

Preventing sport injuries

From evidence to practice

INGRID VRIEND

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Ready?

1. General introduction

Physical activity: health benefits and injuries

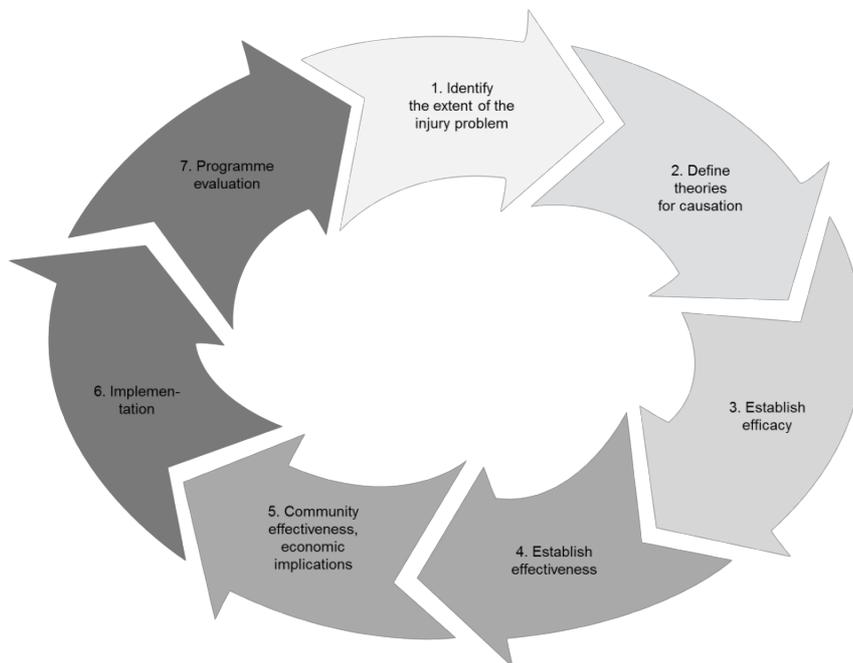
Individuals benefit from regular physical activity including sport participation, since such activities are related to enjoyment, social interaction, weight management, and maintenance and improvement of health [1-3]. The reported inherent health benefits are many, for instance improved musculoskeletal and cardiorespiratory fitness, and reduced risk of multiple disease states, such as hypertension, cardiovascular disease, diabetes, breast and colon cancer, depression, falls and hip or vertebral fractures [2-5]. Physical inactivity [2, 3, 6] and sedentary behaviour [7, 8] have been identified as important risk factors for all-cause mortality and a large number of diseases. From a public health perspective, both a physically active lifestyle and sport participation have been recommended [2, 5, 8, 9], and policies and plans to enhance a physically active lifestyle have been developed and implemented worldwide [2, 10]. From the perspective of an individual, reasons to participate in sport and physical activity are diverse and relate largely to the reported health benefits. Most reported reasons by Dutch individuals are improvement of physical fitness (69%), weight management (57%), relaxation (55%), and/or improvement of general health (48%) [11].

Although current evidence clearly states that the benefits of being physically active outweigh potential harm [2, 9, 12], attention should be paid to the prevention of injuries related to participation in sport and physical activity (hence forward referred to as 'sport injuries') [13]. Sport injuries form a significant health problem at an individual and public health level. Such injuries confront individuals with (temporary) physical inactivity, pain, medical treatment and absence from school or work as possible consequences. At a societal level, the cost related to medical treatment and work absenteeism is substantial. For instance, in the Netherlands, a total of 4.5 million sport injuries annually occur in a population of 12 million individuals who report to be active in sports, with an estimated total cost of 1,500 million euros, including direct medical costs of 520 million euros [14]. Consequently, the prevention of sport injuries is important to maintain and increase a physically active lifestyle and participation in sport throughout the lifespan, and to maximise the related and pursued (health) benefits. Nationwide sport injury prevention programmes have been developed and implemented in the Netherlands, next to public health initiatives promoting physical activity [15, 16].

Preventing sport injuries

Actual on-field sport injury prevention requires large-scale adoption and the correct use of evidence-based preventive measures by the target population [17-19]. To accomplish such a preventive effect, both a wide base of knowledge on sport injury prevention at multiple levels is necessary, as well as a systematic preventive approach [17, 20]. A useful framework for identifying the knowledge and research process necessary to pursue the implementation of effective preventive measures in practice, is the research cycle for health interventions proposed by Tugwell et al. [21]. This cycle states that effective prevention of any health problem is the result of seven consecutive steps, ranging in content from fundamental to practical [22]. These seven steps outline the process of translating scientific evidence into practice. The research cycle has previously been applied to the prevention of ankle sprains in sport [22]. The modified version described in this paper is used as the primary framework for this thesis (Figure 1.1).

Figure 1.1: The translational research cycle of Tugwell et al. [21], modified for the use in sport injury prevention [22]



Applied to sport injury prevention, the research cycle states that the extent of the sport injury problem (i.e. incidence and severity of sport injuries) and the aetiology and mechanisms of injury needs to be established first (steps 1-2), followed by assessing subsequently the efficacy (step 3), and effectiveness and cost-effectiveness of potential feasible preventive interventions (steps 4-5). The research cycle is then followed by the identification of potential facilitators, barriers and other constructs essential for effective implementation in practice (e.g. compliance with the intervention; step 5), after which implementation and evaluation of the impact of preventive interventions in a real-world sport setting concludes the cycle (steps 6-7).

In line with the translational research cycle, two conceptual models developed within the field of sport injury prevention emphasise the relevance of a thorough evidence base and of research at multiple levels, that is, the 'sequence of prevention' of sport injuries of van Mechelen et al. [23], and the 'Translating Research into Injury Prevention Practice' framework (TRIPP) of Finch [17]. Both models identify epidemiological data on the injury problem, and evidence on the efficacy and effectiveness of preventive measures as the basis for sport injury prevention programmes. In addition, the TRIPP-model underlines the importance of research into current preventive behaviours and its determinants, barriers and facilitators for the uptake of preventive measures, and the implementation and evaluation of interventions in real-world sport settings [17]. This requires a structured implementation plan and implementation efforts at various levels [20, 24]. As such, the research cycle captures the research process necessary to pursue the implementation of evidence-based preventive measures.

From evidence....

Following the translational research cycle, the majority of evidence in sport injury prevention is on the incidence and aetiology of sport injuries (steps 1-2) [25]. Evidence on what works is also available. Numerous studies have evaluated the efficacy and (cost-)effectiveness of preventive interventions on the risk of sport injuries (steps 3-5) [25-31], indicating that such injuries can be prevented in real-world sport settings if evidence-based preventive measures and programmes are adopted and effectively used by the target population (e.g. athletes, coaches, sport federations, and other stakeholders; steps 6-7) [17, 19, 24]. This, in general, requires a change in the preventive behaviour of the target population within the sport injury context achieved through implementation efforts [17, 24, 32, 33]. However, few sport injury prevention studies (an

estimated 1% of all studies) have been targeted at the implementation and evaluation of on-field intervention programmes related to steps 6 and 7 of the research cycle [25].

Large-scale adoption and correct use of effective sport injury preventive measures are still considered major challenges [19, 32, 34], and available data on sport injuries in the population substantiate a suboptimal use of effective preventive measures in practice. For instance, in the Netherlands, the overall sport injury risk has been shown to rise over the years [14]. Considering this, additional research is warranted with a focus on the final steps of the research cycle to increase the evidence base on effective implementation [17, 19, 34, 35]. Questions may be raised, however, whether (i) sufficient evidence is available regarding each step of the translational research cycle (Figure 1.1), and whether (ii) the available evidence base on sport injury prevention can effectively be translated to a practical context.

...to practice?

Actual sport injury prevention at a population level is not only determined by evidence on the efficacy and effectiveness of preventive measures, but is also a function of the actual uptake of such measures. Relevant knowledge on effective injury preventive measures needs to be translated in such a way that the target population is reached, and will implement these evidence-based measures into their daily practice [17, 24]. This is influenced by multiple inter-related contextual factors within a specific target group and sport setting [17, 19, 35]. As stated by Finch [35], real-world implementation of injury preventive interventions and evaluation of their effectiveness needs to take into account the sport injury context in which they are introduced, and consider the best method to translate this knowledge to reach the target population. Potentially relevant strategies to translate knowledge on effective preventive interventions to practice include education, contextual modifications, and rule and regulation changes [33, 35-38]. It is recognised that a combination of multiple strategies, implemented at various intervention levels (e.g. at an individual, club, or sport association level) is more effective to support and strengthen sport injury prevention efforts in real-world sport settings [24, 35, 38]. Evaluation of the effectiveness of various strategies to translate knowledge on evidence-based preventive measures to practice is needed.

Objectives and outline of this thesis

The main objective of this thesis is to gain insight into the effectiveness of strategies to translate and implement available evidence on sport injury prevention to broad practice, and as such promote actual sport injury prevention. This can facilitate and support the uptake and (correct) use of effective preventive measures in real-world sport settings to establish effective sport injury prevention at the population level.

The first two chapters describe systematic reviews that focus on summarising available evidence on intervention strategies used in sport injury prevention in general, and on neuromuscular training to prevent ankle sprains, respectively. This relates to steps 3-5 of the translational research cycle (Figure 1.1), aimed at gaining insight on what works in sport injury prevention. *Chapter 2* describes a systematic review aimed at identifying and categorising intervention strategies for the prevention of sport injuries evaluated in the scientific literature, as well as to identify potential intervention strategies that have not yet been evaluated (i.e. potential knowledge gaps). Potential intervention strategies range from those primarily targeted at behavioural modification on the part of an individual (e.g. voluntary use of personal protective equipment, or specific training programmes) to those predominantly based on contextual modifications [33, 36-38]. This review aims to facilitate future sport injury prevention efforts by identifying possible strategies to choose from, given a specific injury problem and a sport context. The identified potential knowledge gaps on sport injury prevention may guide future research in this field. In *Chapter 3* studies on the effect of neuromuscular training programmes (NMT) as a preventive measure for ankle sprains in sport, are evaluated to identify essential components and contexts of effective NMT programmes. This systematic review is included as an example of how available evidence can be used to extract additional information on effective intervention components and on contexts in which interventions have shown to be effective, which may be helpful to develop effective and adoptable interventions, and as such increase the uptake of effective interventions.

As a next step, evidence on what works needs to be translated to and implemented in everyday life. This refers to the final implementation and evaluation steps of the research cycle (Figure 1.1, steps 6-7). *Chapters 4-6* describe effect and process evaluations of three nationwide interventions that were implemented in the Netherlands as part of (inter)national policies on sport injury prevention. The interventions aim to increase the broad uptake of evidence-based preventive measures in real-world sport settings, using different intervention strategies: (i) rule modification in soccer to promote shinguard use (*Chapter 4*), (ii) a nationwide intervention to

increase helmet use in skiers and snowboarders based on health communication (*Chapter 5*), and (iii) eHealth as a practical tool to increase the use of an effective NMT programme to prevent recurrent ankle sprains (*Chapter 6*).

This thesis concludes with a general discussion of the main findings, methodological considerations, and recommendations for future research.

Set?

2. 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.

Objectives | 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.

Introduction

Both a physically active lifestyle and sport participation are recommended because of their inherent health benefits [2, 4, 5, 39]. 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 [13].

Numerous studies and systematic reviews have evaluated the effects of preventive interventions on the risk of sport injuries [25-31], and, as such, these provide an evidence base for implementation efforts [17]. Differences have been found in the type of preventive measure or intervention under study by injury type and sport [27-29]. Most studies have used a randomised controlled trial (RCT) design [30]. RCTs are considered the optimal study design to establish a cause-effect relationship, and, as such, to establish the effect of an intervention [40-42]. Other study designs have also been used in sport injury prevention studies [30], as RCTs are not always feasible in a real-world sport setting due to ethical or practical reasons [40, 41]. 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 [40, 41].

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 [34, 35, 43]. Actual injury prevention in daily practice requires large-scale adoption and the correct use of evidence-based preventive interventions by the target population [17]. 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 [25, 30, 44]. Implementation of such measures requires a behavioural change on the part of an athlete [32, 33]. 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 [25, 33, 37, 38].

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 [24]. 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 [36, 37]. 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. [45] for the prevention of ankle sprains in volleyball. A recent review on snow sport injuries also used the Haddon matrix as its conceptual framework [46].

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.

Methods

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 [24]. 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) [47] and systemic injuries (e.g. heat stress, organ failure, sudden cardiovascular death).

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.

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.

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) [48] 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.

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.

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 [49]. 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 [25, 30].

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 2.1). 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.

Table 2.1: 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 year); adults (18-65 year); elderly (65+ year); 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 [36, 37]; 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) [50]

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 (3x3-matrix): (i) three levels for intervention targets (i.e. 1. host, 2. agent, 3. physical and sociocultural environment), and (ii) the time window or time frame in which an injury occurs (i.e. 1. pre-event, 2. event, 3. post-event) [36, 37].

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 [37, 45]. 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 (5x4-matrix; Table 2.2).

Table 2.2: Definitions used for the modified Haddon matrix with regard to the prevention of acute sport injuries [37, 45]

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

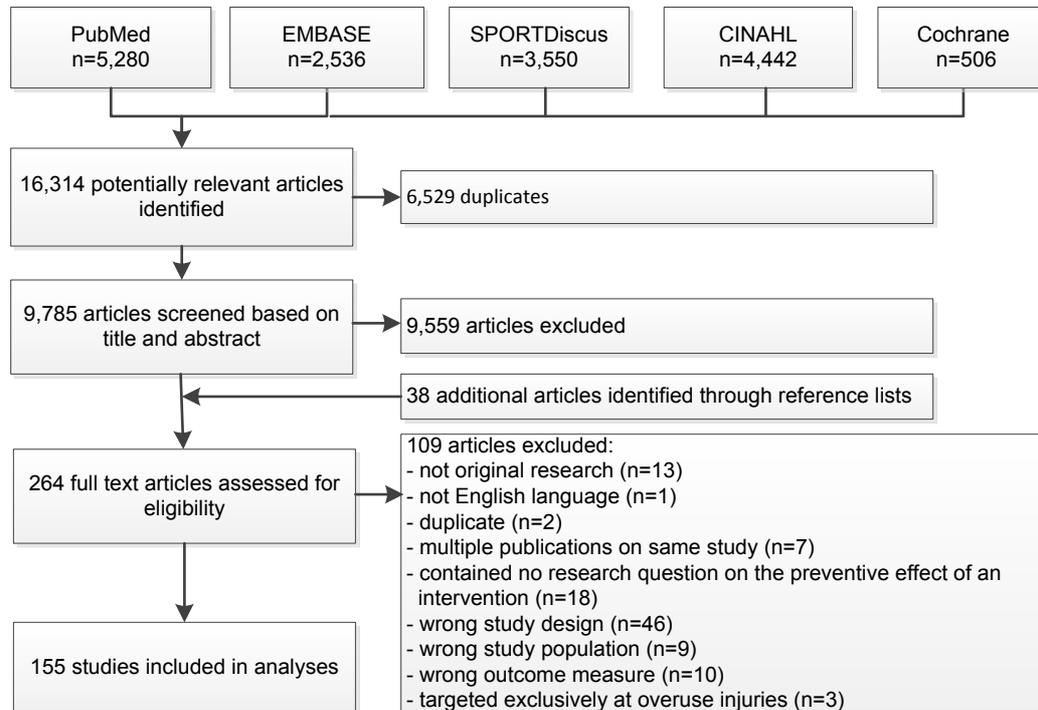
Results

Literature search

The search strategy initially yielded 16,314 articles, of which 226 studies were considered relevant after title and 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 [51-53]. A total of 155 studies were included for analyses (Figure 2.1). 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%) [48, 54-118]. In addition, 23 controlled trials (CTs) (15%) [119-141], 22

prospective cohort studies (14%) [142-163], 39 pretest-posttest designs (25%) [164-202], and 5 interrupted time series (3%) [203-207] were included.

Figure 2.1 Flow chart of literature search and study selection. *CINAHL, Cumulative Index to Nursing and Allied Health Literature; Cochrane, Cochrane Central Register of Controlled Trials*



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) [59, 66, 71, 75, 78, 88, 118, 159], or included athletes at risk based on a psychological high injury risk profile [112, 113] or reduced hip adductor strength [193] (n=3). Another nine studies excluded athletes with a previous (recent) injury at the start of the study [55, 57, 58, 65, 94, 107, 124, 142, 150].

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.

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).

Intervention strategies

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%).

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 [105, 112, 113, 125, 140, 141].

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) [137], 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 2.3).

Table 2.3: 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%)	Training programme to improve ^a <ul style="list-style-type: none"> - physical fitness (n=49) ^b - FIFA 11/11+ (n=9) [72, 83, 91, 95, 100, 109, 110, 126, 175] - psychological/cognitive skills (n=6) [105, 112, 113, 125, 140, 141] Education (n=6): <ul style="list-style-type: none"> - increase risk awareness (n=2) [54, 199] - varied information on injury preventive behaviour (n=4) [60, 80, 129, 194] Multi-component (n=9) [48, 62, 127, 130, 166, 172, 176, 181, 187]	Training programme to improve falling, landing and recovery skills (n=1) [137]	Balance training (n=4) [59, 75, 78, 118] Balance and strength training (n=1) [66]	None
Rules and regulations (sport activity) (n=14; 9%)	New or modified rules of sport (n=2) [173, 185] New law (n=1) [164] Strict enforcement of rules/ penalising (n=2) [167, 170]	Mandatory use of PPE (n=8) [144, 152, 153, 188, 191, 202, 203, 206]	None	Modify the rules of sport (n=1) [207]
Equipment (sport activity) (n=33; 21%)	Introduction of carving skis (n=1) [169] Use of (appropriate) footwear (n=1) [81]	Use of (appropriate): <ul style="list-style-type: none"> - PPE (n=14) [67, 76, 84, 87, 94, 102, 106, 123, 133, 139, 143, 160, 162, 196] - tape (n=2) [69, 134] - brace (n=9) [77, 86, 93, 114, 116, 142, 151, 157, 158] - footwear/orthotics (n=2) [56, 150] - multiple (tape, brace, PPE) (n=2) [156, 161] 	Use of thermal pants (n=1) [159]	Use of braces (n=1) [101]
Context (environment) (n=18; 12%)	Coaching education (n=4) [168, 174, 182, 205] Referee education (n=1) [115] Changing safety culture (fair play programme) (n=1) [149] Policy change ^c (n=5) [154, 177, 178, 180, 204]	Policy for mandatory use of: <ul style="list-style-type: none"> - braces by coaches (n=2) [146, 190] - PPE/sport equipment by league (n=1) [155] - PPE by school (n=1) [197] Use of breakaway bases in softball (n=1) [128]	Rehabilitation programme, including return to play criteria (n=1) [71]	Coaching education/ concussion side-line management tool (n=1) [201]
Multi-component/ multiple interventions (n=5; 3%)	Education (fair play), and new policy on cancelling games (n=1) [179]	Rule change, use of (appropriate) PPE and brace (n=1) [183]	Training programme (balance/strength)/ use of braces (n=1) [88]	Training programme (balance/strength)/ use of braces (n=1) [96] Education/fair play/ mandatory PPE use/ supervision (n=1) [138]

a) including warming-up programmes; b) [55, 57, 58, 61, 63-65, 68, 70, 73, 74, 79, 82, 85, 89, 90, 92, 97-99, 103, 104, 107, 108, 111, 117, 119-122, 124, 131, 132, 135, 136, 145, 147, 148, 163, 165, 171, 184, 186, 189, 192, 193, 195, 198, 200]; c) allowing body checking in ice hockey at a younger age; PPE, personal protective equipment

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 2.4). 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 2.4).

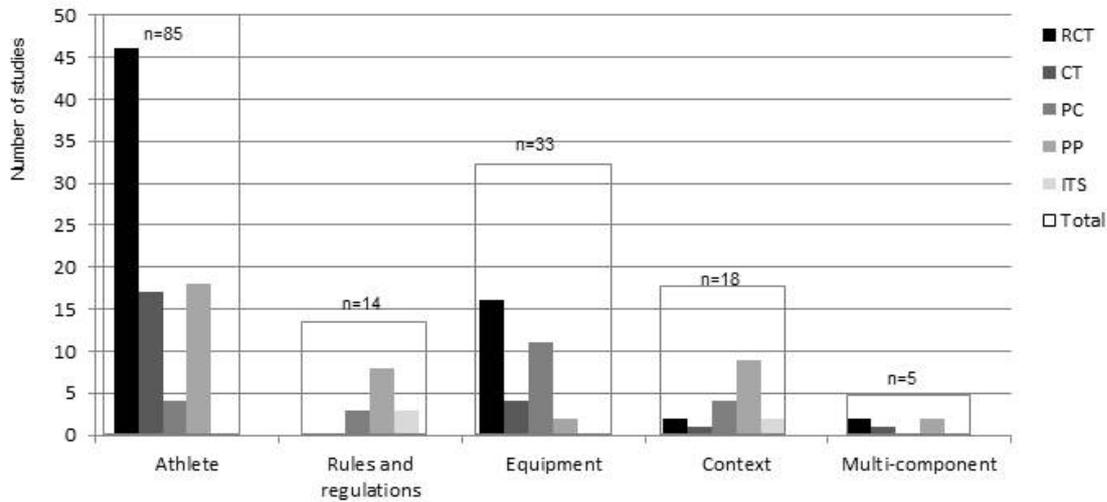
Table 2.4: Absolute number of studies reporting the prevention of acute sport injuries categorised by intervention strategy following the modified Haddon matrix, and the proportion of studies with a statistically significant effect. *Colour coding indicates the proportion of studies with a statistically significant effect: white, <25%; grey, 25-75%; dark grey, ≥75%; -, no studies*

	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

Study design

Differences in study design used in individual studies were distinctive when categorised by Haddon's intervention target (Figure 2.2). 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%).

