE use and rules and regulations, as opposed to soccer. Similarly, differences between strategies used to prevent ankle and knee sprains, as opposed to concussions, can be related to the aetiology and mechanisms of these injuries [10, 192, 193]. However, all possible intervention strategies should be considered when first developing sport injury prevention programmes, and lessons can be learned from strategies used in other sports and injury types. As such, the Haddon matrix presented in this review is a useful tool to identify possible intervention strategies for sport injury prevention.

Based on this review, some knowledge gaps relating to effective sport injury prevention strategies can be identified. New research in these gap areas could be a valuable addition to the current knowledge base of sport injury prevention. This especially applies to research on rule modifications in sport as an intervention strategy. Most research in this area to date has focussed on the preventive effect of mandatory PPE use in the event phase. However, evidence on the effectiveness of rule modifications in the pre-event phase is scarce. Exceptions are two studies on the preventive effect of a new scrum law in rugby [154] and new karate rules [166]. Such strategies have the potential to limit or eliminate dangerous situations in play, and hence prevent sport injury events from occurring. Rule modifications can be of preventive value in the post-event phase

as well, but no studies on this intervention strategy were found. To this category would belong rules that allow free substitution and off-field medical assessment during play to modify the risk of (recurrent) injuries [194]. Furthermore, although sport equipment has been a frequently studied topic in sport injury prevention, studies on the effect of equipment modifications in the pre-event phase are rare. Such preventive interventions do exist in real-world sport settings (e.g. different floor types, tyres to prevent falling in bicycle racing), but the potential preventive effect needs to be formally evaluated. Finally, only few studies were identified on the effect of training programmes other than those aimed at improving the physical skills of athletes. Additional studies are recommended to build on current evidence on the effect of improving psychological or cognitive skills, falling, landing and recovery skills, as well as education of athletes, coaches and referees. Overall, with the total number of 25 different sports considered in the studies included in this review, it is clear that many injury-prone sports have not yet been studied in the literature in this way (e.g. equestrian sport, tennis) [195].

The excess of RCTs used in sport injury prevention studies has been highlighted previously [11], and is not surprising as this study design is considered the gold standard for establishing the preventive effect of an intervention [14, 16, 196]. However, 43% of all injury prevention studies did not use a (randomised) controlled design. The Haddon approach showed that study design and intervention strategy are related. In studies evaluating

strategies geared at rules and contextual modifications, RCTs/CTs were absent or a minority (17%). As most policies and rule modifications under study were introduced at a national level by a national sporting organisation or by law [25], randomisation was impossible and/or a proper control group was lacking. The effectiveness of these interventions could therefore not be evaluated using an RCT or CT design [14, 196]. The frequent use of pretest–posttest designs in these studies appears to be a justified option. Although alternative forms of RCTs have been suggested, including stepped wedge designs (in which an intervention at group level is sequentially implemented if randomisation is impossible) and Solomon four-group designs (to control for the effect of a pretest) [196, 197], these study designs have not yet been used in sport injury prevention studies to our knowledge. Consideration of the use of these designs may be of value in future sport injury prevention research to strengthen knowledge in this field, especially in studies evaluating the effect of group-based interventions.

Our review has some strengths and limitations. A systematic approach was used to identify all relevant sport injury prevention studies. Application of the pre-defined search strategy and inclusion and exclusion criteria resulted in the exclusion of studies not primarily targeting the evaluation of the efficacy or effectiveness of preventive interventions, for instance, aetiological studies establishing risk factors and injury mechanisms [7, 13]. Such studies may, however, provide valuable information related to specific intervention strategies, as illustrated by a study on the association between ice hockey injuries and arena characteristics [198]. The summary provided in this review identifies the amount of evidence (i.e. number of published studies and study designs used) and possible knowledge gaps per intervention strategy in a structured way using the modified Haddon matrix. This can support and strengthen future sport injury prevention efforts. However, additional information about the effectiveness, cost and feasibility of interventions is also necessary for practitioners in order to make a comprehensive decision on what strategy to use for sport injury prevention in everyday practice [199]. Neither did our review assess the effectiveness of preventive interventions, nor the risk of bias of individual studies (i.e. no assessment of the methodological quality of included studies) as per the purpose of this review. Also, an increasing number of implementation studies have been published in recent years [7], providing valuable information on effective implementation components in real-world sport settings [13, 18]. In this review, studies were also included that evaluated the effect of mandatory use of PPE and braces through rule modifications and policy changes. These intervention strategies represent a grey area between evaluating the preventive effect of an intervention and an

implementation strategy. However, implementation of a new or modified rule should ideally be accompanied by implementation efforts at various levels [25].

In this review, we focussed on strategies used in the prevention of acute sport injuries, since the Haddon matrix was not developed for overuse injuries [26]. Only three studies exclusively targeting overuse injuries were excluded for this reason [32–34]. In addition, we limited our search to injury prevention studies reporting clinical outcomes, containing a quantitative injury measure as an outcome. As such, we excluded studies that reported on intermediate risk factors (e.g. biomechanical/physiological outcome measures) [200] and necessary behaviour changes related to sport injury risk as an outcome [201].

The current review may be subject to bias due to our literature search. We included five databases, and limited the search to English-language and peer-reviewed articles. Reference lists from recent systematic reviews and meta-analyses were manually searched for additional literature, which may have contributed to an overrepresentation of (randomised) controlled trials. Another possible source of bias was the exclusion of commuting activities (such as walking and cycling). As a result, studies of bicycle helmets in a general population were not included. These studies may have included helmet use in bicycle racing. However, no study was identified exclusively targeted at bicycle racing. The primary aim of each individual sport injury prevention study was used as a starting point for the categorisation of the extracted data. As a consequence, results of subgroup analyses that dealt with specific injury types or locations were not included in our categorisation.

5 Conclusions

Using a modified version of the Haddon matrix, valuable insight into the extent of the evidence base of sport injury prevention studies was obtained for 20 potential intervention strategies, identifying the number of published studies and study designs used per strategy. This is a promising approach that could be used to monitor potential gaps in the knowledge base on sport injury prevention on an ongoing basis.

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Compliance with Ethical Standards

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Conflicts of interest Ingrid Vriend, Vincent Goutteborge, Caroline Finch, Willem van Mechelen and Evert Verhagen declare that they have no conflicts of interest relevant to the content of this review.

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