Figure 2.2 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

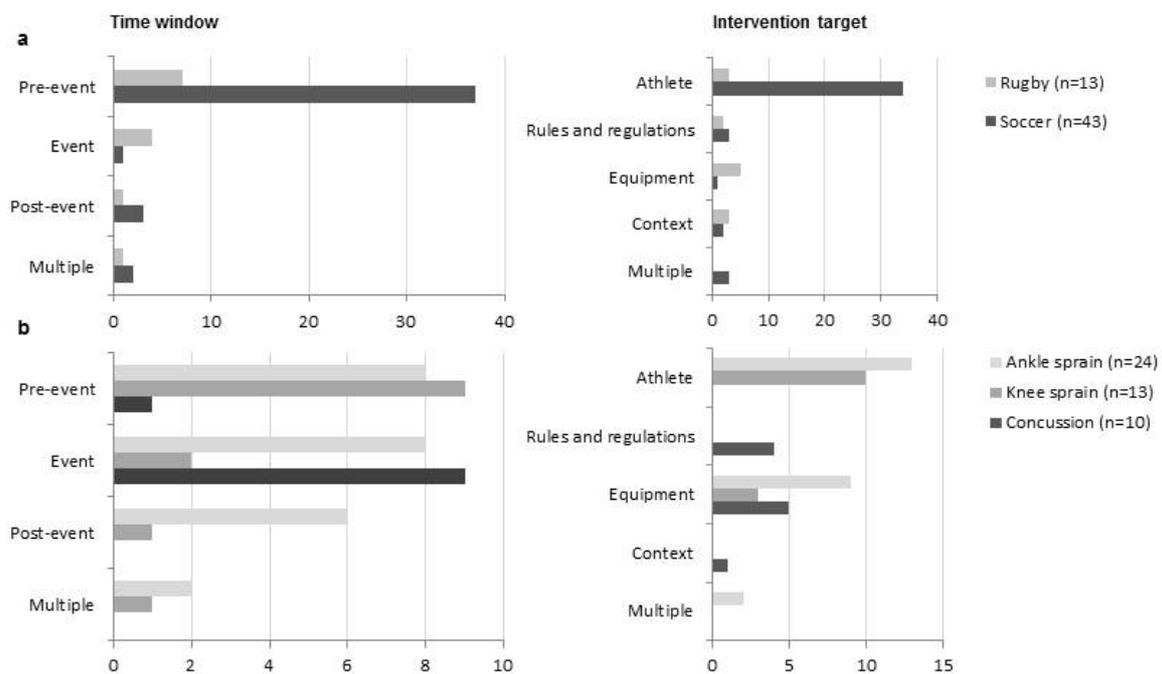


Intervention strategies for specific injury targets

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 (Figure 2.3), 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; Figure 2.3). In the event phase, both studies of knee sprain prevention concerned knee bracing [86, 142]; the studies of ankle sprain prevention (n=8) targeted the effect of brace [77, 86, 114, 157], tape [134], shoe design [56, 150], or a combination of these interventions [69]. 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; Figure 2.3).

Figure 2.3 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



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 [30].

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 [25, 207-209]. Studies specifically aimed at preventing re-injuries were a minority, and were mostly related to recurrent ankle sprains.

Questions can be raised 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 rugby injuries. By its nature, rugby has a high injury rate due to the multiple contact situations [210]. 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 [22, 29, 211]. 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 [173] and new karate rules [185]. 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 [212]. 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) in this way [213].

The excess of RCTs used in sport injury prevention studies has been highlighted previously [30], and is not surprising as this study design is considered the gold standard for establishing the preventive effect of an intervention [40-42]. 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 [24], 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 [40, 41]. 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) [41, 214], 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 [17, 25]. 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 [215]. 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 [216]. 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 [25], providing valuable information on effective implementation components in real-world sport settings [17, 43]. 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 [24].

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 [36]. Only three studies exclusively targeting overuse injuries were excluded for this reason [51-53]. In addition, we limited our search to injury prevention studies reporting clinical outcomes, containing a quantitative injury measure as outcome. As such, we excluded studies that reported on intermediate risk factors (e.g. biomechanical/ physiological outcome measures) [217] and necessary behaviour changes related to sport injury risk as an outcome [218].

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.

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.

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 case of rule modifications and policy interventions.

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Conflicts of interest

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

3. Neuromuscular training is effective to prevent ankle sprains in a sporting population: a meta-analysis translating evidence into optimal prevention strategies

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Abstract

Importance | Ankle sprains are the most common sports-related injuries for which effective preventive measures exist. This review summarises the preventive effectiveness of this neuromuscular training (NMT), culminating in an overview of effective exercise components.

Objective | To assess the preventive effect of NMT for first-time and recurrent ankle sprains in sports.

Evidence review | An electronic literature search of PubMed, SPORTDiscus and EMBASE was conducted (until 24 March 2016) to identify published randomised controlled trials (RCTs), controlled trials (CTs) and time trend analyses related to NMT as a preventive measure for ankle sprains. Methodological quality of relevant studies was assessed using a predefined set of 19 criteria. Meta-analyses were performed on comparable populations and intervention content.

Findings | A total of 30 studies met the inclusion criteria and were analysed (24 RCTs, 3 CTs and 3 time interventions). Studies showed a great diversity in preventive effects and methodological quality (quality score ranged between 47% and 100%). The diversity in preventive effect was independent of study quality and design. A total of 14 studies focussed solely on the effectiveness of balance training, and 16 studies evaluated the effect of balance training combined with adjunct interventions. Pooled data showed a significant reduction in the occurrence of ankle sprains (relative risk (RR)=0.60; 95% CI 0.51 to 0.71). Single-component interventions specifically targeted at ankle sprains achieved preventive effects (RR=0.58; 95% CI 0.48 to 0.72) as opposed to multi-component interventions (RR=0.67; 95% CI 0.37 to 1.24). With respect to interventions targeted at general injuries, significant effects were found using both single-component (RR=0.71; 95% CI 0.52 to 0.97) and multi-component interventions (RR=0.55; 95% CI 0.41 to 0.74). Pooled data showed a significant reduction of NMT on ankle sprains in studies including participants regardless of their injury history (RR=0.59; 95% CI 0.49 to 0.71), and in athletes with a previous ankle sprain (RR=0.69; 95% CI 0.49 to 0.98).

Conclusions and relevance | NMT is effective in reducing ankle sprains in a sporting population, and in athletes with a previous ankle sprain. The evidence for an effect on first-time ankle sprains remains inconclusive. A key element of NMT to prevent ankle sprains is balance training, irrespective of the use of balance boards or other balance devices. Since both single-component and multi-component NMT interventions are effective in reducing ankle sprains, the type most fitting to the context should be chosen for implementation efforts.

Introduction

Ankle sprains are among the most common injuries in sports [219], with a high risk of re-injury during the subsequent 12–24 months [220, 221]. This re-injury can result in chronic pain or instability in 20–50% of all cases [220, 222], high costs related to healthcare and absenteeism from work [223], and decreased participation in sport and physical activity. As such, prevention of ankle sprains is relevant, both from the perspective of the individual athlete as well as from that of the society as a whole.

Various preventive measures and programmes have been introduced to prevent first-time ankle sprains (i.e. primary prevention), recurrent ankle sprains (i.e. secondary prevention) or both [224, 225]. These interventions include the use of external supports (ankle brace, tape, bandages), modified footwear and orthotics, neuromuscular training (NMT) and other exercise programmes, or a combination of these. NMT is also referred to as balance training or proprioceptive training, and often includes exercises using ankle disks, balance or wobble boards [225]. Current evidence indicates that both external ankle supports (tape and braces) [226, 227] and NMT (balance, proprioceptive training) programmes [225, 228] are effective in preventing recurrent ankle sprains, with an approximated 50% reduction in ankle sprain recurrence risk [224].

The majority of studies on the preventive effects of interventions for ankle sprains have reported on NMT programmes [224]. These studies evaluated the effect of NMT on various sports, using multiple study designs, and focused on the effect of NMT as a single intervention or as part of a multi-component intervention [224, 225, 228]. Additional components included strengthening, agility, plyometrics, education or a combination of several components. Large differences were found between studies in effect size, and a number of studies did not find any preventive effect [224, 225]. However, a recent meta-analysis revealed a statistically significant reduction in ankle sprains favouring NMT as a single intervention (i.e. without any adjunct intervention) compared with the control intervention [225]. Current evidence also indicates that NMT is an effective secondary preventive measure, while no significant effect has been found for NMT as a primary preventive measure [224, 225].

Where evidence from high-quality studies is necessary to identify effective preventive measures, additional information is necessary to translate and transfer this knowledge into usable intervention messages and strategies for on-field prevention. This is especially true as large-scale implementation of effective preventive

interventions in real-world sports settings continues to pose a major challenge [34]. Verhagen [22] proposed an approach to bridge the gap between the current wide base of knowledge on effective preventive measures and actual injury prevention in daily practice. In particular, increased insight is essential in the working mechanisms of effective preventive measures, effective and appropriate components of preventive programmes, and contexts in which interventions have shown to be effective [22]. Relevant contexts to be considered include the target population (age, gender, sports) and intervention approach (e.g. supervised or unsupervised, primary or secondary prevention).

As such, it is worthwhile for implementation efforts to compare studies on the preventive effect of NMT with respect to the intervention components and intervention contexts. Since NMT can be evaluated in the general sport population, or in athletes considered to be vulnerable to ankle sprains (i.e. selective prevention), it has been recommended to compare these approaches in terms of effectiveness as well [229].

Therefore, the aim of this review was to identify relevant information for the implementation of NMT as a preventive measure for first-time and recurrent ankle sprains in sports, based on available intervention studies on this topic. Relevant information includes effective and appropriate intervention components and contexts. Specific objectives of this review were (1) to provide an overview of studies on the effectiveness of NMT to prevent first-time and recurrent ankle sprains among athletes; (2) to assess differences in effectiveness of NMT between single-component and multi-component interventions (intervention content); (3) to assess differences in effectiveness of NMT between various target populations (intervention context); and (4) to assess differences in effectiveness of NMT between first-time ankle sprains and recurrent ankle sprains.

Methods

Definition

For the purpose of this review, NMT was defined as an exercise programme or training aimed at improving balance and proprioceptive function at the ankle joint. This is done by re-establishing and strengthening the protective reflexes of the ankle [22] and/or challenging the detection and maintenance of ankle joint position [225]. We considered all interventions as part of NMT that referred to balance training, exercises using balance

boards (also referred to as wobble boards, ankle disks, stability or ankle pads, semi globes), or proprioceptive or NMT as these terms often refer to comparable prevention programmes [225].

Study selection

A search strategy was used to identify all published intervention studies related to NMT as a preventive measure for ankle sprains. Studies on this topic were identified using a computerised literature search (until 24 March 2016) in PubMed, SPORTDiscus and EMBASE. Database-specific thesaurus terms and free-text terms were used for the keywords ankle sprain and prevention, in combination with (neuromuscular or proprioceptive or balance) training, brace, tape and shoe, respectively. Since terminology for neuromuscular, proprioceptive and balance training is often used interchangeably [225], we searched for all terms. Search terms for brace, tape and shoe were included to retrieve all studies focusing on NMT as a component of a multi-intervention programme. Available filters were used to limit the search to human participants and studies published in the English language. No publication date restrictions were used. Reference lists of systematic reviews were screened for additional relevant studies.

A study was included if (a) the study contained research questions regarding the effectiveness of NMT to prevent first-time and recurrent ankle sprains; (b) the study was a randomised controlled trial (RCT), a controlled trial (CT) or a time intervention (i.e. a pretest-posttest design with the pre-interrupted data serving as control condition); (c) the results of the study contained a quantitative measure of ankle sprains as the study outcome (e.g. incidence rates); and (d) the article concerned original research, published in peer-reviewed English journals. Studies that only reported ankle injuries were included as well, as the majority of ankle injuries in sports are known to concern ankle sprains with high rates in numerous sports [219]. Studies involving the rehabilitative treatment of ankle sprains were only included if the interventions under study were intended to reduce the risk of re-injury. Studies aimed primarily at treatment and not at the prevention of ankle sprain recurrences were excluded from this review.

Methodological quality assessment

Methodological quality of all relevant studies was independently scored by two reviewers (IV and EALMV) using the same quality assessment tool that has been applied in two previous reviews on ankle sprain prevention

[224, 230]. In order to consider all possible sources of bias, and to introduce more variability in the methodological quality score (QS), five additional criteria were defined following the Cochrane Collaboration's 'Risk of bias' tool [231]. These criteria were used to assess random sequence generation and allocation concealment (selection bias), blinding of outcome assessment (detection bias), incomplete outcome data (attrition bias) and selective reporting (reporting bias). We omitted the criteria related to performance bias (blinding of participants and personnel) as this was not considered distinctive between the included studies. As such, a set of 19 criteria was used to score the methodological quality (Table 3.1).

Each item of a selected study that met a criterion was assigned a score of '1'. If an item did not meet a criterion, was unclear or was not described, a score of '0' was assigned. The highest attainable score was '19'. However, not all criteria could be assessed for non-RCTs. These criteria were excluded for these studies. The maximal attainable total score was adjusted accordingly, that is, '16' for CTs (i.e. excluding criterion B), and '13' for time interventions (i.e. excluding criteria B, C, F and H). In case of disagreement on QS, both reviewers discussed these differences and tried to reach consensus. We used an arbitrary cut-off score of 60%, which has been used in previous reviews on ankle sprain prevention, and considered an adequate way to distinguish between 'high-quality' and 'low-quality' studies [224, 230].

Table 3.1: Criteria used for the assessment of the methodological quality score of relevant studies

Criteria	Score
A Are relevant participant characteristics described?	
1. Age	0/1
2. Gender	0/1
3. Level of sports activity (e.g. amateur or professional)	0/1
4. Time of sports activities (e.g. hour/week or min/week)	0/1
B Is a randomisation procedure mentioned and adequate?	
1. Is a randomisation procedure mentioned?	0/1
2. Random sequence generation	0/1
3. Allocation concealment	0/1
C Are the intervention and control groups homogeneous with regard to the participant characteristics (i.e. no imbalances in baseline characteristics)?	0/1
D Is a definition for 'injury' given?	0/1
E Are testing or intervention procedures described and performed in sufficient detail?	
1. Applied preventive measure	0/1
2. Time span of intervention	0/1
3. Control of compliance to the intervention	0/1
F Blinding of outcome assessment	0/1
G Are the research design and statistical analysis sufficient?	
1. Statistical analysis is consistent with the research design	0/1
2. Corrected for accurate variables	0/1
3. Are all relevant statistical outcomes presented (e.g. mean, SD, p value)?	0/1
4. Complete outcome data (i.e. no attrition/exclusions from the analysis)?	0/1
5. Are all relevant findings reported (i.e. no selective reporting)?	0/1
H Are the dropouts described for each group separately?	0/1

Data extraction

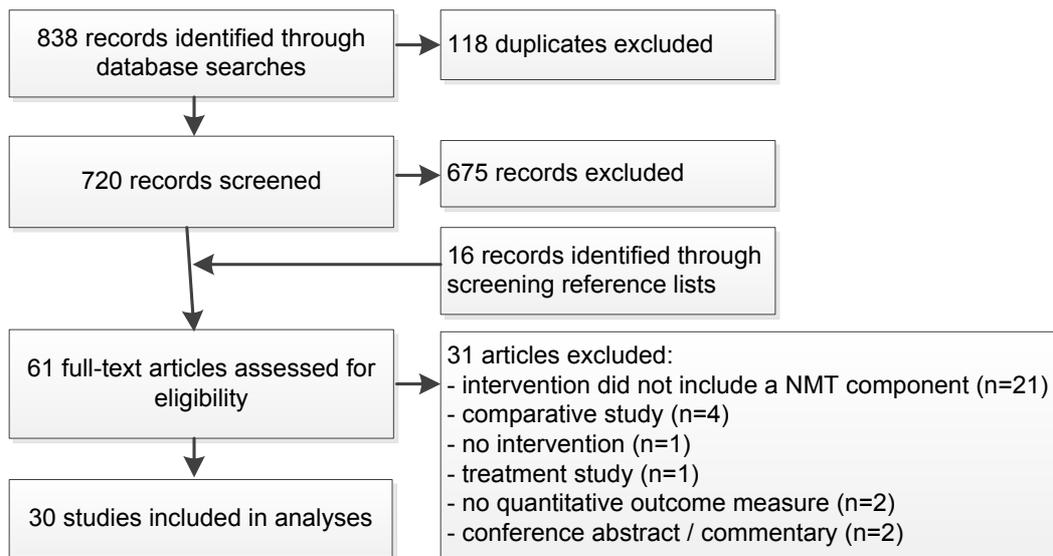
One reviewer (IV) extracted data describing study design, study participants (number, age, gender), intervention content, intervention context, follow-up period and main outcome measures. For the purpose of this study, intervention content was defined (a) by its components: balance, strength, plyometrics, agility, flexibility exercises, education or a combination; (b) as supervised or unsupervised (e.g. by trainer, coach or physiotherapist) and (c) using sport-specific or generic exercises. Intervention context was defined by (a) the target population: general sport population, athletes with and without previous ankle sprain or reduced ankle function; (b) injury scope: ankle sprain, lower extremity (LE) injury or any injury, and (c) type of sports. To assess the preventive effects of NMT programmes, unadjusted relative risks (RR) with 95% CIs were extracted. If these measures were not provided, they were calculated on the basis of the ankle sprain incidence data reported. Where appropriate, study results of comparable populations and interventions were pooled using a random-effect model. In order to reduce heterogeneity through risk of bias in pooled effect estimates, only 'high-quality' studies were included in the meta-analyses [231]. Statistical heterogeneity was assessed using the Chi² test for heterogeneity ($p < 0.1$) and the I² statistic [231].

Results

Literature search

A total of 838 studies were found, of which 61 full-text articles were screened (Figure 3.1). Twenty-one studies were excluded as the intervention under study did not include NMT [56, 62, 69, 71, 73, 77, 86, 101, 114, 116, 134, 150, 157, 183, 232-238]. Another 10 studies were excluded because they compared multiple interventions without a control condition [103, 239-241], did not contain a quantitative measure of ankle sprains or ankle injuries as study outcome [129, 242], involved treatment of ankle sprains [59], did not assess an intervention effect [243], or concerned a conference abstract [244] or commentary [245]. This resulted in a total of 30 relevant studies: 24 RCTs [61, 63-66, 75, 78, 82, 83, 85, 88, 90-92, 95, 96, 98, 100, 104, 108, 109, 118, 246, 247], 3 CTs [122, 131, 135], and 3 time interventions (prospective cohort studies) [166, 175, 186]. One relevant study was not included in the analyses as no RR could be calculated on the basis of the ankle sprain incidence data reported [175].

Figure 3.1: Flow chart of literature search and study selection. *NMT, neuromuscular training*



Methodological quality

Since the method of establishing methodological quality for the original 14 criteria did not differ from that in a previous review [224], the quality of corresponding studies was not reassessed for those criteria. The QS of the studies ranged between 47% and 100% (Table 3.2). Five studies were considered to be of low quality [66, 75, 96, 118, 186], and were excluded from the meta-analyses.

The relevant studies showed a great diversity in the RR of ankle sprain and methodological quality. The diversity in preventive effect was independent of study quality and design (Figure 3.2).

Target population and study outcome

The intervention in four studies was solely targeted at athletes with a previous ankle sprain [66, 78, 88, 96]; another three studies involved the rehabilitative treatment of current ankle sprains intended to prevent re-injuries [75, 118, 247] (Table 3.3). Of all studies, 13 reported on ankle sprains (or ankle injuries) as a primary outcome [61, 66, 75, 78, 85, 88, 96, 98, 118, 122, 166, 186, 247]. However, most studies evaluated the effect of NMT on any injury [63-65, 83, 91, 95, 100, 109, 135, 246] or on LE injuries [82, 90, 92, 104, 108, 131, 175] including ankle sprains (or ankle injuries) as a secondary outcome.

Effect of NMT by intervention content

All interventions under study included balance training exercises, with 70% using balance boards/devices. A total of 14 studies focused solely on the effectiveness of balance training [61, 65, 66, 75, 78, 85, 88, 96, 98, 108, 118, 122, 131, 186], whereas the other studies evaluated the effect of a multi-component intervention.

Additional intervention components often included strengthening, plyometrics and agility exercises (Table 3.4).

Pooled data based on the included studies showed a significant reduction in the occurrence of ankle sprains, favouring NMT in interventions that included a form of balance training (RR=0.60; 95% CI 0.51 to 0.71), and in interventions that included balance training using a balance device (RR=0.60; 95% CI 0.50 to 0.72) (Table 3.4).

Moreover, NMT interventions including balance training without using balance boards (or other balance devices) also achieved preventive effects (RR=0.60; 95% CI 0.44 to 0.83). This result showed significant heterogeneity ($I^2=61\%$; $p=0.008$).

Effect of NMT by intervention context

Pooled data revealed a significant reduction in the occurrence of ankle sprains using single-component interventions targeted at ankle sprains (RR=0.58; 95% CI 0.48 to 0.72; Figure 3.3). No significant effect was found for multi-component interventions (RR=0.67; 95% CI 0.37 to 1.24; Figure 3.3). With respect to interventions targeted at LE or general injuries, pooled data revealed significant effects on the occurrence of ankle sprains using both single-component (RR=0.71; 95% CI 0.52 to 0.97; Figure 3.4) and multi-component interventions (RR=0.55; 95% CI 0.41 to 0.74; Figure 3.4).

With respect to the target population of NMT interventions, pooled data showed a significant reduction of NMT on ankle sprains in studies including participants regardless of their injury history (RR=0.59; 95% CI 0.49 to 0.71), and in athletes with a previous ankle sprain (RR=0.69; 95% CI 0.49 to 0.98; Table 3.5). We could only calculate the RR for one study with regard to the prevention of new ankle sprains, and no significant effect was found (RR=0.55; 95% CI 0.28 to 1.08) [85].

The effect of NMT was evaluated in a variety of sports (Table 3.3). Per sport, the percentage of studies showing a significant reduction in ankle sprains varied from 33% in handball [92, 104, 135], 40% in soccer [66, 88, 91, 95,

96, 100, 108, 109, 131, 175], 50% in basketball [61, 65, 83, 122] to 100% in volleyball [98, 166]. Single studies evaluated the effect of NMT in indoor soccer [64], floorball [90], and American Football [186].

Figure 3.2: Overview of relevant studies, showing RR of ankle sprain (NMT vs control) related to the methodological quality score of studies, taking study design into account. The methodological quality score ranges from 0% (low quality) to 100% (high quality). *CT*, controlled trial; *NMT*, neuromuscular training; *n.s.*, not significant effect; *RCT*, randomised controlled trial; *RR*, relative risk; *sign.*, significant effect

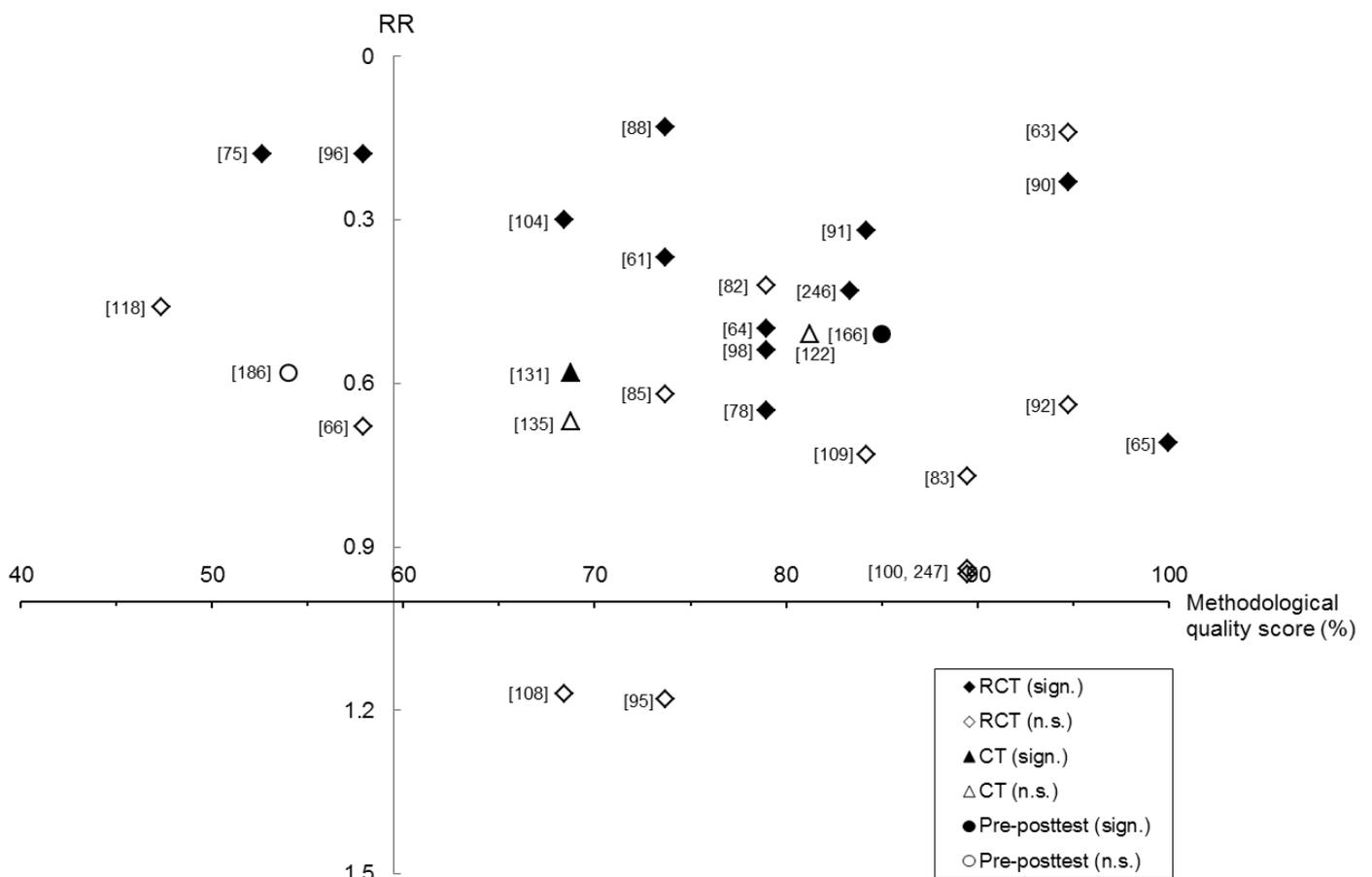


Table 3.2: Methodological quality score of relevant studies on the prevention of ankle sprains

Reference	Study design	A1	A2	A3	A4	B1	B2	B3	C	D	E1	E2	E3	F	G1	G2	G3	G4	G5	H	Total score	Percent age	
Bahr et al. [166]	Pretest-posttest	1	1	1	1	-	-	-	-	1	1	1	0	-	1	0	1	1	1	-	11	85	
Cumps et al. [122]	CT	1	1	1	1	-	-	-	0	1	1	1	1	0	1	0	1	1	1	1	1	13	81
Eils et al. [61]	RCT	1	1	1	1	1	1	0	0	1	1	1	1	0	1	0	1	1	0	1	14	74	
Emery et al. [63]	RCT	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	1	18	95
Emery et al. [65]	RCT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19	100
Emery & Meeuwisse [64]	RCT	1	1	1	1	1	0	1	0	1	1	0	1	1	1	1	1	0	1	1	15	79	
Engebretsen et al. [66]	RCT	0	1	1	1	1	0	0	0	1	1	1	1	0	1	0	1	0	1	0	11	58	
Grooms et al. [175]	Pretest-posttest	1	1	1	1	-	-	-	-	1	1	1	1	-	1	1	1	0	1	-	12	92	
Holme et al. [75]	RCT	1	1	1	0	1	1	0	0	0	1	1	1	0	1	0	0	0	0	1	10	53	
Hupperets et al. [78]	RCT	1	0	0	0	1	1	0	1	1	1	1	1	1	1	1	1	1	1	1	15	79	
LaBella et al. [82]	RCT	1	1	1	1	1	1	0	0	1	1	0	1	1	1	1	0	1	1	1	15	79	
Longo et al. [83]	RCT	1	1	1	1	1	1	1	0	1	1	1	1	1	1	0	1	1	1	1	17	89	
Malliou et al. [131]	CT	1	0	1	0	-	-	-	1	1	1	1	0	0	1	1	1	1	1	0	11	69	
McGuine & Keene [85]	RCT	1	1	1	1	1	1	0	1	1	1	1	1	0	0	1	1	1	0	0	14	74	
McHugh et al. [186]	Pretest-posttest	1	0	1	0	-	-	-	-	1	1	1	1	-	0	0	1	0	0	-	7	54	
Mohammadi [88]	RCT	1	1	1	1	1	0	0	1	1	1	1	0	0	1	1	1	1	0	1	14	74	
Olsen et al. [92]	RCT	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	18	95	
Owoeye et al. [91]	RCT	1	1	1	1	1	1	0	1	1	1	1	1	0	1	0	1	1	1	1	16	84	
Parkkari et al. [246]	RCT	1	1	1	1	1	1	0	0	1	1	1	1	0	1	0	1	1	1	1	15	83	
Pasanen et al. [90]	RCT	1	1	1	1	1	1	1	1	1	1	1	1	0	1	1	1	1	1	1	18	95	
Petersen et al. [135]	CT	0	1	1	1	-	-	-	1	1	1	1	0	0	1	0	0	1	1	1	11	69	
Söderman et al. [108]	RCT	1	1	1	1	1	0	0	1	1	1	1	1	0	1	0	1	0	0	1	13	68	
Soligard et al. [109]	RCT	1	1	1	1	1	0	0	1	1	1	1	1	1	1	0	1	1	1	1	16	84	
Steffen et al. [100]	RCT	1	1	1	1	1	0	1	1	1	1	1	1	1	1	0	1	1	1	1	17	89	

Tropp et al. [96]	RCT	0	1	1	0	1	0	0	0	1	1	1	0	0	1	1	1	1	0	11	58
van Beijsterveldt et al. [95]	RCT	1	1	1	1	1	0	0	0	1	1	1	1	0	1	1	1	1	0	14	74
van Rijn et al. [247]	RCT	1	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	17	89
Verhagen et al. [98]	RCT	1	1	1	1	0	0	1	1	1	1	1	0	1	1	1	1	0	1	15	79
Wedderkopp et al. [104]	RCT	1	1	1	1	1	0	0	1	1	1	1	0	0	1	1	1	0	1	13	68
Wester et al. [118]	RCT	1	1	0	0	1	0	1	0	1	1	1	0	0	1	0	1	0	0	9	47

For non-RCTs, a score for B could not be assessed. The following criteria could not be assessed for time interventions (i.e. a pretest-posttest design): B, C, F, and H; CT, controlled trial; RCT, randomised controlled trial.

Table 3.3: Overview and characteristics of relevant studies on the prevention of ankle sprains

Study	Participants				Intervention			Outcome				
	Reference	Design	Follow-up period	N	Gender (% M); Age (year, mean(±SD), [range]) (I/G/CG)	Sport population	Sports		Single or multi-component	Intervention	Sport-specific or generic exercises	Individual or group-based (supervised)
Bahr et al. [166]	Pretest-posttest	2 seasons	814	52; 23.2(4.2) M/22.4(4.3) F	General	Volleyball	Multi	Multi-component	Injury prevention programme during warm-up	Generic	Group (coach)	Ankle sprains (time-loss)
Cumpps et al. [122]	CT (cluster)	1 season	50	73/63; 17.7(3.9)/18.0(2.7)	General	Basketball	Single	Single	BT programme during warm-up	Sport-specific	Group (coach)	Ankle sprains (time-loss)
Eils et al. [61]	RCT (cluster)	1 season	172	60/59; 22.6(6.3)/25.5(7.2)	General	Basketball	Single	Single	BT programme during training	Sport-specific	Group (coach)	Ankle injuries (time-loss)
Emery et al. [63]	RCT (cluster)	6 months	120	50; [14-19]	General	Diverse ^a	Multi	Multi	Home-based BT programme, including core stabilisation	Generic	Individual (unsupervised)	Ankle sprains (medically treated or time-loss)
Emery et al. [65]	RCT (cluster)	1 year	920	49/52; [12-18]	General	Basketball	Single	Single	BT programme during warm-up, and a home-based BT programme	Sport-specific	Both (coach)	Ankle sprains (medically treated or time-loss)
Emery & Meeuwisse [64]	RCT (cluster)	1 year	744	58/31; [13-18]	General	Indoor soccer	Multi	Multi	Injury prevention programme during warm-up, and a home-based BT programme	Sport-specific	Both (coach)	Ankle sprains (medically treated or time-loss)

Engelbrechtsen et al. [66]	RCT	1 season	508	100; NS	Athletes with previous ankle sprain or reduced function	Soccer	Single	BT programme	Generic	Individual (unsupervised)	Ankle sprains (time-loss)
Grooms et al. [175]	Pretest-posttest	1 season	41	100; 20.1(2.0)	General	Soccer	Multi	F-Marc 11+ (warm-up programme)	Sport-specific	Group (coach)	Ankle sprains (medically treated or time-loss)
Holme et al. [75]	RCT	1 year	71	59/64; 25.5(3.8)/27.4(4.6)	Athletes with acute ankle sprain (medically-treated)	Diverse	Single	Rehabilitative BT programme	Generic	Group (physiotherapist)	Recurrent ankle sprains
Hupperets et al. [78]	RCT	1 year	522	53/52; 28.6(11.8)/28.0(11.6)	Athletes with previous ankle sprain	Diverse	Single	Home-based BT programme	Generic	Individual (unsupervised)	Recurrent ankle sprains (self-reported, time-loss, leading to cost)
LaBella et al. [82]	RCT (cluster)	1 season	1,492	0; 16.2(1.1)/16.2(1.5)	General	Soccer	Multi	Injury prevention programme during warm-up	Generic	Group (coach)	Non-contact ankle sprains (time-loss)
Longo et al. [83]	RCT (cluster)	1 season	121	100; 13.5(2.3)/15.2(4.6)	General	Basketball	Multi	F-Marc 11+ (warm-up programme)	Sport-specific (soccer)	Group (coach)	Ankle injuries
Malliou et al. [131]	CT (cluster)	1 season	100	NS; 16.7(0.5)/16.9(0.7)	General	Soccer	Single	BT programme	Sport-specific	-	Ankle sprains (time-loss)

McGuine & Keene [85]	RCT (cluster)	-	765	33/30;	16.6(1.1)/16.4(1.2)	General	Soccer	Basketball	Single	BT programme	Sport-specific	Group (ns)	Ankle sprains (time-loss)
McHugh et al. [186]	Pretest-posttest	3 seasons	125	NS; [15-18]		General	American Football	Single	BT programme (during weight training)	ns	ns	Group (coach)	Ankle sprains (time-loss)
Mohammadi [88]	RCT	1 season	80	100; 24.6(2.6)		Athletes with previous ankle sprain	Soccer	Single	Home-based BT training	Generic	Generic	Individual (unsupervised)	Recurrent ankle sprains
Olsen et al. [92]	RCT (cluster)	1 season	1,837	16/11;	16.3(0.6)/16.2(0.6)	General	Handball	Multi	Injury prevention programme during warm-up	Sport-specific	Sport-specific	Group (coach)	Acute ankle injuries (medically-treated or time-loss)
Owoeye et al. [91]	RCT (cluster)	1 season	416	100; 17.8(0.94)/	17.5(1.1)	General	Soccer	Multi	F-Marc 11+ (warm-up programme)	Sport-specific	Sport-specific	Group (coach)	Ankle injuries (time-loss)
Parkkari et al. [246]	RCT (cluster)	6 months	968	100; 19 [18-28]		General	Diverse ^b	Multi	Injury prevention programme	Generic	Generic	Both (instructor)	Ankle injuries (medically-treated)
Pasanen et al. [90]	RCT (cluster)	1 season	457	0;	24.2(5.0)/23.3(4.8)	General	Floorball	Multi	Injury prevention programme during training, and at home	Sport-specific	Sport-specific	Both (coach)	Non-contact ankle sprains (time-loss)
Petersen et al. [135]	CT (cluster)	1 season	276	0; adults		General	Handball	Multi	Injury prevention programme	Sport-specific	Sport-specific	Group (coach)	Ankle sprains (time-loss)
Söderman et al. [108]	RCT (cluster)	1 season	140	0;	20.4(4.6)/20.5(5.4)	General	Soccer	Single	Home-based BT programme	Generic	Generic	Individual (unsupervised)	Traumatic ankle sprains (time-loss)
Soligard et al. [109]	RCT (cluster)	1 season	1,892	0; 15.4(0.7)		General	Soccer	Multi	F-Marc 11+ (warm-up programme)	Sport-specific	Sport-specific	Group (coach)	Ankle injuries (time-loss)

Steffen et al. [100]	RCT (cluster)	1 season	2,020	0; 15; 4(0.8)	General	Soccer	Multi	F-Marc 11 (warm-up programme)	Sport-specific	Group (coach)	Ankle injuries; recurrent ankle sprains (time-loss)
Tropp et al. [96]	RCT (cluster)	6 months	236	100; NS	Athletes with previous ankle sprain or reduced function (G); general (CG)	Soccer	Single	BT programme	Generic	-	Recurrent ankle sprains (time-loss)
van Beijsterveldt et al. [95]	RCT (cluster)	1 season	456	100; 24.4(4.1)/25.1(4.3)	General	Soccer	Multi	F-Marc 11 (warm-up programme)	Sport-specific	Group (coach)	Ankle injuries (medically-treated or time-loss)
van Rijn et al. [247]	RCT	1 year	102	37.0(11.9); [18-60]	Athletes with acute ankle sprain (medically-treated)	NS	Multi	Rehabilitative training programme (first 3 months post-injury)	Generic	Individual (physiotherapist)	Recurrent ankle sprains
Verhagen et al. [98]	RCT	1 season	1,127	45/41; 24.4(2.8)/24.2(2.5)	General	Volleyball	Single	BT programme during warm-up	Generic	Group (coach)	Ankle sprains (time-loss)
Wedderkopp et al. [104]	RCT (cluster)	1 season	237	0; [16-18]	General	Handball	Multi	Injury prevention programme	Sport-specific	Group (coach)	Ankle sprains (time-loss or unable to sport participation with considerable discomfort)

Wester et al.	RCT	230 days (±62.9)	48	13; 25(7.2)	Players with residual symptoms following ankle sprain (medically-treated)	Diverse	Single	Rehabilitative BT programme (first 12 weeks post-injury)	Generic	Individual (NS)	Recurrent ankle sprains
[118]											

a) Students from physical education classes; b) Military training, including marching, cycling, skiing, orienteering, swimming, drill training, combat training, jogging, team sports and circuit training; BT, balance training; CG, control group; CT, controlled trial; F, female; F-Marc, FIFA Medical Assessment and Research Centre; IG, Intervention group; M, male; NS, not specified; RCT, randomised controlled trial; SD, standard deviation.

Table 3.4: Overview of relevant studies, showing relative risk of ankle sprain (NMT versus control), intervention components, study design and quality score

Reference	Design	QS (%)	RR (95% CI)	Balance	Balance board ^a	Strength	Plyometrics ^b	Agility	Stretching	Technique	Education
Bahr et al. [166]	pretest- posttest	85	0.51 (0.32-0.81)	+	+					+	+
Cumps et al. [122]	CT	81	0.51 (0.20-1.32)	-	-						
Elis et al. [61]	RCT	74	0.37 (0.17-0.83)	+							
Emery et al. [63]	RCT	95	0.14 (0.02-1.13)	-	-						
Emery et al. [65]	RCT	100	0.71 (0.52-0.97)	+	+						
Emery & Meeuwisse [64]	RCT	79	0.50 (0.26-0.93)	+	+	+		+		+	
Engelbrechtsen et al. [66] *	RCT	58	0.68 (0.36-1.30)	-	-						
Grooms et al. [175] *	pretest- posttest	92	#	-							
Holme et al. [75] *	RCT	53	0.24 (0.06-0.99)	+	+						
Hupperets et al. [78]	RCT	79	0.65 (0.49-0.87)	+	+						
Labella et al. [82]	RCT	79	0.42 (0.18-1.01)	-							
Longo et al. [83]	RCT	89	0.77 (0.13-4.42)	-							
Malliou et al. [131]	CT	69	0.58 (0.41-0.82)	+	+ ^c						
McGuine & Keene [85]	RCT	74	0.62 (0.38-1.02)	-	-						
McHugh et al. [186]	pretest- posttest	54	0.58 (0.33-1.02)	-	-						
Mohammadi [88]	RCT	74	0.13 (0.02-0.91)	+	+						
Olsen et al. [92]	RCT	95	0.64 (0.40-1.03)	-	-						

Owoeye et al. [91]	RCT	84	0.32 (0.16-0.64)	+	+	+	+	+	+								
Parkkari et al. [246]	RCT	83	0.43 (0.24-0.75)	+		+		+	+								
Pasanen et al. [90]	RCT	95	0.23 (0.11-0.50)	+	+	+	+	+									
Petersen et al. [135]	CT	69	0.67 (0.27-1.69)	-	-				-								
Söderman et al. [108]	RCT	68	1.17 (0.59-2.30)	-	-												
Sollgard et al. [109]	RCT	84	0.73 (0.49-1.08)	-	-	-	-	-									
Steffen et al. [100]	RCT	89	0.94 (0.69-1.28)	-	-	-	-	-									
Tropp et al. [96] *	RCT	58	0.18 (0.06-0.59)	+	+												
van Beijsterveldt et al. [95]	RCT	74	1.18 (0.80-1.73)	-		-	-										
van Rijn et al. [247]	RCT	89	0.95 (0.52-1.73)	-				-									
Verhagen et al. [98]	RCT	79	0.54 (0.34-0.85)	+	+												
Wedderkopp et al. [104]	RCT	68	0.30 (0.13-0.70)	+	+	+	+										
Wester et al. [118] *	RCT	47	0.46 (0.21-1.01)	-	-												
Total effect estimate	RR (95% CI)	0.60	(0.51-0.71)	0.60	(0.50-0.72)	0.54	(0.39-0.74)	0.62	(0.46-0.84)	0.52	(0.39-0.69)	0.52	(0.38-0.72)	0.57	(0.41-0.79)	0.50	(0.36-0.69)
	Chi ² (p-value)	0.002		0.03		0.0002		0.001		0.08		0.26		0.49		0.7	
	I ² (%)	51		44		69		66		43		25		0		0	
Total studies (n)		30		21		13		12		10		6		2		3	
Studies preventive effect (%)		47		52		38		25		40		50		50		67	

a) Balance training including exercises using a balance board, wobble board, semi-globe, ankle disk, stability pad or balance mat

b) Jumping exercises

c) Using the 'Biodex Stability System' balance device, mini trampoline and balance boards

* Excluded from meta-analyses; #, RR could not be calculated; +, Included intervention component (significant preventive effect of NMT on ankle sprains); -, Included intervention component (no significant preventive effect of NMT on ankle sprains); CI, confidence interval; CT, controlled trial; NMT, neuromuscular training; QS, methodological quality score of included studies; RCT, randomised controlled trial; RR, relative risk.

Figure 3.3: Forest plots showing relative risk of ankle sprain (neuromuscular training (NMT) vs control) for interventions targeted at the prevention of *ankle sprains* using balance training (single-component interventions) (top), and multi-component interventions including balance training (bottom)

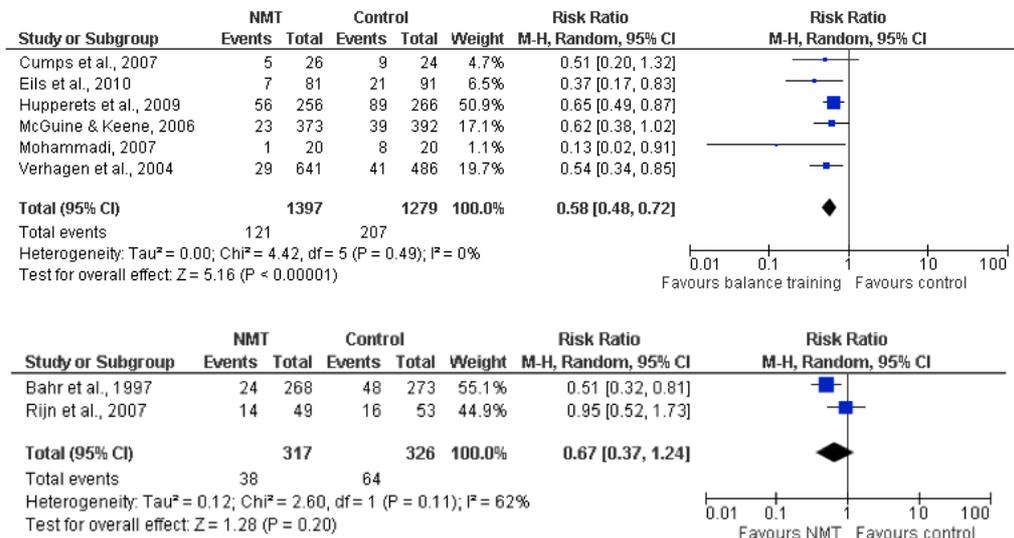


Figure 3.4: Forest plots showing relative risk of ankle sprains (neuromuscular training (NMT) vs control) for interventions targeted at the prevention of *lower extremity or general injuries* using balance training (single-component interventions) (top), and multi-component interventions including balance training (bottom)

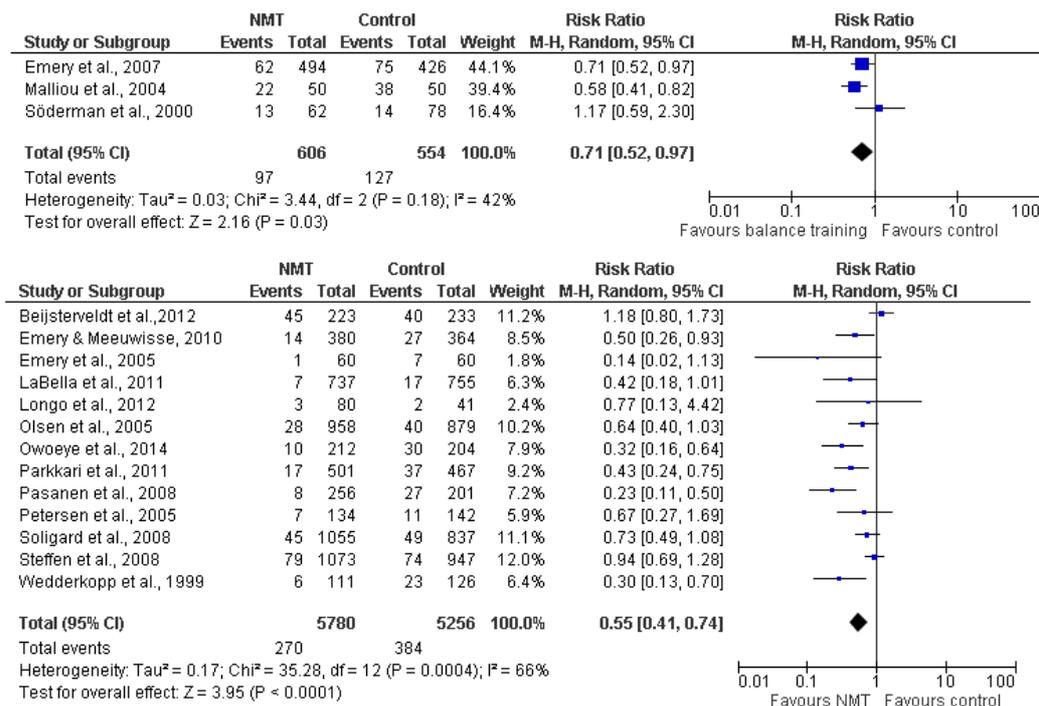


Table 3.5: Relative risk of ankle sprain (NMT versus control) for interventions in participants regardless of injury history (overall), participants with a previous ankle sprain, and participants with no previous ankle sprain

Reference	Design	QS (%)	Overall	Recurrent ankle sprains	First-time ankle sprains
			RR (95% CI)	RR (95% CI)	RR (95% CI)
Bahr et al. [166]	pretest-posttest	85	0.51 (0.32-0.81)		
Cumps et al. [122]	CT	81	0.51 (0.20-1.32)		
Eils et al. [61]	RCT	74	0.37 (0.17-0.83)		
Emery et al. [63]	RCT	95	0.14 (0.02-1.13)		
Emery et al. [65]	RCT	100	0.71 (0.52-0.97)		
Emery & Meeuwisse [64]	RCT	79	0.50 (0.26-0.93)		
Hupperets et al. [78]	RCT	79		0.65 (0.49-0.87)	
LaBella et al. [82]	RCT	79	0.42 (0.18-1.01)		
Longo et al. [83]	RCT	89	0.77 (0.13-4.42)		
Malliou et al. [131]	CT	69	0.58 (0.41-0.82)		
McGuine & Keene [85]	RCT	74	0.62 (0.38-1.02)	0.72 (0.35-1.46)	0.55 (0.28-1.08)
Mohammadi [88]	RCT	74		0.13 (0.02-0.91)	
Olsen et al. [92]	RCT	95	0.64 (0.40-1.03)		
Owoeye et al. [91]	RCT	84	0.32 (0.16-0.64)		
Parkkari et al. [246]	RCT	83	0.43 (0.24-0.75)		
Pasanen et al. [90]	RCT	95	0.23 (0.11-0.50)		
Petersen et al. [135]	CT	69	0.67 (0.27-1.69)		
Söderman et al. [108]	RCT	68	1.17 (0.59-2.30)		
Soligard et al. [109]	RCT	84	0.73 (0.49-1.08)		
Steffen et al. [100]	RCT	89	0.94 (0.69-1.28)		
van Beijsterveldt et al. [95]	RCT	74	1.18 (0.80-1.73)		
van Rijn et al. [247]	RCT	89		0.95 (0.52-1.73)	
Verhagen et al. [98]	RCT	79	0.54 (0.34-0.85)		
Wedderkopp et al. [104]	RCT	68	0.30 (0.13-0.70)		
Total effect estimate					
RR (95% CI)			0.59 (0.49-0.71)	0.69 (0.49-0.98)	
Chi ² (p-value)			0.002	0.25	
I ² (%)			53	27	

Total studies (n)	21	4	1
Studies protective effect (%)	48	50	0

CI, confidence interval; CT, controlled trial; NMT, neuromuscular training; QS, methodological quality score of included studies; RCT, randomised controlled trial; RR, relative risk.

Discussion

A practically relevant result of this systematic review is that NMT programmes possess a significant preventive effect on ankle sprains in athletes, irrespective of the content and context of the intervention, study design and methodological quality of included studies. The total effect estimate for RR of ankle sprain (NMT vs control) was 0.60 (95% CI 0.51 to 0.71). This preventive effect has been established in the general sport population, and in athletes with a previous ankle sprain. However, the individual studies show a great diversity in preventive effects and methodological quality (Figure 3.2). This diversity in effects can be explained by the variability among studies in content and context of the interventions. Therefore, additional analyses were done by intervention content and context.

Since all interventions included balance training exercises, this component seems a prerequisite for NMT programmes to prevent ankle sprains (irrespective of the use of a balance device) based on the current literature. To further identify key elements of NMT programmes to prevent ankle sprains, we assessed differences in outcomes between single-component (i.e. only balance training) and multi-component interventions (i.e. balance training combined with one or more adjunct interventions). A significant preventive effect on ankle sprains was found for single-component programmes. This effect was present in interventions targeting either any (LE) injury or ankle sprains (Figures 3.3 and 3.4). These results indicate that balance training alone may be sufficient to prevent ankle sprains, and reinforce previous findings on this topic [224, 225].

The preventive effect and key elements of multi-component interventions remain inconclusive. Only two studies evaluated the effect of multi-component interventions specifically targeted at ankle sprains [166, 247]. Pooled results based on these two studies should be interpreted with caution. Only 5 of the 13 studies evaluating the effect of multi-component interventions on ankle sprains as a secondary outcome reported a statistically significant effect. The lack of effect in these individual studies may be due to insufficient power to

detect a significant reduction in ankle sprains. However, pooled results reached statistical significance but showed significant heterogeneity. Additional studies are necessary to determine if interventions including adjunct components next to balance training possess greater preventive value compared with balance training alone. This information can be used to optimise interventions with respect to effectiveness, attractiveness and usability in daily practice (e.g. require less time and effort) [92, 216]. As such, this may increase the adoption and level of compliance of the intervention, and actual prevention of ankle sprains [17].

Subgroup analyses revealed that NMT programmes are effective in reducing the risk of recurrent ankle sprains (Table 3.5). A significant preventive effect was found also when considering athletes regardless of their history of ankle sprains (i.e. the entire general sport population). Since only one study presented results considering athletes without a previous injury, no conclusion could be drawn on the primary effect of NMT on ankle sprains. These results underline the effect of NMT as a secondary preventive measure found in previous reviews [224, 230] and meta-analysis [225]. However, another meta-analysis on this topic did not find a significant secondary preventive effect [248]. The latter meta-analysis included only two studies, of which one was a 'lower quality' study. Preventive NMT programmes are often part of the warm-up or training of a sports team, not differentiating between athletes with or without a previous injury. Future studies should assess whether different exercises or intervention components are needed for both groups.

Other intervention aspects should also be considered for the evaluation and implementation of NMT as a preventive measure for ankle sprains. These include the type of sports, supervision, and sport-specific or generic exercises. The integration of sport-specific exercises within a prevention programme may increase its attractiveness, usability and effectiveness as lower-extremity coordination was found to be influenced by movements of the upper body [135]. Related to these aspects, both significant and non-significant results were found in the included studies. Meta-analyses were not performed as studies were clinically too heterogeneous when all these aspects were taken into account [231].

The preventive effect of NMT is most often evaluated in soccer, basketball, handball and volleyball. This choice is justified as ankle sprains are very common injuries in these sports [219]. However, it is recommended that the preventive effect of NMT is also evaluated in other sports at risk for ankle sprains (e.g. field hockey, rugby, netball and tennis).

Our review had some strengths and limitations. In contrast to previous reviews on this topic [224, 225, 230], we used an extended list of 19 criteria to assess methodological quality of all included studies. More variability in the QS was introduced using this list. Unlike other reviews, evidence based on RCTs, CTs and pretest–posttest designs were combined representing different evidence levels. This can be considered a strength, as we provided an overview of all relevant prospective studies. However, this also resulted in higher methodological heterogeneity among the included studies, and results of the presented meta-analyses must be interpreted with caution. A visual overview was provided of studies on the effect of NMT in preventing ankle sprains, taking the methodological study quality and study design into account (Figure 3.2). This overview was used to identify differences in outcomes between various study designs and methodological QS. Another strength is the use of meta-analyses to assess pooled estimates of the preventive effect of NMT in ankle sprains. ‘Low-quality’ studies [230] were excluded from the meta-analyses to reduce heterogeneity through risk of bias and increase validity of results [231]. In order to compare study effects, we calculated the unadjusted RR of individual studies on the basis of data provided. This resulted in different outcomes with respect to the intervention effect in seven studies compared with the adjusted outcomes provided [64, 65, 82, 91, 118, 122, 135]. Almost all studies in this review included active sport participants. One study included participants active in military training that consisted of various sports and physical activities. Another study did not specify the study population with regard to sports [247], but was included since the results were considered valid for athletes as well. We did not consider the level of compliance to the interventions in our review. However, this is relevant additional information as compliance rates affect study outcomes [249], and have implications for implementation efforts [17].

Conclusions

This review provides evidence for the effect of NMT in preventing ankle sprains, taking aspects into account related to both intervention content and context. NMT is effective in reducing ankle sprains in a sporting population, and in athletes with a previous ankle sprain. The evidence for an effect on first-time ankle sprains remains inconclusive. A key element of NMT in preventing ankle sprains is balance training, irrespective of the use of balance boards. Since both single-component and multi-component interventions are effective in reducing ankle sprains, the type most fitting to the context should be chosen for implementation efforts. As such, this review holds practical value for implementation efforts and for the future development of NMT interventions aimed at preventing ankle sprains in sports.

What is already known?

- Ankle sprains are the most common sports-related injury across various sports.
- Neuromuscular training (NMT) has been shown in various studies to reduce the risk of recurrent ankle sprains.

What are the new findings?

- Preventive effects of NMT are found independent of study design and study quality.
- Only NMT intervention programmes that include balance training show a preventive effect on ankle sprains.
- Both single-component as well as multiple-component NMT interventions show a preventive effect on ankle sprains.

Competing interests

None declared

Go!

The Dutch experience: studies evaluating the effectiveness of different intervention strategies in sport injury prevention

4. Shinguards effective in preventing lower leg injuries in football: population-based trend analyses over 25 years

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Abstract

Objectives | The majority of football injuries are caused by trauma to the lower extremities. Shinguards are considered an important measure in preventing lower leg impact abrasions, contusions and fractures. Given these benefits, Fédération Internationale de Football Association introduced the shinguard law in 1990, which made wearing shinguards during matches mandatory. This study evaluated the effect of the introduction of the shinguard law for amateur players in the Netherlands in the 1999/2000-football season on the incidence of lower leg injuries.

Design | Time trend analyses on injury data covering 25 years of continuous registration (1986–2010).

Methods: Data were retrieved from a system that records all emergency department treatments in a random, representative sample of Dutch hospitals. All injuries sustained in football by patients aged 6–65 years were included, except for injuries of the Achilles tendon and Weber fractures. Time trends were analysed with multiple regression analyses; a model was fitted consisting of multiple straight lines, each representing a 5-year period.

Results | Patients were predominantly males (92%) and treated for fractures (48%) or abrasions/contusions (52%) to the lower leg. The incidence of lower leg football injuries decreased significantly following the introduction of the shinguard law (1996–2000: -20%; 2001–2005: -25%), whereas the incidence of all other football injuries did not. This effect was more prominent at weekends/match days. No gender differences were found.

Conclusions | The results significantly show a preventive effect of the shinguard law underlining the relevance of rule changes as a preventive measure and wearing shinguards during both matches and training sessions.

Introduction

Association football, commonly known as football or soccer, is played by an estimated 265 million people, making it the world's most popular team sport [250]. In the Netherlands, over 1.7 million people (11% of the population) play football; of these players, over 1.1 million are members of football clubs [250]. Participation in sports and exercise activities is generally acknowledged to have long-term health benefits, but also entails the risk of sustaining sports injuries [251]. Football has a high injury rate, predominately to the lower extremities [252, 253]. The most common lower leg injuries are sprains, strains and contusions [252-254]. One of the less frequent, but more severe football injuries is a fracture of the tibia or fibula [254]. Recent epidemiological studies in the Netherlands underline these findings [213, 255, 256]. The majority of football injuries are caused by trauma, often due to contact with another player [252, 253, 256]; the lower extremities are often injured during tackling from the side or the front [253, 257].

Fédération Internationale de Football Association (FIFA), the sport's international governing body, has developed various preventive strategies to control the injury risk through measures directed at the game's physical aspects (the facility, equipment and environment), management aspects (e.g. laws of the game) or human aspects (e.g. player behaviour) [251]. One of the strategies was the introduction of the shinguard law in 1990, which made the wearing of shinguards compulsory during matches [258, 259]. The Royal Netherlands Football Association (KNVB) introduced this rule at the start of the 1992/1993-football season for all professional players and 1999/2000-season for all amateur players [260]. Few studies indicate that shinguards are effective in reducing the number of minor impact-related injuries such as contusions, abrasions and lacerations [254, 261, 262]; more recent findings indicate that shinguards provide some measure of protection against tibia fractures, although the level of protection varies significantly according to differences in shinguard design and material type among the commercially available shinguards [254]. Rule and regulation changes can reduce injuries in sport; however, there is a lack of research into the effects of these changes [209].

The aim of the present study was to assess the effectiveness of the introduction of the shinguard law in football on the incidence of lower leg football injuries at a population level. The main focus was on trends in the incidence of lower leg injuries among football players, concentrating on a change in this trend during the implementation period of the shinguard law in the Netherlands for all amateur players (1999/2000). Other

factors that might have influenced this trend were taken into account. To our knowledge, the method of trend analyses has not been used previously to evaluate the preventive effect of shinguards.

Methods

Data were obtained from an existing database, the Dutch Injury Surveillance System (LIS). No additional data were gathered. LIS is a continuous monitoring system, which records all unintentional and intentional injury treated at emergency departments (EDs) in a random sample of Dutch hospitals, and is operated by The Dutch Consumer Safety Institute VeiligheidNL. The participating hospitals are geographically spread across the country, and are regarded representative of general and teaching hospitals in the Netherlands with EDs [255, 263]. Data are available from 1986 onwards and include details of the injury (type of injury, anatomical region), medical treatment, cause of injury, injury mechanism, and patients' age and gender. Within LIS, a physician or other health caregiver diagnoses all injuries, including sports injuries. A nationwide registration of hospital discharges was used to extrapolate ED treatments in the LIS sample to national estimates of ED treatments.

Hospitals collect the accident and injury information that is registered within LIS. All hospitals participating in LIS have given permission for the data registration, exchange and analyses by the Dutch Consumer Safety Institute. All data registered are anonymous; individuals cannot be identified based on these data, and the data are not incriminating for the patients attending the ED of the hospitals included. Therefore, and since the data were obtained from an existing database, no Ethics Committee approval was obtained, and no patient consent was required.

In this study, all injuries sustained in football in the Netherlands during organised activities (matches, training sessions, tournaments) and non-organised activities (leisure football) were included. The study population consisted of men and women aged 6–65 years. Lower leg injuries were defined as abrasions, contusions and fractures of the lower leg, excluding injuries to the ankle and knee. These injuries are expected to be preventable by shinguards, whereas sprains and strains are not. Injuries of the Achilles tendon and so-called Weber fractures (lateral malleolar fractures) were excluded, as these injury types were expected not to be preventable by shinguards. Weber fractures frequently coincide with ankle injuries. The type of injury was classified in accordance with the consensus statement on injury definitions and data collection procedures in

studies of football injuries [264]. Statistical analyses were performed as follows. Data covering 25 years of continuous registration (1986–2010) were used in this study to analyse time trends in the incidence of (1) lower leg football injuries treated at EDs, and (2) all other football injuries treated at EDs. Both trends were compared in order to monitor changes in injury incidence over time, focusing on changes in this trend during the implementation period of the shinguard law for all amateur players (1999/2000), since the number of professional players is relatively very small [250]. Data were analysed with multiple regression analyses on monthly injury figures. A model was fitted that consists of a string of multiple straight lines, each representing a five-year period. The time trends were controlled for seasonal and weather influences. Trends were indexed (1986 was set at 100) for an informative comparison of the time trends. Unfortunately, no sports exposure data were available in LIS. We therefore assumed that the exposure time for lower leg football injuries and for all other football injuries were equal, and that only the incidence of lower leg football injuries would be affected by the shinguard law.

Separate trend analyses were performed on the incidence of lower leg football injuries treated at an ED (1) excluding female football players to establish whether the notable increased participation of female football players accounts for any changes in the time trends, and (2) for injuries sustained either on weekdays or at weekends (over the period 1997–2010; index 1999 = 100) to establish whether the effect of the shinguard law differed for matches (almost all matches are played at weekends) versus training sessions (mostly held on weekdays). Data on the day of the week on which an injury is sustained have been available in LIS since 1997.

The mean annual number of (lower leg) football injuries treated at EDs in the Netherlands was determined based on the LIS data (1986–2012) to illustrate the extent of this injury problem.

The statistical significance change of a trend was set at $p < 0.05$. Data for all respondents were analysed using SPSS PASW statistical software package, version 18.0.

Results

Over the period 1986–2010, a total of 152,043 ED treatments for football injuries were registered in LIS, of which 7,640 involved treatments for abrasions, contusions and/or fractures of the lower leg. Patients ranged from 6 to 65 years in age (mean age 22.4 years; SD 9.63) with the majority being male (92% men, 8% women).

Time trend analyses (1986–2010) for lower leg football injuries and for all other football injuries treated at an ED are shown in Figure 4.1. In 1996–2000, the incidence of football injuries showed a significant decrease for lower leg injuries (–20%; $p = 0.004$) and for all other football injuries (–23%; $p < 0.000$).

From 2001 onwards, the incidence of lower leg injuries continued to decrease significantly. They decreased by 25 per cent ($p = 0.004$) in 2001–2005 and stabilised in 2006–2010, while the incidence of all other football injuries stabilised in 2001–2005, and increased in 2006–2010 (18%, $p = 0.006$). The annual incidence rates for lower leg injuries are also shown in Figure 4.1; they too showed a steep decrease in 1999–2002.

The injury trend shown in Figure 4.1 is based on both male and female football players. Injury trends were no different after injuries sustained by female football players (8% of total football injuries) were excluded from the analysis. The trend in the incidence of lower leg injuries for male football players (–20% in 1996–2000; $p = 0.003$) was similar to the trend in the incidence of lower leg injuries for both male and female football players (–20% in 1996–2000; $p = 0.004$).

Time trends were analysed for injuries sustained on weekdays versus those sustained at weekends, as almost all matches are played at weekends. In 1997–2001, both trends showed a significant decrease for lower leg injury incidence: injuries sustained at weekends decreased by 25% ($p = 0.004$), and injuries sustained on weekdays decreased by 24% ($p = 0.022$). Figure 4.2 shows the annual incidence of football injuries sustained at weekends versus on weekdays. Both at weekends and on weekdays, a decrease in the annual number of lower leg football injuries is visible since 1999. However, a slightly steeper decrease is visible for injuries sustained at weekends since 1999. Injuries sustained on weekdays follow the same pattern but with a delay of two years.

Over the period 1986–2012, a mean annual number of 2,600 lower leg fractures (48%) and abrasions/contusions (52%) sustained in football were treated at Dutch EDs for patients aged 6–65 years accounting for five per cent of all football injuries in the Netherlands for players in this age category.

Figure 4.1: Time trend in the incidence of football injuries treated at an Emergency Department (1986–2010; male and female players); index 1986 = 100

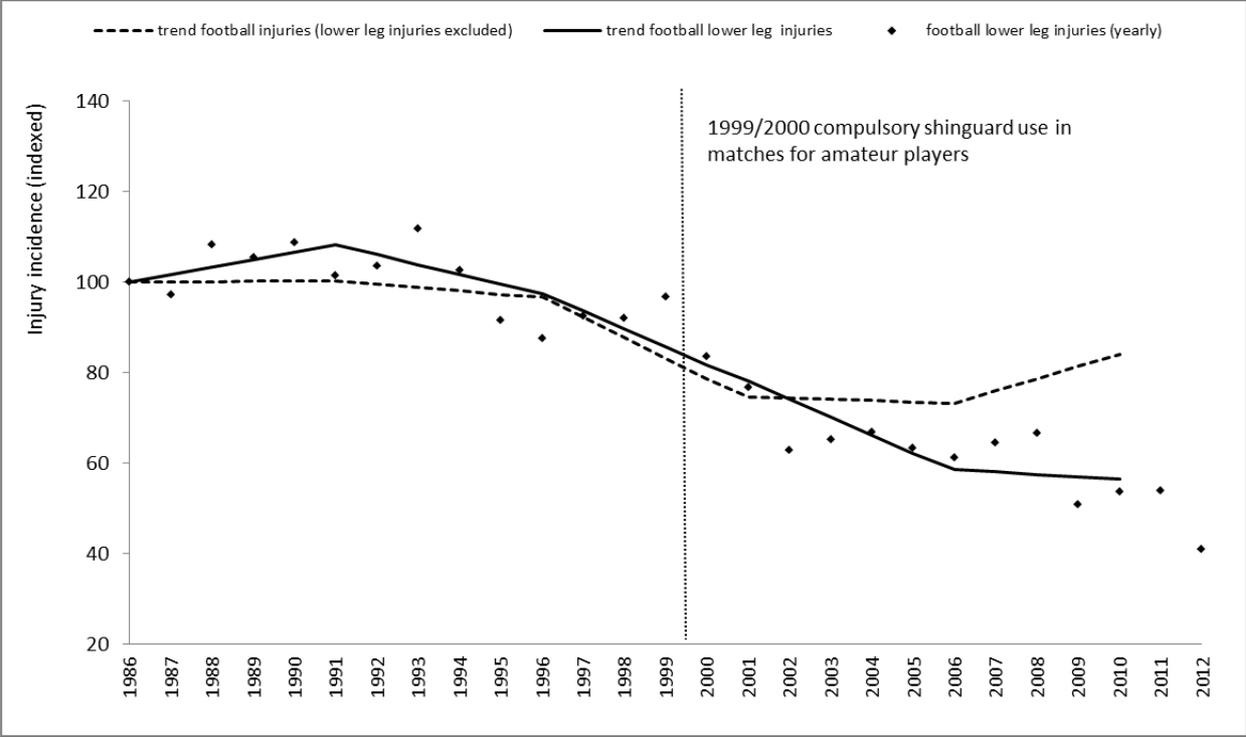
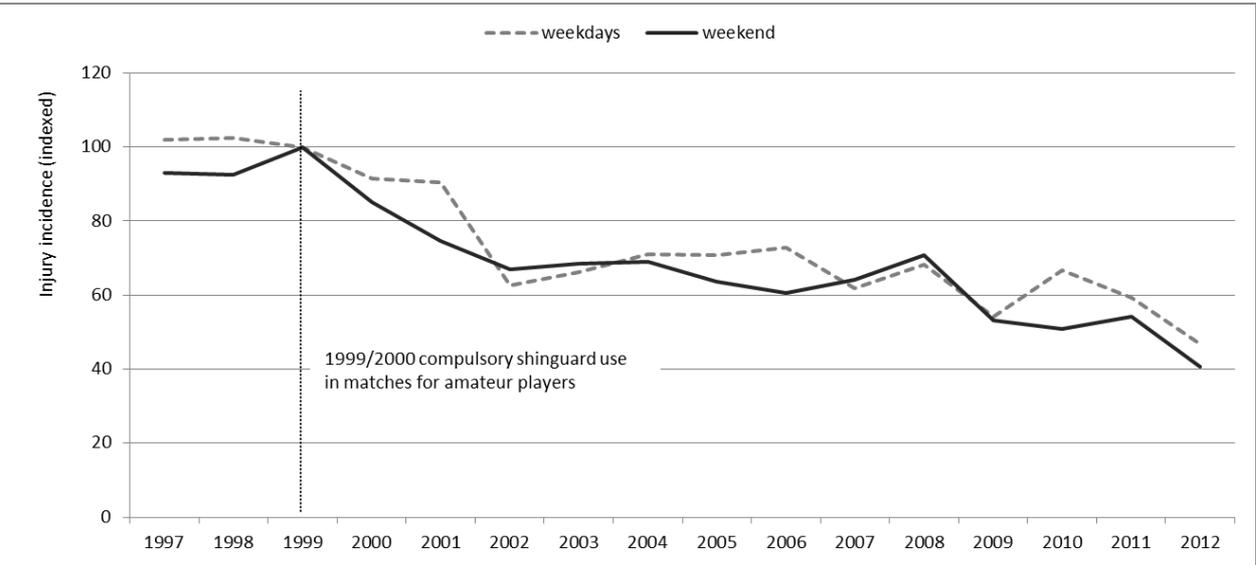


Figure 4.2: Annual incidence of lower leg football injuries on weekdays versus at weekends treated at an Emergency Department (1997–2012; male and female players); index 1999 = 100



Discussion

Few studies have evaluated the preventive effect of shinguards with regard to the incidence and severity of lower leg injuries. Studies concerning this effect are multifactorial prevention programmes [26, 252], observational studies [262] or studies analysing the biomechanical properties of shinguards [254, 261]. More methodologically well-designed studies are recommended to evaluate the effectiveness of shinguards in preventing lower leg injuries, especially fractures of the tibia or fibula [26, 251, 252].

Ethical concerns and the compulsory use of shinguards during matches in the Netherlands since 1999/2000 make it nearly impossible to set up a controlled study to answer this question. One possibility is to evaluate the effect during training sessions, since the use of shinguards is compulsory only during matches. However, the literature shows that the injury risk of lower leg football injuries is much higher during matches compared to training sessions [253, 265]. Observational studies, by using an association between the football injury and exposure, can also be an option. In this population-based study, we used data on football injuries treated at EDs over a period of 25 years. It is interesting to see that the incidence of lower leg football injuries decreased significantly following the introduction of the shinguard law at the start of the 1999/2000-footballseason for all amateur players (compulsory use of shinguards during matches), whereas the incidence of all other football injuries remained the same. These results indicate a strong preventive effect of shinguards in football and substantiate earlier findings regarding their effectiveness.

Separate analyses were done to determine whether factors other than the implementation of the shinguard law could have affected the trends in the incidence of lower leg injuries and that in the incidence of other football injuries. These factors were shinguard use during training sessions and an increase in the number of female players. In addition, the introduction of artificial turf in the late 1990s and other contemporaneously introduced football rules were taken into account.

The shinguard law applies only to matches, although the KNVB has, and many football clubs may also have, stimulated the use of shinguards during training sessions. In the Netherlands, almost all matches are played at weekends, and training sessions are mainly held on weekdays. The results of the trend analyses showed a similar decrease in the incidence of football injuries at weekends (matches) and on weekdays (training sessions) in 1997–2001, with a delayed effect on the decrease in the incidence of injuries sustained on

weekdays compared to injuries sustained at weekends. It is possible that the compulsory use of shinguards during matches has a positive effect on the uptake rate during training sessions. In the Netherlands, 73% of football players used shinguards at all times during training sessions in 2011 [266]. Two studies report the use of shinguards during almost all football matches but less frequently during training sessions, namely by 38% of all football players in Iceland, and during 59% of all training sessions in New Zealand [267].

With the notable increased participation of female football players in recent years [250, 268] possible differences between male and female players with regard to the incidence, nature and cause of injuries might have contributed to the significant decrease in the trend in lower leg football injuries. Limited information on injuries in female football players is available [252, 268]. Although it is clear that female football players are at an increased risk of suffering anterior cruciate ligament (ACL) injuries [265, 268], the relation between gender and lower leg injury is unclear [265]. Our results indicate that the injury trends remained the same when female football players were excluded from the analysis. With only a small percentage of all patients in our registration being female (8%), the number of injuries sustained by female football players was too small to estimate reliable annual incidence rates and separate trends.

Another possible confounding factor is the introduction of artificial turf surfaces as an alternative to natural grass. The first generation of artificial turf appeared in the late 1960s, the second in 1980–1990 and the third in the late 1990s (which was when the shinguard law was introduced in the Netherlands). The effect of these synthetic surfaces on injury rates has been established in football. Studies found no major differences between the incidence, severity, nature or cause of either training or playing injuries sustained on new-generation artificial turf and grass by either men or women [50, 268, 269].

One last relevant factor is the effect of contemporaneously introduced rule changes by FIFA and KNVB. Since 1998, a tackle from behind that endangers the safety of an opponent must be sanctioned as serious foul play [259]. In the preceding years, there had already been increased focus by referees on violent tackles. Tackling is one of the major causes of lower leg football injuries [253, 257, 270]. With injuries resulting from trauma [271], player-to-player contact [272, 273], and tibial fractures due to tackles [274] being more common during matches than during training sessions, this rule change has probably resulted in fewer tackles during matches and therefore affected the incidence of lower leg football injuries during matches. It cannot, however, explain

the similar trend seen during training sessions. Since 2005, any tackle that endangers the safety of an opponent must also be sanctioned as serious foul play [259]. Being tackled from the side was found to have the greatest propensity for causing injury in male football players [257, 270], while sliding tackles have been reported to have the highest injury potential in women's football [268]. This could have affected the incidence of lower leg football injuries and the incidence of other football injuries during matches, but cannot explain the trend differences found in 1996–2000.

Our study had some limitations, for example missing exposure data. Over time, the exposure to football has increased considerably and the increase in the number of female players is especially notable [250]. We assumed that any changes in exposure level for lower leg injuries were equal to changes in exposure level for all other football injuries. A second assumption was that the shinguard law would not affect the incidence of football injuries other than lower leg injuries. However, the introduction of personal protective equipment usually implies a change or modification in the behaviour of the athlete (e.g. tackling) and might have increased the injury risk [26]. Possible changes in players' behaviour has not been monitored over time. Furthermore, no information was available on the uptake rate of shinguards over time or the type of shinguards used by players over time (design, material type and size). Various types of shinguards are available and allowed in football. FIFA rules dictate that shinguards must be covered entirely by the socks, must be made of rubber, plastic or a similar suitable material, and must provide a reasonable degree of protection [258]. The level of protection against tibia fractures may vary significantly among commercially available shinguards [254]. Additional data, such as the uptake rate of shinguards during training sessions and matches, and the type of shinguards used, are valuable in order to further evaluate the preventive effect of shinguards on lower leg injuries in football.

To prevent lower leg injuries, shinguards must be not only effective, but also accepted, adopted and complied with by the athletes and sports organisations they are targeted at [17]. More consistent use of shinguards during training sessions and matches can help to prevent contact injuries. Referees, trainers and sports clubs can be supportive by ensuring adherence to these rules and by educating players [26].

Conclusions

Shinguards are considered an important measure in preventing lower leg impact injuries. However, few studies have evaluated this effect. In this population-based study, trend analyses confirm earlier findings regarding the effectiveness of shinguards in preventing impact-related injuries of the lower leg in football, i.e. abrasions, contusions and fractures of the tibia and fibula. We used data covering a period of 25 years on injuries sustained in Dutch football and treated at hospital emergency departments. The incidence of lower leg football injuries decreased significantly following the introduction of the shinguard law in the Netherlands in the 1999/2000-football seasons, i.e. the compulsory use of shinguards for amateur players in matches, whereas the incidence of all other football injuries did not decrease significantly over time. The use of shinguards during training sessions should therefore also be strongly recommended. During the implementation period of the shinguard law, another rule change was introduced. This regarded the sanctioning of tackles, and has probably contributed to the effect of the shinguard law on the incidence of lower leg injuries during matches, but cannot explain the similar trend differences seen during training sessions.

Practical implications

- Preventive strategies directed at changes to rules and regulations can be effective to prevent sport injuries.
- This study emphasises the relevance of wearing shinguards by football players as a preventive measure during matches, training sessions and all other football activities.
- Trainers, coaches, physicians, physical therapists and parents (in case of youth players) should strongly recommend the use of shinguards by football players at all times.
- Long-term registration of sports-related injuries by physicians and physical therapists is an important and relevant tool to gain insight in trends in the incidence of sports injuries.
- An observational study, with data based on a continuous registration system, can deliver valuable information to evaluate the effectiveness of preventive measures at a population level within the 'real-world' implementation context in addition to experimental and controlled study designs.

Acknowledgments

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5. Effectiveness of a nationwide intervention to increase helmet use in Dutch skiers and snowboarders: an observational cohort study

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Submitted

Abstract

Objective | Helmet use in Dutch recreational skiers and snowboarders (DRSS) remains low. This study evaluated the effects of exposure to a nationwide intervention on relevant determinants of helmet use, and helmet use in DRSS.

Methods | The Intervention Mapping protocol was used to develop an in-season intervention programme targeted at adult DRSS. A prospective single-cohort study was conducted to evaluate the impact of intervention exposure on determinants of helmet use (i.e. knowledge about head injury risk and preventive measures, risk perception, attitudes to head injury risk and helmet use, intention to helmet use), and self-reported helmet use. A random sample of 363 DRSS from an existing panel participated in this study. Data were collected using online questionnaires before and immediately after the 2010/2011-intervention season. In a separate sample of 363 DRSS intervention reach was assessed after the 2010/2011-season.

Results | Overall, no significant associations were found between intervention exposure and the determinants of helmet use. However, subgroup analyses revealed intervention effects on risk perception and knowledge in specific subpopulations. Intervention exposure had a significant, positive effect on helmet use in DRSS ($\beta=0.23$; 95% CI 0.017 to 0.44). Subgroup analyses revealed that this effect was found in: 1.skiers, 2.female DRSS, 3.young skiers, and 4.intermediate skiers. Overall intervention reach was 28.1%, with differences found between skiers and snowboarders.

Conclusions | Exposure to a nationwide intervention programme was associated with increased self-reported helmet use in DRSS. Differences were found in intervention effectiveness and reach between subpopulations. These differences must be taken into account when developing and evaluating future interventions.

Introduction

Alpine skiing and snowboarding are popular winter sports worldwide [275, 276], and practiced by approximately 850,000 Dutch [277]. Head injuries are common in skiing and snowboarding [275, 278, 279] with possible serious consequences, including long-term and serious disabilities, and death [275, 276, 280].

Depending on study design and definition used, the proportion of head injuries ranges from 3% to 30% of all ski and snowboard-related injuries [275, 278, 279]. This underpins the importance for head injury prevention.

Helmet use is recommended for skiers and snowboarders as they have been shown to reduce head injury risk ranging from 15% to 60% [276, 281], with a pooled estimate of risk reduction by 35% [282]. However, a public health impact can only be achieved if helmets are widely adopted and consistently used [24]. Helmet use rate has increased over the last decade from 16% to 25% in 2002/2003, up to 73% to 89% in 2013/2014 [283-285]. This may be a consequence of compulsory helmet use in several countries for children and during lessons [279, 286], increased public awareness about head injury risk and the protective effect of helmets [275, 279, 287, 288], increased helmet availability, enhanced design and comfort, and reduced helmet costs [287, 289].

Despite these positive developments, helmet use among Dutch recreational skiers and snowboarders (DRSS) remained inconsistent [290] and low, with a mere 34% in 2011 [291]. This faces us with the challenge to increase helmet use as an effective preventive measure among DRSS.

As current policy in Europe is to leave the decision to wear a helmet to the adult skier and snowboarder, effective implementation strategies should focus on behavioural change as a key factor for success [32, 288].

Therefore, in the Netherlands, a nationwide in-season intervention was developed intended to increase consistent helmet use among adult DRSS. Previous studies indicated that non-legislative community-based approaches can be effective in increasing helmet use [292, 293]. However, little is known about the impact of nationwide interventions on the uptake of helmets.

Therefore, the primary aim of this study was to evaluate the effect of this nationwide intervention on relevant determinants of helmet use, and actual helmet use among DRSS. The underlying hypothesis was that exposure to the intervention would be associated with a significant change in these outcomes. Differences in effect were expected by age, gender, snow sport type, and skill level [287, 289, 294, 295]. As such, we evaluated the effect in predefined subpopulations of DRSS as well. While randomised controlled trials are considered the optimal

research design for establishing intervention effects, randomization and inclusion of a proper control group were not feasible as we evaluated a nationwide intervention. Instead, a prospective single-cohort study was used, with self-reported exposure to the intervention as the comparator condition. This design is considered an optimal method to evaluate nationwide (policy-level) interventions [41]. As an intervention can only have an impact within the target population reached [24], the secondary aim was to assess the reach of the intervention within the intended target population.

Methods

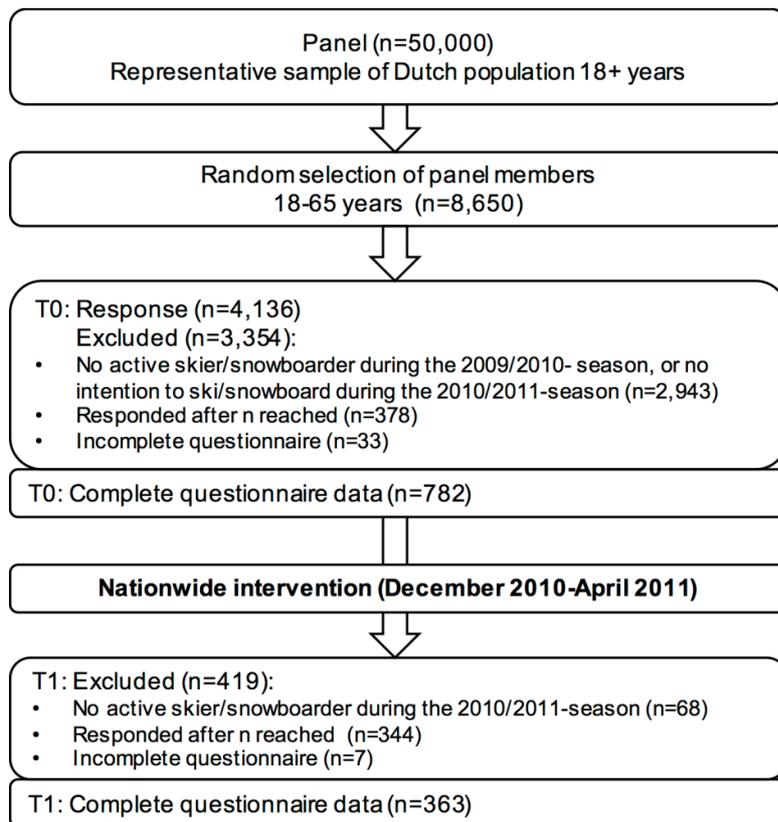
Study design and participants

A prospective single-cohort study was conducted during the 2010/2011-winter sport season to evaluate the effect of exposure to the intervention on changes in relevant determinants of helmet use, and self-reported helmet use in DRSS. Measurements were done prior to the intervention start (December 2010; T0) and immediately after the winter sport season (April 2011; T1). Online questionnaires were used for data collection. Potential study participants were members of an existing Dutch online research panel by their own choice (50,000 members; inVotes, No Ties B.V.). This panel is considered representative for the Dutch population because of its use in accordance with the Dutch standard of a sampling method, and data collecting method [296]. A random sample of 8,650 panel members aged 18-65 years was invited to participate in this study by e-mail. Eligible for study inclusion were adult active skiers (aged 18-65 years), and young snowboarders (aged 18-24 years) as their risk of sustaining a head injury is relatively high [279, 280, 297]. Respondents were screened for study eligibility in two steps based on the first questions of the online questionnaire. At T0, respondents were invited to complete the full T0-questionnaire if they had been active in skiing or snowboarding during the 2009/2010-season, or intended to be active during the upcoming 2010/2011-season. At T1, all respondents with complete data at T0 were invited to complete the full T1-questionnaire if they had been active in skiing or snowboarding during the 2010/2011-season (Figure 5.1).

In order to ensure a representative sample of DRSS into the study, the inclusion of participants was stratified by winter sport activity, age and gender, all based on a known distribution of DRSS over the period 2006-2009 [213]. Inclusion was closed when a predefined target number of respondents was reached (T0: n=775; T1:

n=360). The target number of respondents was based on pragmatic considerations, in addition to unknown effect rates of a nationwide intervention on helmet use. Respondents with incomplete questionnaires were not included. All participants consented to study participation by implication of their panel membership, and acceptance of our invitation to participate. No Ethics Committee approval was required as study participants were not subject to any (medical) procedures or instructions to change their behaviour.

Figure 5.1: Flow chart of study participants



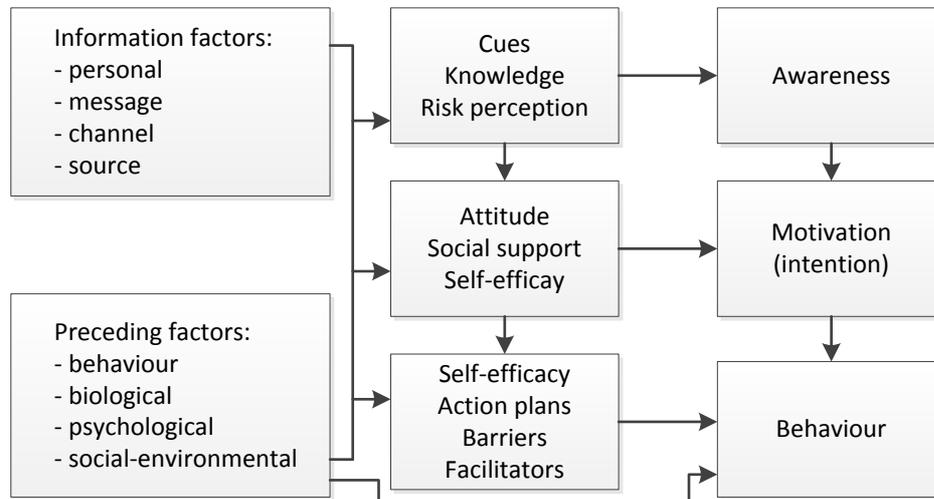
Intervention ‘Use your head, wear a helmet’

An in-season intervention ‘Use your head, wear a helmet’ was developed intended to increase actual helmet use among adult DRSS, and first implemented in the 2010/2011-winter sport season at a national level. The intervention strategy focussed on behavioural change, aimed to increase DRSS’ awareness related to the risk of sustaining a head injury in skiing/snowboarding and its possible long-term consequences, their motivation to use a helmet, and actual helmet use.

Multiple complementary intervention components were developed aimed to reach DRSS at a local and/or national level. At a local level, the intervention consisted of a special version of a high striker or 'strongman game' machine that was implemented in four Dutch indoor ski halls successively during the season. The strongman game was located at a central and freely accessible location within the ski hall, accompanied by volunteers. Ski hall visitors could strike the strongman game on a voluntary basis, or witness someone else strike it: the harder the strike, the higher the puck would rise, with indications ranging from headache to skull fracture as possible consequences of a blow to the head. Flyers, including information about head injury risk and the preventive effect of helmets in skiing/snowboarding, were distributed by volunteers accompanying the strongman game, and were freely available at Dutch ski halls during the season. In addition, the intervention consisted of an informative website. The implementation of the intervention was accompanied by a press release, website banners, and online and offline advertisements. A Dutch Olympic snowboard champion acted as intervention ambassador. All intervention components consequently referred to the intervention website, and used the slogan 'Use your head, wear a helmet' to depict the main intervention objective.

The intervention was developed using the intervention mapping (IM) protocol [20]. Dutch indoor ski halls (used for skiing and snowboarding) with snow surfaces were chosen as intervention setting, as in the Netherlands no natural ski/snowboard facility exists. The integrated behavioural change (I-Change) model was used as a theoretical framework to identify relevant determinants and preceding factors of helmet use among DRSS (Figure 5.2) [298]. Relevant determinants were identified in the literature, including social support [294], awareness of both head injury risk and severity [288], and attitudes towards helmet use [287, 289, 294]. A study among DRSS revealed negative cognitions towards helmet use, low risk perception and low knowledge about preventive measures [299]. As a next step, intervention objectives were specified for knowledge, risk perception, and attitudes. Appropriate theory-based methods were identified from the literature to change these determinants, and translated into practical strategies [20]. An overview of practical strategies used (related to the intervention objectives and methods) is provided in supplementary file A (page 95). Relevant preceding factors for helmet use in skiers and snowboarders (i.e. age, gender, snow sport type, and skill level) [287, 289, 294, 295] were also identified in literature, and taken into account in the intervention development and evaluation. Both intervention strategy and intervention materials were pilot tested within the setting of a Dutch indoor ski hall and adjusted based on the outcomes [300].

Figure 5.2: I-Change model (version 2.0) used as a theoretical framework for the development and evaluation of the intervention, explaining motivational and behavioural change in helmet use (adapted from de Vries, 2013) [298]



Outcome measures and measurements

Information on personal characteristics (age, gender), ski/snowboard activity during the season (i.e. ski/snowboard/ both), self-reported skill level (i.e. beginner/ intermediate/ advanced/ expert level), history of head injury in skiing/ snowboarding (yes/no), and self-reported (determinants of) helmet use was gathered at T0 and T1 through online questionnaires. Determinants of helmet use were assessed through 25 items in the questionnaire, divided across the following constructs: knowledge, perceived knowledge, risk perception, attitude, social support, and intention to helmet use (Table 5.1). Cronbach's alpha was used to test the internal consistency of items within constructs (α -values of ≥ 0.65). Scores within each construct were summed for analyses, leading to the following measures: knowledge (0-2), perceived knowledge (0-6), risk perception (0-8), attitude (0-56), social support (0-4), and intention to helmet use (0-1). Helmet use was assessed separately for skiing and snowboarding. For participants active in both skiing and snowboarding, helmet use was calculated by combining individual scores on helmet use in skiing and snowboarding. In order to compare these combined scores with those individuals only active in skiing or snowboarding, totals for participants active in both sports were recategorised to 0 'never', 1 'sometimes', 2 'often', 3 'always'. Outcome measures were knowledge, perceived knowledge, risk perception, attitude, intention to helmet use, and self-reported helmet use.

Table 5.1: Operationalisation of determinants of helmet use, and actual self-reported helmet use

Measure	Operationalisation	Number of items	Measurement scale	Response categories
Knowledge	Assessment of the proportion of head injuries out of every 100 hospital admissions due to a ski/snowboard injury	1	three-point Likert scale	0 'wrong', 1 'good estimate', 2 'right'
Perceived knowledge	Participants' judgement whether their knowledge is sufficient about (i) the risks of sustaining ski/snowboard injuries, (ii) measures to prevent such injuries, and (iii) the importance of helmet use in skiing/snowboarding	3	three-point Likert scale	0 'no', 1 'maybe', 2 'yes'
Risk perception	Participants' judgment regarding their own risk for (i) sustaining a head injury while skiing/snowboarding, and (ii) sustaining such an injury with long-term physical consequences	2	five-point Likert scale	0 'very low' to 4 'very high'
Attitude	Statements about ski/snowboard helmet use	14	five-point Likert scale	0 'I totally disagree' to 4 'I totally agree'
Social support	Ski/snowboard helmet use by relevant others within the participants' network, and whether they encountered support for helmet use	4	dichotomised	0 'no', 1 'yes'
Intention to helmet use ^{a, b}	Intention to use a helmet (more often) while skiing/snowboarding	1	dichotomised	0 'no', 1 'yes'
Helmet use ^b	Frequency of self-reported helmet use while skiing/snowboarding	1	four-point Likert scale	0 'never', 1 'sometimes', 2 'often', 3 'always'

a) Information was only gathered when respondents did not (always) use a helmet; b) assessed separately for skiing and snowboarding

Information on intervention reach and indoor ski hall visits during the season was gathered at T1. Reach was defined as the proportion (%) of participants familiar with the intervention and/or exposed to at least one of its components (strongman game, website, flyer, online/offline media; yes/no). For this purpose, a second independent sample of 5,360 panel members was invited by e-mail to complete only the T1-questionnaire. This second sample was added to avoid possible bias from the T0-measurement in assessing intervention reach. The same eligibility criteria and sampling method were used as outlined for the first sample.

Statistical analyses

Descriptive analyses were used to assess baseline helmet use, intervention reach, and indoor ski hall visits during the 2010/2011-season. Differences between subpopulations of DRSS were checked using Chi-square-tests. Multiple linear and logistic regression analyses were used to evaluate the effect of exposure to the intervention on the outcome measures (i.e. knowledge, perceived knowledge, risk perception, attitude, intention to helmet use, and helmet use). This was assessed by evaluating the association between intervention exposure and individual changes in each outcome measure over the 2010/2011-season (i.e. the differences in the outcome value at T1 and T0). All regression analyses were adjusted for baseline helmet use. Models were additionally checked and adjusted for possible confounding, and/or effect modification (i.e. age, gender, skill level, visits to participating ski halls during the season, history of ski/snowboard head injury, winter sport activity, social support). The association between intervention exposure and individual changes in each outcome was also evaluated for predefined subpopulations of DRSS, that is, skiers, snowboarders, males and females. Furthermore, subgroup analyses for age groups and skill levels were done in skiers only, as the sample sizes were too small for snowboarders and for individuals active in both sports. Differences were considered significant with a significance level of 0.05. Data were analysed using SPSS 22.

Results

Participants

At baseline, 4,136 (48%) of the approached panel members responded. Most respondents were not included as they were no active skier or snowboarder (71%). A total of 782 eligible respondents completed the T0-questionnaire within a week. Herewith, the predefined target number of participants was reached and

inclusion was closed. All 782 respondents were invited to complete the T1-questionnaire. At T1, 75 respondents were excluded and 344 participants responded after the predefined target number of participants was reached. As such, 363 participants with complete data at T0 and T1, were included in the analyses on the association between exposure and outcome (Figure 5.1). Most study participants (66%) were skiers, and helmet use differed significantly by winter sport activity with lowest helmet use found in skiers (Table 5.2). At baseline, only a small percentage of DRSS had a history of head injury in skiing/snowboarding (4.7%). Of all participants, 15.7% had been active in an indoor ski hall; 54.8% in natural ski surroundings, and 29.5% combined both during the season.

Table 5.2: Characteristics of study participants, indoor ski hall visits and intervention exposure during the intervention season; study participants with complete data at T0 and T1 were included (n=363, %)

	Study participants (T1)	Baseline helmet use (T0)				Indoor ski hall visits (T1)	Intervention exposure (T1)
		Never	Some-times	Often	Always		
Overall		43.3	10.2	19.8	26.7	45.2	34.4
Gender							
Male	57.6	44.0	9.6	18.7	27.8	44.0	35.4
Female	42.4	42.2	11.0	21.4	25.3	46.8	33.1
Age (years)							
18-34 years	65.3	43.8	12.1	20.8	23.3	48.1	30.4*
35-65 years	34.7	42.3	6.5	17.9	33.3	39.7	42.1
Winter sport activity (2010/2011)							
Ski	65.6	53.2**	8.6	13.2	25.0	37.0**	31.5*
Snowboard	11.0	34.3	18.8	18.8	28.1	62.5	27.5
Ski + Snowboard	23.4	26.1	10.8	33.3	29.7	60.0	45.9
Ski and age (years) ^a							
Ski 18-34 years	57.6	56.2	10.0	14.6	19.2	38.7	26.3*
Ski 35-65 years	42.4	48.9	6.7	11.1	33.3	34.7	38.6
Ski and skill level (self-reported) ^a							
Beginner	18.1	39.5	9.3	20.9	30.2	65.1**	48.8*
Intermediate	29.4	46.9	10.9	17.2	25.0	42.9	31.4
Advanced/expert	52.6	61.9	7.1	8.0	23.0	24.0	25.6

p-value: * <0.05, ** <0.001 between subpopulations

a) Only skiers were included (n=238); respondents active in both skiing and snowboarding, were excluded.

Intervention effects

Overall, no significant associations were found between intervention exposure and any of the determinants of helmet use (Table 5.3). Subgroup analyses revealed that intervention exposure was associated with (i) increased risk perception in snowboarders ($\beta=1.62$; 95% CI=0.14-3.09); (ii) decreased knowledge in young skiers ($\beta=-0.31$; 95% CI=-(0.57-0.057)); and (iii) decreased perceived knowledge in novice skiers ($\beta=-1.22$; 95% CI=-(2.34-0.09)).

Table 5.3: Values of outcome measures before (T0) and after the intervention season (T1) for the exposed and unexposed groups, and overall associations between intervention exposure and outcome measures (n=363) based on multiple linear regression analyses (for knowledge, perceived knowledge, risk perception, attitude, self-reported helmet use) and logistic regression analyses (for intention to helmet use)

Outcome measure	Exposed (n=125) ^a		Unexposed (n=238) ^a		Crude model ^b			Adjusted model ^c		
	T0	T1	T0	T1	β/OR ^d	95% CI	p-value	β/OR ^d	95% CI	p-value
Knowledge (objective)	1.26 (0.62)	1.16 (0.63)	1.25 (0.66)	1.28 (0.65)	-0.11	(-3.05-0.085)	0.270	-0.14 ^{1,7,8}	(-0.31-0.023)	0.091
Knowledge (perceived)	4.88 (1.50)	4.90 (1.53)	4.97 (1.54)	4.94 (1.41)	0.12	-0.26-0.49	0.543	-0.20 ^{1,2,4,5,8}	-0.54-0.15	0.265
Risk perception	2.54 (1.56)	3.34 (1.74)	2.18 (1.49)	2.89 (1.76)	0.16	-0.25-0.56	0.453	0.062 ^{1,3,7,8}	-0.35-0.48	0.768
Attitude	42.2 (10.28)	44.4 (9.66)	37.95 (10.14)	39.96 (10.46)	0.49	-1.34-2.32	0.600	-0.19 ^{1,8}	-1.99-1.55	0.830
Intention ^e	29.4	31.5	14.2	15.9	1.45	0.51-4.16	0.484	0.21 ^{1,2,4,7,8}	0.026-1.65	0.137
Helmet use	1.75 (1.15)	1.98 (1.11)	1.04 (1.29)	1.11 (1.32)	0.34	0.13-0.55	0.002	0.23⁸	0.017-0.44	0.034

OR, odds ratio; CI, confidence interval

Note: Higher scores indicate increased knowledge, risk perception, attitude (more perceived advantages/less disadvantages), intention towards helmet use, and helmet use; significant changes in bold; a) values are presented as the mean (with corresponding standard deviation), or as percentage of the population (for intention); b) All models were a priori adjusted for baseline helmet use; c) Models were additionally adjusted for: 1) baseline value of the outcome measure, 2) age, 3) gender, 4) skill level, 5) visits to participating ski hall, 6) history of ski/snowboard head injury, 7) winter sport activity, 8) social support; d) OR was used for 'intention'; e) Only participants who did not (always) use a helmet at T0 and T1 were included in the analyses (n=217).

Consistent self-reported helmet use increased over the intervention period from 26.7% to 33.9%. Overall, exposure to the intervention was associated with an increase in self-reported helmet use ($\beta=0.23$; 95% CI=0.017-0.44) (Table 5.3). Both winter sport activity and gender acted as effect modifiers in the relationship between intervention exposure and helmet use. Subgroup analyses revealed that significant associations between exposure and helmet use were found in four subpopulations: skiers, female DRSS, younger skiers, and skiers at an intermediate skill level (Table 5.4). Most DRSS were exposed to multiple intervention components (75.2%).

Table 5.4: Mean values (\pm SD) of self-reported helmet use before (T0) and after the intervention season (T1) for the exposed and unexposed groups, and associations between intervention exposure and self-reported helmet use for predefined subpopulations based on multiple linear regression analyses

Helmet use	n	Exposed		Unexposed		Adjusted model ^a		
		T0	T1	T0	T1	β	95% CI	p-value
DRSS (n=363):	n							
Winter sport type								
Ski	238	1.50 (1.18)	2.00 (1.19)	0.88 (1.26)	0.90 (1.27)	0.46 ⁸	0.19-0.72	0.001
Snowboard	40	2.00 (0.87)	2.00 (1.10)	0.96 (1.29)	1.23 (1.33)	0.15 ^{3,5,8}	-0.73-1.04	0.722
Ski and snowboard	85	2.15 (1.01)	1.95 (1.00)	1.65 (1.25)	1.78 (1.28)	-0.40 ^{2,4,5,8}	-0.83-0.04	0.073
Gender								
Male	209	1.82 (1.19)	1.92 (1.17)	1.01 (1.29)	1.15 (1.32)	0.44 ^{2,4,5,7,8}	-0.19-0.42	0.443
Female	154	1.65 (1.09)	2.08 (1.04)	1.08 (1.30)	1.07 (1.32)	0.35 ⁸	0.03-0.67	0.035
Skiers only (n=238):	n							
Age								
18-34 years	139	1.11 (1.06)	1.81 (1.21)	0.84 (1.22)	1.85 (1.24)	0.50 ⁸	0.11-0.88	0.012
35-65 years	99	1.87 (1.19)	2.18 (1.16)	0.95 (1.33)	0.97 (1.33)	0.19 ^{5,8}	-0.19-0.58	0.316
Skill level								
Beginner	43	1.80 (1.11)	2.15 (1.04)	1.36 (1.36)	1.27 (1.24)	0.19 ^{2,8}	-0.45-0.83	0.542
Intermediate	70	1.36 (1.14)	2.05 (1.21)	1.17 (1.29)	1.04 (1.32)	0.70 ⁸	0.12-1.28	0.019
Advanced/expert	125	1.41 (1.27)	1.88 (1.29)	0.62 (1.17)	0.73 (1.23)	0.31 ^{5,8}	-0.02-0.65	0.068

SD, standard deviation; CI, confidence interval; Note: Higher scores indicate increased helmet use; significant changes in bold. a) All models were a priori adjusted for baseline helmet use; models were additionally adjusted for: 1) baseline value of the outcome measure, 2) age, 3) gender, 4) skill level, 5) visits to participating ski hall, 6) history of ski/snowboard head injury, 7) winter sport activity, 8) social support.

Intervention reach

A total of 2,540 approached panel members of the second sample responded (47.4%). The majority was not eligible (n=2,008) and as such excluded. Another 169 panel members responded after the predefined target number of respondents was reached, resulting in a second sample of 363 participants. This sample of DRSS was comparable to the first sample with respect to age, gender, activity, skill level, and indoor ski hall visits. Overall intervention reach was 28.1%. The majority of DRSS exposed to the intervention, had visited a participating ski hall during the season (65.7%). Intervention reach was significantly lower in skiers (23.2%) as compared to snowboarders (27.1%), and DRSS active in both sports (44.6%; Chi² test, p=0.002). No other differences in intervention reach were found between subpopulations.

Discussion

Our intervention intended to change the preventive behaviour of DRSS to adopt helmets as a proven effective measure. We evaluated the impact of exposure to the nationwide intervention in a real-world sport context. Exposure to the intervention was associated with increased self-reported helmet use. Subgroup analyses revealed that this association was accomplished in four specific subpopulations, that is, in skiers, female DRSS, younger skiers, and skiers at an intermediate skill level. However, hardly any association between intervention exposure and determinants of helmet use was found. This may be due to the internal validity of the questions used. With respect to knowledge, only one quantitative question was used about injury risk. The use of multiple questions, both quantitative and qualitative, is preferred. Another explanation may be the use of self-reported outcome data using Likert-scales. Actual differences over time may not have been accounted for if participants did not rank themselves in a different scale. Although this study did suggest a behavioural change through the intervention, actual determinants of this change need to be further elucidated in order to develop more efficient and targeted interventions in the future.

Nearly one third of the target population was reached during the 2010/2011-intervention season. This is low for a public health intervention targeted at a whole community [301], but considered successful as the intervention was implemented successively in only four (out of seven) Dutch indoor ski halls with snow surfaces. However, questions can be raised whether the intervention was successful in reaching the most

relevant subpopulations. Both young, intermediate and expert skilled skiers were relevant target populations given their low helmet use rates at baseline. However, intervention exposure and ski hall visits during the season were low in these groups. Although the intervention was successful in increasing helmet use in skiers, the success rate of the intervention can be expected to increase by optimizing its reach within young, intermediate and expert skilled skiers. Exposure of the identified subpopulations to the intervention should be extended and increased within and next to the indoor ski hall setting. These results emphasise the added value of subgroup analyses in the evaluation of an intervention. Moreover, it should be stressed that differentiating relevant subgroups is also important in any intervention development [20]. Although differences between subgroups of DRSS (i.e. skiers and snowboarders, age groups) had been accounted for in the development of our intervention, other characteristics (e.g. by skill level) should be considered as well in future adaptations of this programme.

The current study is not the first to evaluate the effect of a nationwide intervention on helmet use among skiers and snowboarders. Bianchi et al. evaluated the 'Protect yourself with a helmet'-campaign in Switzerland [302]. Increased observed helmet use rate was found during the campaign period, together with increased public risk awareness and vulnerability consciousness. However, in this study only a small correlation was found between campaign recognition and helmet use [302], making the impact of the campaign unclear [288]. Increased helmet use was attributed to wide media coverage after a few fatal ski injuries involving celebrities during the same period [288]. Another study reported on the effects of a community-based programme to increase ski/snowboard helmet use, including a social marketing campaign and a free helmet loaner programme [303]. An increase in observed helmet use was found, but no information was available on the correlation between campaign recognition and observed helmet use. A recent study reported an increase in observed helmet use following a social marketing and educational campaign; however, no control group was included [304]. Other national campaigns did address snow sport safety in general, including helmet use and education on safe conduct [279, 305]. No evaluation studies of these campaigns were found.

A strength of our study is the use of the IM protocol to develop an evidence-based intervention tuned to our target population [20, 32]. Multiple components and strategies were included at an individual level within the ski hall setting, and at a national level using health communication elements. As such, the intervention was not limited to individuals within the population-at-risk, and had characteristics of a public health campaign as well

[306]. As DRSS have been reached who visited an indoor ski hall and those who did not, intervention components at both levels have proven to be of value.

As we evaluated a nationwide intervention, randomisation and inclusion of a proper control group was not feasible. Therefore, we cannot draw conclusions towards the causal effects of the intervention on changes in determinants of helmet use, and in self-reported helmet use. Instead we used a prospective single-cohort study [307], and assessed the association between intervention exposure and individual changes in each outcome measure over the intervention season. It is possible that factors other than exposure to the intervention may have contributed to the observed results. To avoid selection bias, a random sample of panel members was invited to participate in our study, and inclusion was stratified based on a known distribution of DRSS [213]. However, selection bias may have occurred as 'first-responders' were included in the analyses, since inclusion was closed at a predefined target number of respondents. Incomplete questionnaires were excluded from the analyses. Although the number of incomplete questionnaires was very low, this may have caused bias as well.

A potential limitation of our study is that outcome measures were based on self-reports, with the inherent risk of bias due to ill-reported or unreported data. This may especially be true for skill level and helmet use due to a tendency of giving socially desirable responses. It is known from previous research that baseline measurements can trigger study participants' awareness about the topic, and as such bias the effect of the intervention under study [308]. Such a measurement effect must be taken into consideration in our study, especially since the baseline measurement was conducted shortly before the intervention start. Therefore, we included a second independent sample of DRSS to assess intervention reach. Although not significantly different, intervention reach was higher among DRSS that had been exposed to the baseline measurement as compared to DRSS that had not (34.4% versus 28.1%; Chi² test, p=0.066). As a consequence of including this second sample, we had to limit the number of participants in the T1-measurement as compared to the T0-measurement.

Conclusions

To our knowledge, this is the first study quantifying the effect of exposure to a nationwide intervention on self-reported helmet use in winter sports. Differences were found in intervention effect and reach between subgroups of DRSS. These differences must be taken into account when developing and evaluating interventions. Additional research is necessary to determine intervention components that impact (most) on helmet use. Although the current study did not link a behavioural change in helmet use to actual injury reduction in skiing and snowboarding, such a reduction can be expected when helmets are used.

What is already known on this subject

- Head injuries are common in skiing and snowboarding with possible serious consequences, including long-term and serious disabilities and death.
- Helmet use is recommended for all recreational skiers and snowboarders to reduce the incidence and severity of head injury.
- Effective implementation strategies should focus on behavioural change as a key factor for success.

What this study adds

- Self-reported helmet use differs significantly between subgroups of winter sport participants.
- A nationwide intervention using multiple components and strategies, both at an individual and national level (health communication elements), can be successful to increase self-reported helmet use.
- Differences in intervention reach and effect between subgroups of a target population should be considered when developing and evaluating interventions.

Acknowledgements

The intervention ‘Use your head, wear a helmet’ (in Dutch: ‘Gebruik je kop, helm op’) was developed and implemented by the Dutch Consumer Safety Institute VeiligheidNL in cooperation with the Dutch Ski Federation. The authors thank the ski and snowboard halls for their participation in implementing the intervention.

Competing interests

The authors declare no conflicts of interest that are relevant to the content of this study.

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Supplementary file A

Intervention objectives, methods and practical strategies used in the intervention ‘Use your head, wear a helmet’ aimed to change the behaviour of Dutch recreational skiers and snowboarders related to helmet use

Determinant	Theory-based methods [20]	Practical strategies
Intervention objective		
Knowledge		
DRSS have accurate knowledge about risks of (head) injuries in skiing/ snowboarding, possible long-term consequences of head injuries, and helmets as an effective preventive measure	Information transfer	Information included in website and flyers about the injury risk and long-term consequences of head injuries in skiing/snowboarding, and the preventive effect of helmets. Practical tips and information about helmet purchase.
	Chunking	Consequent use of the slogan ‘Use your head, wear a helmet’ to depict the main intervention objective.
	Using imagery	The ‘strongman game’ visualises the possible consequences of a blow to the head while skiing/snowboarding.
Risk perception		
DRSS are aware of their individual risk for sustaining a head injury while skiing/ snowboarding, and the possible long-term (and severe) physical consequences of such an injury	Consciousness raising	As the ‘strongman game’ confronts with consequences of a blow to the head while skiing/ snowboarding, individuals become aware of and acknowledge the risks of sustaining a head injury without helmet use; 3D-animation included in the website visualises the consequences of a blow to the head within the skull.
	Personalise risk	Information included in website and flyers about the individual injury risk of a blow to the head from a fall while skiing/ snowboarding.
	Scenario-based risk information	Personal stories included in website from individuals who did sustain a head injury while skiing/ snowboarding.
	Framing	Gain-framed messages included in website and flyers about helmet use, emphasising the advantages (preventive effect) of helmets.
Attitude		
DRSS have a positive attitude regarding helmet use as a result of perceived advantages over perceived disadvantages, and reduced misconceptions regarding helmet use	Shifting perspective; Information transfer	Facts, practical information and tips about helmet purchase and helmet use included in website.
DRSS, Dutch recreational skiers and snowboarders		

6. Implementation of an app-based neuromuscular training programme to prevent ankle sprains: a process evaluation using the RE-AIM Framework

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Abstract

Background/aim | Contemporary electronic media is regarded as a practical tool in the dissemination of preventive measures and interventions. For this purpose an app (free of charge) was developed including an efficacious programme for the prevention of ankle sprain recurrences. This study evaluated the implementation effectiveness of this 'Versterk je enkel' app.

Methods | The app was evaluated within its practical context using the Reach Effectiveness Adoption Implementation Maintenance (RE-AIM) Framework. The launch of the app was accompanied by a press release, website banners, as well as online and offline advertisements. Data for the evaluation of the app were objectively registered through Google Analytics. Data were obtained in February 2013 based on 25,781 users resulting in follow-ups of 18 months (iOS version) and 15 months (Android version), respectively. Users questionnaires provided a qualitative view of the objectively assessed measures (n=82) to gain insight into the demographics of users, reasons to download, user experience and how the information was used.

Results | The app reached only 2.6% of the projected target population. User ratings for the app's relevancy, clarity, usefulness, appeal, information and reliability were high. App usage indicates that compliance with the embedded programme was low.

Conclusions | Although the app was well received by the users, targeted efforts are required to ensure proper uptake and usage of the app by the target population. This also holds true for eHealth and mHealth efforts aimed at athlete care and injury prevention in general.

Introduction

Ankle sprains continue to pose a significant burden to the individual athlete as well as to society as a whole. Ankle sprains are the most common athletic injury [29, 219, 309], carry high costs from a societal perspective [223, 310, 311], and may result in long-term symptoms [247, 312]. As such, prevention of these injuries continues to be an important goal for sports medicine and injury prevention. Research has shown that externally applied supports and neuromuscular training programmes are very successful in preventing recurrent cases of ankle sprains, from the effectiveness and cost perspectives [223, 224, 311]. Therefore, preventive measures, preferably through continued neuromuscular training, are recommended after rehabilitation in evidence-based treatment guidelines [313].

Despite ankle sprains being prevalent, and despite an active approach to implement epidemiological evidence on (cost)effective measures, a wide-scale uptake of effective preventive measures, and thus actual prevention of ankle sprains under real-life conditions, is lagging behind. The previously mentioned neuromuscular training programme for the secondary prevention of ankle sprains had poor compliance [78]. On the level of the individual athlete, secondary analysis of data from a randomised controlled trial on the effectiveness of this programme indicated that the established preventive effect had been achieved in a subsample of compliant participants resulting in significant population effects [314]. Although analyses considered an intention-to-treat approach, this study showed there is a lot to gain at the individual as well as the population level by increasing the uptake of and compliance with these simple effective preventive exercises. In general, this arguably also holds true for the wide-scale uptake of effective preventive measures under real-life conditions in sports medicine [17, 315].

In an attempt to bridge the implementation gap between research and practice there is an alleged role of eHealth in general and mHealth in particular [316-318]. Generically, eHealth can be defined as the practice of medicine and public health supported by electronic processes and communication. In line with this definition, mHealth is the practice of eHealth using mobile devices and applications. In order to employ this potentially important communication channel to support the dissemination and implementation of preventive measures, the Dutch Consumer Safety Institute (VeiligheidNL) developed a freely available, evidence-based mobile application (app) to prevent recurrent cases of ankle sprains: 'Versterk je enkel' ('Strengthen your ankle') [319,

320]. An evaluation was undertaken to describe the implementation effectiveness of the 'Versterk je enkel' app.

Methods

Intervention

The app contains an 8-week neuromuscular training programme described and evaluated for preventive effectiveness in a previous randomised controlled trial [78, 311, 321]. The training programme offers a set of six exercises for the prevention of ankle sprain recurrences and has been linked to a 50% reduction in the recurrence risk, if used and complied with by the athlete [78]. For the original trial offline printed materials were produced [321]. The app contained a full translation of these materials into an interactive package, including videos of individual exercises and an interactive training schedule providing feedback through push messaging (Figure 6.1). The original programme and materials were developed in cooperation with the Netherlands Association of Sports Medicine and Dutch organisations for physical therapy and sports physical therapy, the EMGO+ Institute for Health and Care Research and participating Dutch sports associations (soccer, volleyball). Volleyball trainers, coaches and athletes were involved in a pilot intervention.

Figure 6.1: Screenshots of the app



The app was launched for iOS in September 2011, and for Android in November 2011. The app is free to download through the iTunes App store [320] and Android Market/Google Play [319, 322]. The launch of both apps was accompanied by a press release, resulting in notable exposure in national online and offline media. In addition, advertisements and banners to guide potential users to the app were placed in the print media and on relevant sports and sports medical websites.

Design

We evaluated the app within its practical context using the Reach Effectiveness Adoption Implementation Maintenance (RE-AIM) Framework [24, 323]. The RE-AIM Framework designed by Glasgow et al. [323] is originally developed to evaluate the public health impact of health promotion interventions. This framework describes five interacting dimensions to evaluate the public health impact of interventions, that is, 'Reach', 'Effectiveness', 'Adoption', 'Implementation' and 'Maintenance'. The operational definitions of these dimensions for our study are given below.

Data for the evaluation of the app were acquired through objective data of 25,781 users registered through Google Analytics [324], Android Market [319, 322] and Appfigures [325]. These data were obtained in February 2013 resulting in follow-up periods between 18 and 15 months. In addition, app users were invited from within the app to complete an online questionnaire. This questionnaire provided additional and subjective insight into the demographics of users, how the users became aware of the existence of the app, reason(s) for downloading the app, frequency of app use, knowledge about the app content, user experience and app evaluation. A total of 90 questionnaires were completed from the launch of the app to May 2012 included, of which 82 contained complete data usable for analyses. Additional information on user experience was gathered through reviews in Android Market [319, 322] and iTunes App Store [325].

Outcome measures

Reach

Reach was defined as the number of app downloads as a proportion of the total number of ankle sprains sustained in sports in the Netherlands over the follow-up period. From app launch to 28 February 2013, the number of downloads of the app have been obtained through the Android Market [319, 322] and iTunes App

Store [320]. The total number of ankle sprains, medically and non-medically treated, was estimated based on registry data of VeiligheidNL [309]. Data were obtained from the national survey 'Injuries and Physical Activity in the Netherlands' [256] including demographic characteristics of the athletes, details of the sports injury (type of injury, anatomical region), medical treatment, cause of injury and injury mechanism. This survey interviews 10,000 respondents (4–80 years of age) through telephone or Internet. Data used in the current study covered 6 years (2006– 2011) of continuous registration.

Effectiveness

Within the RE-AIM Framework effectiveness is defined as the success rate of the product to achieve its intended goal(s). In relation to the app, the overall goal is to reduce the number of recurrent ankle sprains through completion of the preventive exercise programme. The embedded exercises have been previously evaluated for effectiveness in a randomised controlled trial [78]. Therefore, it can be argued that effective usage of the app will reduce ankle sprain recurrence risk. In addition, adoption and implementation of the app and its embedded exercises are described in other RE-AIM dimensions. Therefore, we chose to define effectiveness for the current evaluation as the user experience of the app, while the rationale to translate an effective preventive programme into an app was to increase compliance through enhanced user friendliness and experience.

User reviews and responses were obtained from the users questionnaires, as well as via the iTunes App store (n=84) [325] and Android Market (n=18) [319, 322]. In addition, the app's Appsfire score was noted [326]. The Appsfire score is based on the rating and ranking performance over time, developer's track record and online reviews for an app, and provides an objective score between 0 and 100; a score higher than 75 corresponds to a 'good' rating.

Adoption

Adoption was described in terms of usage of the app after download. Data have been obtained through a combination of data registered through Google Analytics [324] and users questionnaires. App usage data were obtained from the launch of the app onwards, providing objective insight into the actual use of the app after

installing. Registered data included the number of unique users and frequency of use, number of page visits within the app, usage time per app visit, as well as new and recurrent use of the app.

Implementation

Implementation is the extent to which the intervention is implemented as intended in the real world. In relation to the current evaluation this was defined as the percentage of users that followed the embedded exercise programme as intended. Data from Google Analytics and questionnaires were used to describe implementation.

Maintenance

Maintenance is the extent to which the intervention is sustained over time. This is a difficult dimension to describe in relation to the current study, while the app implements an 8-week training programme for the prevention of ankle sprain recurrences. Exercises are no longer required after 8 weeks of training and prolonged use was not the goal of the intervention. In addition, app usage during the 8-week training period was described in the dimension adoption and implementation. Therefore, maintenance was not addressed in this evaluation.

Results

Reach

The annual number of all ankle sprains in the Netherlands due to sport participation is estimated at 650,000 [309]. Over a period of 18 months, this corresponds to an estimated 975,000 ankle sprains that make up the target population. Over the follow-up period the iPhone version was downloaded 20,262 times (of which 19,292 times in the Netherlands) and the Android version 5,519 times by unique users, with an average number of 27 (iPhone) and 10 (Android) downloads per day. These totals correspond to a reach of 2.6%, which is a low percentage in light of the attention given to the app. Peak number of downloads was reached soon after the launch, and stabilised thereafter at a low level for the entire follow-up period.

Questionnaire data provided additional insight into the demographics of the users that downloaded the app.

Of all respondents 72% (n=59 of 82) reported a previous ankle sprain, which was self-treated with 42% (n=34 of

82) of all cases. Reasons for download are depicted in Figure 6.2 and indicate that the app was also downloaded out of interest rather than an actual intent to use the app for its content. As such, reach of the app into the target population is lower than 2.6%.

Figure 6.2: Reasons for app download (% of users, questionnaire data; n=82)

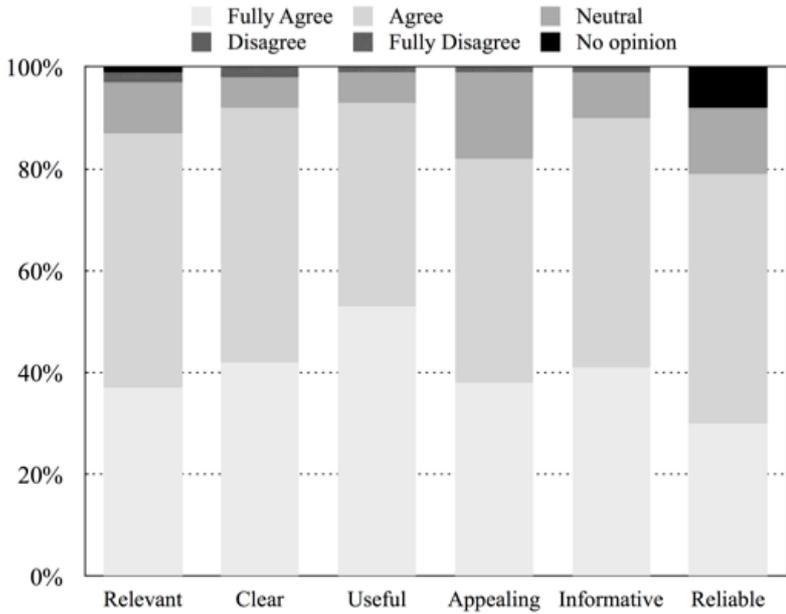


Effectiveness

Questionnaire respondents scored high on given statements regarding the app’s relevancy, clarity, usefulness, appeal, information and reliability (Figure 6.3). Respondents rated the app with a score of 8.1 of 10. This rating corresponds to the ratings from the Android Market (4 of 5) and iTunes App store (4 of 5). The Appsfire score is with a score of 62 of 100, distinctly lower than user reviews.

In written iTunes and Android Market reviews users appreciated the clarity and ease of use of the app. The only written negative review (Android Market) indicated that the size of the app (16 MB) was too big for its content and functionality. A notable share of questionnaire respondents (19%; n=16 of 82) asked about the future availability of similar apps for other injuries and other anatomical locations, which may be regarded as an approval of the current app by the users.

Figure 6.3: User ratings of app characteristics (% of users, questionnaire data; n=82)

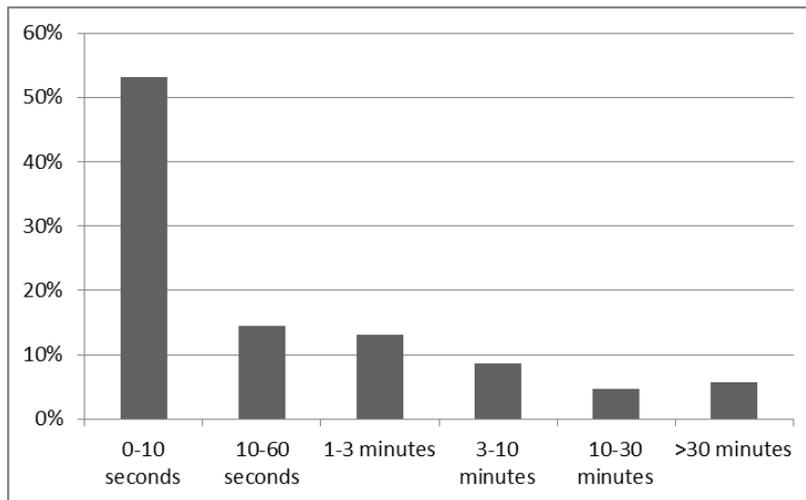


Adoption

Of all questionnaire respondents 38% (n=31 of 82) did not actively use the app, whereas 33% (n=27 of 82) used the app frequently (i.e. multiple times per week). Others report infrequent use of the app, which corresponds to Google Analytics data reporting that over the course of the follow-up period 24,360 unique users have accessed the app 80,670 times in total; 3.3 app sessions per user. Of all users 32.8% were new and 67.2% accessed the app more than once.

The app consists of 65 pages in total. Per session users viewed 9.4 pages within the app. However, most often 2 pages were visited (21.6%), followed by 20 pages or more (13.9%) or 1 page (10.4%). The bounce rate (i.e. the percentage of users that only access 1 page within the app) was 10. This indicates a skewed distribution of users who actually use the app and those that do not. This skewness is also apparent in usage time per visit (Figure 6.4).

Figure 6.4: Usage time per app visit (n=25,781)



Implementation

Google Analytics showed a mean of 3.3 app sessions per unique user over the follow-up period. This number lies far below the 24 prescribed exercise sessions embedded in the 8-week training programme (3 sets of exercises per week). Mean usage time per app visit was 16:25 min. One set of exercises will take 15–20 min on average. Only 32% (n=26 of 82) of all questionnaire respondents indicated to have followed the entire programme and 59% (n=48 of 82) stated to have followed part of the programme. However, it is unknown how long the latter respondents had been using the app at the time of questionnaire completion. It is likely that part of this group was still following the programme at the time of completion. Of all respondents, the majority (65%; n=53 of 82) stated that they intended to use the programme in the future; only 4% (n=3 of 82) had no (further) intent to conduct the exercises, and 26% (n=21 of 82) stated that they might complete (more) exercises.

Discussion

Until now, only a few apps are publicly available containing a claim to prevent sports and physical activity-related injuries. A recent review of this topic found that of 18 iPhone and iPads apps only four incorporate evidence on efficacious preventive measures or treatment protocols [316]. This study evaluated the implementation effectiveness of the 'Versterk je enkel' app aimed at the prevention of recurrent ankle sprains

through the advocacy of an evidence-based neuromuscular training programme. The dissemination of this app seemed encouraging, based on the total number of downloads since its release. However, these totals correspond to a low percentage of potential users, that is, athletes who sustained an ankle sprain over that period. In addition, actual app usage did not indicate that users conducted the number of required exercise sessions for the embedded programme to be effective.

The objectively assessed information on app usage did not reveal what information was actually viewed within the app or how this information was used. As such, questionnaires were included in the app to provide a qualitative view of these objectively assessed measures. Owing to the low users questionnaire response (n=82), probably as a result of the non-prominent location of the questionnaire within the app, responses are most likely not representative of the entire population of app users. Unfortunately, no information is available on demographics of non-responders to make comparisons. It is likely that responders are those with positive experiences and therefore are motivated to complete the questionnaire. This argument arguably also applies to those who took the effort to review the app within the iTunes Store or Android Market. As such, we believe that the actual user experiences and ratings may be lower than described.

Recent reviews and content analyses regarding the use of social networking websites (SNSs) with regard to concussion management in sports have indicated that SNSs have the potential to be a viable adjunct to traditional concussion management programmes [317, 318, 327]. General practitioners' opinion towards their use in concussion management has also been shown to be positive [317]. Overall, these studies indicate that SNSs have a high potential for the sharing and dissemination of knowledge regarding prevention and management of specific injuries in sports. Owing to the widespread use of smartphones within the community [328], similar uses may arguably be viable for apps as well. The current evaluation, however, indicated that many issues need to be addressed to realise this potential for this app and may apply to other health-related apps as well.

In light of the above the title of the current manuscript may be misleading, while no structured implementation plan was employed. The implementation of the app followed an ecological approach. Regular dissemination channels of the Dutch Consumer Safety Institute were followed, resulting not so much in an 'implementation' strategy but more so in a 'marketing' strategy to promote the app within the target population. Unfortunately

we have not been able to track the successes and failures of this approach, and have only been able to establish how effective the strategy was in reaching the target population through the outcomes described in the current paper. The current study has indicated that a 'marketing' type of strategy may not be the optimal method of implementing an evidence-based app. Consequently, future similar efforts are recommended to follow a structured and well-described implementation scheme. We also need to know the target population better before venturing in future implementation of evidence-based prevention apps. What can be read between the lines of the current results is that the target population may not be intrinsically interested in the use of apps for injury prevention. From the results of the current study one could argue that the exposure of the app to the public may not have been optimal, but if the target population was interested in apps for injury prevention they would have come across the app in the iTunes store, Android Market or any search engine.

The reach and adoption of this app may be improved following Rogers' Diffusion of Innovations Theory [329]. This theory is considered to be one of the most successful approaches for understanding the uptake and adoption of interventions [35], and defines relative advantage, compatibility with needs, simplicity and trialability as relevant intrinsic characteristics of innovations that influence an individual's decision to adopt or reject an innovation. These factors may be influenced in a positive manner if the app is consistent with an athlete's training regime, treatment and rehabilitation, and is personally recommended by professionals in sports and medicine so-called influential opinion leaders. In addition to our efforts to promote the app through online and offline media, it might therefore be valuable to have general practitioners, physical therapists, trainers and coaches promote proper usage of the app by the target population. User reviews in our study appear consistent with this need. It is recommended to further study various contexts by which these tools can be effectively employed as a communication channel to support implementation for athlete care.

Conclusions

Despite widespread marketing of the app through a variety of channels, reach and adoption of the app within the target population was found to be low. In general, results of the current study indicate that targeted efforts are required to ensure proper uptake and usage of the app by the target population. We believe the latter holds true for eHealth and mHealth efforts targeted at athlete care and injury prevention in general.

What are the new findings?

- Providing athletes with an mHealth tool, supported with exposure in national online and offline media, is insufficient to disseminate effective interventions to the field.
- Although eHealth and mHealth are considered important tools for the sharing and dissemination of knowledge on prevention and management of specific injuries in sports, targeted efforts are required to ensure proper uptake and usage by the target population.
- Further studies are required on contexts by which eHealth and mHealth tools can effectively be employed as a communication channel to support the dissemination and implementation of preventive measures for athlete care.

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

- eHealth and mHealth, and specifically the use of apps and Social Media, are likely to become integrated parts of clinical practice.
- Targeted implementation efforts are required to ensure proper uptake and usage of eHealth and mHealth tools by the target population.
- Well-designed and planned evaluations must be conducted to describe the effectiveness and implementation success of eHealth and mHealth tools.

Competing interests

None

7. General discussion

Sport injuries present a significant health problem at an individual and public health level [14, 310]. As such, sport injuries counteract the many inherent health benefits related to regular physical activity and sport participation. Prevention of sport injuries is an important prerequisite to maintain and increase a healthy physically active lifestyle and to maximise the pursued (health) benefits from such a lifestyle [22]. Actual prevention of sport injuries in real-world sport settings requires large-scale adoption and correct use of evidence-based preventive measures by the target population [17, 19]. This, in general, requires a change in the preventive behaviour of the target population within the sport injury context. As such, a wide evidence base on effective preventive measures and knowledge on effective strategies to translate and implement available evidence into broad practice are necessary to improve population health. The main aim of this thesis was, therefore, to gain insight in the effectiveness of such strategies using two different approaches: (i) summarising and evaluating available evidence on intervention strategies used in sport injury prevention studies, and (ii) describing effect and process evaluations of three nationwide interventions aimed at increasing the broad uptake of evidence-based preventive measures in real-world sport settings. These studies were included as examples of how different intervention strategies can contribute to effective implementation, that is, rule and regulation changes, health communication, and the use of a mobile application. In this chapter the main findings of this thesis are presented and discussed, together with the strengths and limitations of the methods used. Finally, implications and recommendations for practice and future sport injury prevention research are presented.

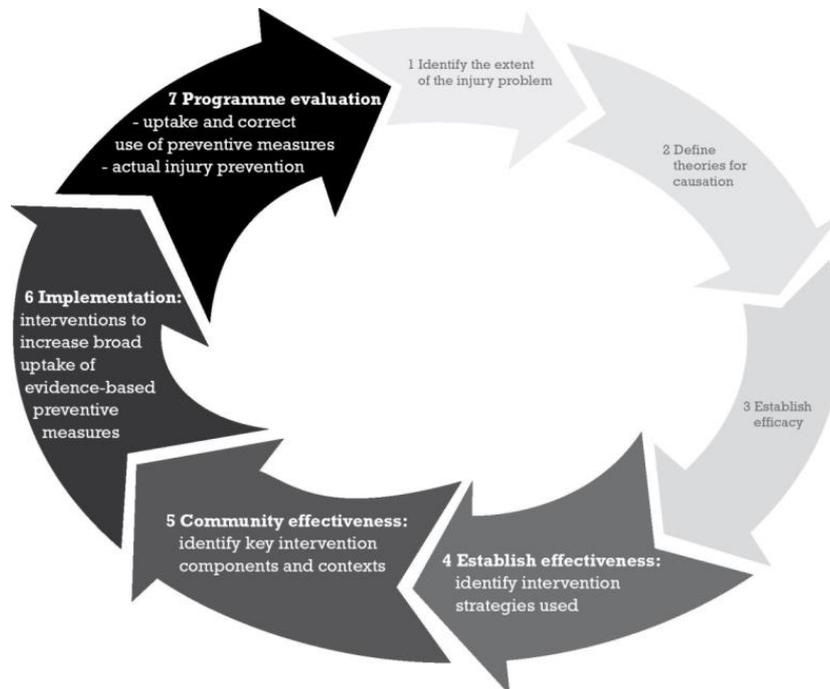
Conceptual models

It is acknowledged that, in order to accomplish sport injury preventive effects at a population level, both a systematic approach and a wide base of knowledge are necessary [17, 20, 35]. A number of conceptual models have been used to meet these conditions and have guided the research presented in this thesis.

First, the translational research cycle model modified for the use in sport injury prevention [21, 22] has been used as the primary framework in this thesis to outline the process of translating evidence into practice (Figure 7.1). The first part of this thesis relates to steps 3-5 of the modified research cycle. Two systematic reviews are

presented, aimed at gaining insight in intervention strategies used in sport injury prevention studies (*Chapter 2*) and identifying essential elements of neuromuscular training (NMT) as an effective intervention to prevent ankle sprains (*Chapter 3*). These reviews aimed at providing guidance in developing effective and useable interventions, and as such strengthen the translation and implementation of the available evidence to broad practice [22]. The second part of this thesis contributes to steps 6 and 7 of the translational research cycle, that is, the implementation and evaluation of preventive interventions in practice. Three interventions, using different intervention strategies, were implemented and evaluated at a national level in the Netherlands as part of (inter)national policies on sport injury prevention. The need for additional research in this field has been previously emphasised [17, 19, 34, 35]. The first two steps - identifying the extent of the sport injury problem, and establishing the aetiology and mechanisms of sport injuries - were not part of the research presented in this thesis.

Figure 7.1: The translational research cycle modified for the use in sport injury prevention [21, 22]; the research objectives addressed within this thesis relate to steps 3 - 7



Furthermore, a modified version of the original Haddon matrix has been used to identify and categorise 20 potentially relevant intervention strategies for the prevention of acute sport injuries (presented in Table 2.3) [36, 37]. Finally, indicators used in process evaluations to assess the public health impact of interventions were derived from the RE-AIM Framework, identifying five interacting dimensions (i.e. reach, effectiveness, adoption, implementation and maintenance of the intervention) [24, 323].

Main findings

Uneven distribution of intervention strategies used in sport injury prevention studies

Using a modified version of the Haddon matrix, the results in *Chapter 2* provide valuable insight into the extent of the evidence base of sport injury prevention studies for 20 potential intervention strategies. This review showed that interventions used in sport injury prevention studies primarily targeted behavioural modifications in individuals, most often through training programmes aimed at building individuals' capacity before the injury event to reduce the injury risk (e.g. improved physical fitness, skills and techniques). In contrast, research related to some specific intervention strategies is underrepresented, that is, only a limited number of studies evaluated the preventive effect of rule and regulation changes, contextual modifications, education, and psychological or cognitive skills training. Additional research is necessary to build on the current evidence regarding the effect of such intervention strategies to broaden the evidence base for implementation efforts. This is especially true for rule and regulation changes and contextual modifications as, in general, these strategies have the potential to reach and affect large populations (i.e. targeting a group or society level, based on an ecological approach to injury prevention) [37], and are found to be more effective in injury prevention compared to intervention strategies that predominantly target behavioural modifications at an individual level [33, 37, 38].

Context-specific intervention strategies

Although a range of intervention strategies should be considered to support and strengthen sport injury prevention efforts in practice [33, 37, 38], it is important to realise that not all strategies are equally appropriate for all sports, injury types and/or sport settings. From *Chapter 2* it can be concluded that differences found in intervention strategies used in sport injury prevention studies can be related to the nature

of the sport, and the aetiology and risk mechanisms of injuries under study. Nonetheless, lessons can be learned from strategies used within different sport injury contexts.

Key intervention components identified

In *Chapter 3* a systematic review and meta-analyses are presented on the prevention of ankle sprains through the application of neuromuscular training (NMT) programmes, aimed to identify essential ‘key’ intervention components. NMT programmes are effective in preventing recurrent ankle sprains [224, 225, 228]. However, available evidence indicates that compliance with these evidence-based programmes is low [78, 239], which can significantly affect study outcomes [249, 314]. Identification of essential elements of evidence-based interventions can facilitate intervention adaptations that may result in increased compliance without impacting results. Based on *Chapter 3*, a key component of NMT in preventing ankle sprains is balance training, irrespective of the use of balance boards. Both single-component (i.e. balance training alone) and multi-component interventions are effective in reducing ankle sprains. Relying on these study outcomes, the type of intervention most fitting to the context should be chosen for implementation efforts. This substantiates the significance of an increased insight in the working mechanisms of effective interventions for implementation efforts.

Intervention strategies: from evidence to practice

Effectiveness of rule modification in sport

Chapter 4 evaluates the preventive effect of rule modification as an intervention strategy. The shinguard law made the use of shinguards compulsory in football (i.e. soccer) matches for all amateur players in the Netherlands from the 1999/2000-season onward. Data covering 25 years of continuous registration (1986-2010) of soccer injuries treated at Emergency Departments of Dutch hospitals were used to evaluate the effect of this rule change. Time trend analyses showed that the incidence of lower leg soccer injuries decreased significantly following the introduction of the shinguard law, whereas the incidence of all other soccer injuries did not. These results strongly suggest the relevance of rule and regulation changes as an intervention strategy to prevent sport injuries. However, as rule and regulation changes generally apply to all players involved within a specific sport or setting, the potential advantages and disadvantages of rule modification aimed at preventing

sport injuries should be well considered. This includes, for instance, whether a rule modification has a potential preventive effect for all players concerned, and whether it affects other aspects of the game that are not the object of the modification [208].

Health communication for changing preventive behaviour

Chapter 5 describes the effectiveness and reach of a nationwide intervention to increase voluntary helmet use in Dutch recreational skiers and snowboarders (DRSS). A prospective single-cohort study was conducted using online questionnaires for data collection before and after the intervention season. Study results showed a significant positive association between exposure to the intervention and self-reported helmet use in DRSS, with differences found between specific subpopulations. However, perhaps due to the lack of internal validity of the questions used, no significant associations were found between intervention exposure and any of the (self-reported) determinants of helmet use (i.e. knowledge, perceived knowledge, risk perception, attitude, social support and intention to helmet use). The intervention consisted of multiple components, implemented locally within the ski hall setting and nationally using health communication elements. Both implementation levels proved to be of value to reach our target population. Within the field of injury prevention, the contemporary use of various intervention elements that impact at multiple levels (i.e. influencing factors at an individual, group, and (inter)national level) is recommended, as it may be more effective than preventive measures affecting one level only [38].

eHealth as a practical tool

The third evaluation study assessed the implementation effectiveness of a Dutch mobile application including an evidence-based NMT programme to prevent recurrent ankle sprains (i.e. the 'Versterk je enkel' app) [319, 320] using the RE-AIM Framework (*Chapter 6*). The public health impact of the app depends on a large-scale implementation, and on compliance with the embedded programme. While the use of eHealth in general and mHealth in particular (through the use of mobile applications) is considered a practical tool for the dissemination of sport injury preventive interventions [316], the number of app downloads was low compared to the annual number of ankle sprains due to sport participation in the Netherlands. Current figures substantiate these findings with a mean reach of 4% within the target population since app release to date (September 2011 up to December 2016; VeiligheidNL, personal communication, 2017) [330].

Although the app was valued for its use by the target population, compliance with the embedded programme was low. The low compliance was in line with previous findings [78, 239]. Increased insight in users' perspectives (e.g. needs, wishes and possibilities) related to the app's characteristics, its daily use, and the embedded programme may be essential to increase compliance. Convenience in use, for instance, has found to be essential for (prolonged) health app use in daily practice [331]. The 'Versterk je enkel' app had been adapted based on information through the process evaluation, and further adjustments may be wanted. Moreover, the study results strongly indicate the need for targeted implementation efforts to ensure large-scale adoption and correct use of a mobile application.

A recent study added valuable information, indicating that both the 'Versterk je enkel' app and traditional, written materials using the same NMT programme showed similar effectiveness in terms of intervention compliance and incidence rates of self-reported ankle sprains [332, 333]. This allows the target population to choose their preferred method, which may increase use of and compliance with the NMT programme [332].

Methodological considerations

Methodological strengths and limitations of the individual studies have been described in the previous chapters. In addition, some limitations that are inherent to the methods used need to be discussed and emphasised when interpreting the overall results. This includes issues related to systematic reviews, study designs used in sport injury prevention studies, and the evaluation of nationwide interventions.

Systematic reviews

The strength of the results of a review depends on a systematic approach to identify all relevant published papers, and on the methodological quality of individual studies included in the review to minimise bias [334]. Both reviews included in this thesis used a systematic approach aiming for inclusion of all relevant studies (*Chapters 2 and 3*). Studies were considered for inclusion if the study design included a control group or a control condition, and if data were registered prospectively. Consequently, both intervention studies and observational studies were included. Inherent to the study design applied, the studies included represent different evidence levels and risks of bias [41].

As the primary aim of the first review (*Chapter 2*) was to identify and categorise sport injury prevention studies by intervention strategy used, risk of bias in individual studies was not assessed (i.e. no assessment of the methodological quality of relevant studies). A comparable approach has been used in previous systematic reviews aimed at providing an overview of published sport injury prevention studies [25, 30]. The second review (*Chapter 3*), evaluating the effectiveness of NMT to prevent ankle sprain in a sporting population, did assess the methodological quality of individual studies. A modified checklist was used to consider all possible sources of bias and to introduce more variability in the quality score. Not all criteria could be assessed for non-randomised controlled trials (non-RCTs) and the maximum quality score was adjusted accordingly. Although the use of this modified checklist allows for the inclusion of different study designs in the meta-analyses, attention should be given to the fact that similar quality scores (presented as a percentage of the maximum attainable score) do not imply similar strength of results for all individual studies. Consequently, both differences in methodological quality score and in study design need to be considered when interpreting individual study outcomes and pooled effect estimates regarding the effectiveness of preventive measures.

In *Chapter 3* a graph is introduced to provide a full visual overview of all relevant studies included in a meta-analysis (Figure 3.2). This graph displays the preventive effect of individual studies related to the methodological quality score and study design used. By providing this overview, preventive effects of NMT were found independent of study quality and study design. It is in general recommended that 'low quality' studies are excluded from meta-analyses to reduce heterogeneity through risk of bias and to increase validity of the results [231]. However, meta-analyses need to balance risk of bias with precision and use an arbitrary cut-off score to distinguish 'low-quality' from 'high-quality' studies [230, 231]. The graph proposed in *Chapter 3* can provide insight into the consequences of applying a specific cut-off score, by showing the number of studies excluded together with their outcomes.

Study designs used in sport injury prevention studies

Relying on the results of the systematic review presented in *Chapter 2* non-RCTs have been used extensively in sport injury prevention studies, especially in studies on the effectiveness of rule and regulation changes and contextual modifications (Figure 2.2). Although an RCT is considered the gold standard for establishing the effectiveness of preventive interventions [40-42], other study designs (e.g. pretest-posttest designs and

interrupted time series) appear to be valid options when inclusion of a control group is not feasible, for instance, in case of rule modifications and policy interventions implemented at an (inter)national level. Systematic reviews are generally used to support decision making in the development of preventive interventions and strategies for sport injury prevention in practice [334]. If only RCTs would be considered for inclusion in such reviews, a wide base of relevant knowledge remains unavailable for practice.

Evaluating nationwide interventions

As we evaluated nationwide interventions in real-world sport settings, implemented as part of (inter)national policies on sport injury prevention (*Chapters 4, 5 and 6*), we were confronted with limitations in available study designs to evaluate the effectiveness of these interventions. Exposure to the intervention was not controlled by the researchers, and randomisation and inclusion of a proper control group was therefore not feasible. Consequently, no conclusions can be drawn regarding the causal effects of these interventions on the outcome measures under study, that is, incidence of lower leg football injuries (*Chapter 4*), determinants of helmet use and actual helmet use (*Chapter 5*), and the implementation of an NMT programme to prevent ankle sprains through app use (*Chapter 6*). Instead, we established associations between intervention exposure and outcome and controlled for possible confounders, using statistical analyses and deductive reasoning to determine whether factors other than the implementation of the intervention could have affected our study outcomes. Information on the five RE-AIM dimensions is considered essential to understand why and how an intervention has worked or had limited effects within a specific target group and sport setting [19, 24]. These dimensions were evaluated based on self-reported data of study participants (*Chapters 5 and 6*). However, to our knowledge, no data are available that have monitored these aspects during and after the implementation period of the shinguard law (*Chapter 4*). The question remains to what extent in this latter study relevant stakeholders (e.g. individual players, coaches and referees) actually complied with this new regulation.

The intervention programmes presented in *Chapters 5 and 6* were evaluated by researchers who contributed to the intervention development as well. This is not unusual in studies evaluating the effect of public health interventions. In a recent publication, de Winter et al. [335] stated that the majority of studies (84%) evaluating health interventions for youth in the Netherlands were performed by researchers involved in the intervention development. They argued that this meant that researchers were acting as their own judge and jury, and that

this could lead to more positive outcomes. This potentially confounding factor was remedied by including independent researchers in the studies presented in *Chapters 5 and 6*. However, it should be noted that, in our experience, involving the developers of interventions in the evaluation process results in a more comprehensive evaluation.

A need for subgroup analyses

Where possible, subgroup analyses should be used to increase insight into the working mechanisms of effective interventions and into subgroups that benefit (most) from implementing such interventions. For instance, essential intervention components and contexts of NMT to prevent ankle sprains have been identified using meta-analyses (*Chapter 3*). Subgroup analyses also proved to be of value to assess the effectiveness of mandatory shinguard use to prevent lower leg soccer injuries (*Chapter 4*), and to identify subpopulations that benefit (most) from a nationwide intervention aimed at increasing helmet use in DRSS (*Chapter 5*). However, we came across some limitations in applying subgroup analyses to evaluate essential components of this latter intervention. As the aim of the evaluation study was to evaluate the effectiveness of the nationwide intervention as a whole in a real-world sport context, exposure to the intervention (i.e. to one or more intervention components) was not controlled by the researchers. As such, our study design was not suited to unravel the effect of individual components on the outcome measures. Additional research is necessary to identify intervention components that contribute most to the targeted behaviour change, and as such develop more efficient interventions.

Implications

Implications for practice

Apply available evidence in practice

The public health impact of evidence-based interventions depends on effective implementation within the sport injury context. Relevant questions that need to be answered when developing, implementing and evaluating interventions are (i) whether the embedded preventive measure is evidence-based, and (ii) whether the intervention strategy is effective to translate and implement available evidence to broad practice, and as such reach the target population and change their preventive behaviour.

Relying on the results of both reviews presented in this thesis, a large evidence base is available on preventive interventions that predominantly target behavioural change on the part of individual athletes (i.e. strategies at an individual level). This evidence, based on scientific research, is available to be applied in daily practice.

Relevant stakeholders (e.g. health professionals, sport federations, policy makers) have the opportunity and responsibility to use the available evidence as an essential starting point when developing and implementing sport injury preventive interventions. However, the available evidence is not absolute. Additional information is necessary to make a thorough decision on what strategy to use for the implementation of sport injury prevention in daily practice, including information about the cost-effectiveness and feasibility of interventions in daily practice [33, 216].

Include target populations

As effective implementation relies on the broad support and behaviour change from the target population and relevant others (e.g. coaches, referees, sport clubs) to adopt and use evidence-based preventive measures [20, 24, 218], it is important for relevant stakeholders to consider the needs, wishes, possibilities and demands of these target populations when developing and implementing a preventive intervention. This requires knowledge on the current preventive behaviour and its determinants, and on potential facilitators and barriers for the uptake of preventive measures within a specific sport injury context [20, 24, 32, 216]. Relevant information should be gathered, preferably through active involvement of the target population and relevant others within the developing process of interventions, and through process evaluations among these groups. This emphasises the need for additional research in the field of intervention evaluation.

A call for higher-level intervention strategies

From a public health perspective, evidence-based preventive measures should be implemented in such a way that large populations can be reached and affected. This argues for the implementation of so-called higher-level intervention strategies, that is, interventions targeting a group or society level. This, in general, includes the application of rule and regulation changes, policies, product and other contextual modifications. Although the evidence base of these strategies is lagging compared to strategies that predominantly target a behaviour change on the part of individual athletes (i.e. strategies at an individual level), the available evidence is promising and provides new opportunities for sport injury prevention. Stakeholders should consider the

feasibility of implementing such strategies more frequently, and should call for supplementary studies to evaluate their effectiveness. However, as not all intervention strategies are equally relevant for all injuries and sport injury contexts, the preferred option must be chosen considering multiple contextual factors within a specific target group and sport setting [17, 19, 35]. Again, this underlines the relevance of active involvement of the target population and relevant others within the developing process of interventions.

Implications for future sport injury prevention research

Based on the results presented in this thesis, some challenges and opportunities for future sport injury prevention research can be identified. These challenges and opportunities relate to the questions raised in the introduction, whether (i) sufficient evidence is available regarding each step of the translational research cycle (Figure 7.1), and whether (ii) the available evidence base on sport injury prevention can effectively be translated to a practical context.

A need for a more comprehensive evidence base on sport injury prevention

Potential gaps in the knowledge base on sport injury prevention have been identified (*Chapter 2*). This especially applies to studies on the effectiveness of higher-level intervention strategies, including rules and regulation and contextual modifications aimed to prevent sport injuries. These knowledge gaps provide new opportunities for sport injury prevention research. Next, with respect to strategies primarily targeting behavioural changes on the part of individual athletes, additional studies are warranted on the preventive effect of education, and psychological and cognitive skill training. In general, a need for additional research should not only be based on existing gaps in the knowledge base on sport injury prevention, but should also originate from needs and knowledge gaps experienced in daily practice. Stakeholders can identify relevant research questions within a specific sport injury context. Combined efforts of science and practice are necessary to identify relevant research questions that provide new opportunities for effective sport injury prevention in daily practice.

Extensive use of available evidence

A wide evidence base on sport injury prevention is available for implementation efforts. The available evidence should be used more extensively to identify components of effective interventions that impact most on sport

injury prevention. Similarly, specific subpopulations and sport settings can be identified that benefit most from a specific intervention. This yields valuable information about the working mechanisms of effective interventions. Through this approach, evidence can be translated into effective and usable interventions that can be implemented in real-world sport settings, which may result in increased adoption and high compliance [22]. This approach has been applied to NMT programmes aimed at preventing recurrent ankle sprains using meta-analyses (*Chapter 3*), and can potentially be applied to many more areas of sport injury prevention.

Alternative study designs

Non-RCTs can be valid options to evaluate the effectiveness of sport injury preventive interventions. This especially applies to the evaluation of interventions implemented at an (inter)national level, and strategies targeted at rule and regulation changes and contextual modifications in sport. Alternative forms of RCTs have been suggested in literature, including stepped wedge designs (in which an intervention is sequentially implemented if randomisation is possible) and Solomon four group designs (to control for the effect of a pretest) [41, 214]. The use of these study designs should be considered in future sport injury prevention research.

Real-world evaluation studies

The effect and process evaluations included in this thesis targeted outcome measures at the level of the target population (i.e. the end user of preventive measures). Additional evaluation studies are necessary, also including the level of relevant stakeholders to gain insight in why and how an intervention was (not) effective in real-world sport settings. Increased insight in reasons for (the lack of) compliance with effective interventions is especially warranted, as illustrated in *Chapter 4* by the study on the implementation effectiveness of an evidence-based app. As the public health impact of interventions relies on effective implementation and sustainability at all relevant target intervention levels (e.g. at an individual, group, or sport association level), it is essential to include all target intervention levels when evaluating interventions [24, 336].

Overall conclusion

Actual prevention of sport injuries in real-world sport settings requires large-scale implementation of evidence-based preventive measures. Actual prevention relies on a sustained change in the preventive behaviour of individuals in order to adopt and properly use such measures. Study results indicate that a range of potentially relevant intervention strategies is available to support and strengthen implementation efforts. However, not all strategies are based on sufficient evidence or are relevant for all sport injury contexts. Results showed that the majority of evidence targeted behavioural modifications in individuals. Additional research is needed to build on the evidence base for specific intervention strategies, including rule and regulation changes, policies, product and other contextual modifications. Although the evidence base of these strategies is lagging compared to other strategies, the available evidence is promising and provides new opportunities for sport injury prevention. This is especially true as these strategies rely less on behavioural modification on the part of the individual athlete and have the potential to reach and affect large populations. Moreover, additional analyses can yield information on essential intervention components and contexts that can be translated into more usable interventions without impacting effectiveness. Joined efforts of science and practice are needed to understand the working mechanisms of effective interventions, support effective implementation through evidence-based interventions that are adopted and complied with, and to stimulate practice-driven research that fits the needs of specific sport injury contexts.

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Summary

Ready? From evidence to practice

Sport injuries present a significant health problem at an individual and public health level, and counteract the many inherent health benefits related to regular physical activity and sport participation. Consequently, the prevention of sport injuries is important to maintain and increase an active lifestyle. Actual prevention of sport injuries in real-world sport settings depends on a large-scale adoption and proper use of evidence-based preventive measures by the target population. Numerous studies and systematic reviews have evaluated the efficacy and effectiveness of preventive interventions on the risk of sport injuries, and as such provided a wide evidence base for implementation efforts. However, available data on sport injuries substantiate a suboptimal use of effective preventive measures in practice, and effective implementation is still considered an important challenge. Next to a wide evidence base on effective injury preventive intervention, knowledge is required on intervention strategies to reach the target population and to affect their preventive behaviour. A range of potentially relevant strategies should be considered, including education, contextual modifications, and rule and regulation changes. As such, the main objective of this thesis was to gain insight into the effectiveness of intervention strategies to translate and implement available evidence on sport injury prevention to a broad practical context, and consequently promote actual sport injury prevention.

The research described in this thesis is presented in two parts. First, systematic reviews are presented evaluating available evidence on what works in sport injury prevention (*Set?*). Second, effect and process evaluations of three interventions were included as Dutch examples of how different intervention strategies can contribute to effective implementation (*Go!*).

Set? Available evidence on what works in sport injury prevention

Intervention strategies to prevent sport injuries

Implementation of preventive measures requires behavioural change on the part of an athlete to adopt and use evidence-based preventive measures as intended. *Chapter 2* describes a systematic review aimed to identify intervention strategies for the prevention of acute sport injuries evaluated in the scientific literature, and to identify potential intervention strategies not yet evaluated (i.e. potential knowledge gaps), using a

modified version of the Haddon matrix. The modified version of the Haddon matrix represented 20 potential intervention strategies for sport injury prevention. These strategies range from those primarily targeted at behavioural modifications on the part of an individual (e.g. specific training programmes or education), through strategies geared at the sport activity (i.e. rule and regulation changes in sport, and use of appropriate equipment) to those predominantly based on contextual modifications. This latter category includes policy changes and interventions aimed at behavioural change on the part of relevant others within the sport injury context (e.g. coaches, allied health staff, sporting federations). Five electronic databases were searched for relevant studies, including a control group/condition, prospective data collection, and a quantitative injury outcome measure.

Our search strategy resulted in the inclusion of 155 studies, mostly randomised controlled trials (RCTs, 43%) and controlled trials (CTs, 15%), next to observational study designs. Results showed that interventions primarily targeted behavioural modifications in individuals, most often through training programmes aimed at building individuals' capacity before the injury event to reduce the injury risk ('pre-event' phase), or targeted the use of equipment to avoid injury in the 'event phase'. Studies in the area of rule and regulation changes, education, psychological and cognitive skills training, and contextual modifications were underrepresented. Studies specifically aimed to prevent re-injuries ('post-event' phase) were a minority. Based on these results, additional research is necessary to build on the current evidence regarding the effectiveness of these intervention strategies. The overview provided in this review can facilitate future sport injury prevention efforts by identifying possible strategies to choose from, given a specific injury problem and a sport injury context. Next, this approach has proven to be useful to reveal potential gaps in the knowledge base regarding the prevention of sport injuries, thereby providing new opportunities for sport injury prevention research.

Key intervention components and relevant contexts

Aim of the systematic review described in *Chapter 3* was to summarise available evidence on the effectiveness of neuromuscular training (NMT) to prevent ankle sprains, resulting in an overview of effective components and contexts of NMT programmes. This study was included as an example of how available evidence can be used to extract additional information on essential 'key' intervention components that impact (most) on injury

prevention, and on contexts in which interventions have shown to be effective, which in turn may be helpful to develop effective and adoptable interventions.

An electronic literature search of PubMed, SPORTDiscus and EMBASE was conducted to identify published RCTs, CTs, and pretest-posttest designs on the preventive effect of NMT for ankle sprains in sport.

Methodological quality of relevant studies was assessed, and only high-quality studies were included in the meta-analyses. A total of 30 studies were included in the analyses (24 RCTs, 3 CTs, 3 pretest-posttest designs). Studies showed a great diversity in preventive effects and methodological quality (quality score ranged between 47% and 100%). However, the diversity in preventive effect was independent of study quality and study design. A total of 14 studies focussed solely on the effectiveness of balance training, and 16 studies evaluated the effect of balance training combined with adjunct interventions. Pooled data showed a significant reduction in the occurrence of ankle sprains (relative risk (RR)=0.60; 95% CI 0.51 to 0.71). Single-component interventions specifically targeted at ankle sprains achieved preventive effects (RR=0.58; 95% CI 0.48 to 0.72), as opposed to multi-component interventions (RR=0.67; 95% CI 0.37 to 1.24). With respect to interventions targeted at lower extremity or general injuries, significant effects were found on the prevention of ankle sprains using both single-component (RR=0.71; 95% CI 0.52 to 0.97) and multi-component interventions (RR 0.55; 95% CI 0.41 to 0.74). The evidence for a preventive effect on first-time ankle sprains remains inconclusive, as opposed to the effect of NMT on recurrent ankle sprains and in a general sporting population.

Based on this study it can be concluded that a key element of NMT to prevent ankle sprains is balance training, irrespective of the use of balance boards or other balance devices, and that both single-component and multi-component NMT interventions are effective in reducing ankle sprains. Therefore, the type of intervention most fitting to the context should be chosen for implementation efforts.

Go! The Dutch experience

Studies evaluating the effectiveness of different intervention strategies

As a next step, evidence on what works needs to be translated to and implemented in everyday life. The second part of this thesis describes effect and process evaluations of three nationwide interventions that were implemented in the Netherlands, as part of (inter)national policies on sport injury prevention. The

interventions aimed to increase the broad uptake of evidence-based preventive measures in real-world sport settings, using different intervention strategies.

Effectiveness of rule modification in sport

The study in *Chapter 4* exemplifies rule modification in sport as intervention strategy. Fédération Internationale de Football Association (FIFA) introduced the shinguard law in 1990, which made wearing shinguards mandatory during matches. The effect of introducing this law in the Netherlands in the 1999/2000-soccer season was evaluated using time trend analysis on injury data, covering 25 years of continuous registration (1986–2010) of all emergency department treatments in a random, representative sample of Dutch hospitals. All injuries sustained in football by patients aged 6–65 years were included, differentiating lower leg injuries expected to be preventable by shinguards from other injuries.

Results showed that the incidence of lower leg soccer injuries decreased significantly following the introduction of the shinguard law (1996–2000: –20%; 2001–2005: –25%), whereas the incidence of all other soccer injuries did not. This effect was more prominent during weekends (i.e. predominantly on match days). No gender differences were observed. Based on the study design used, no conclusions can be drawn regarding the causal effects of the rule modification and the incidence of lower leg injuries. However, the available evidence indicated a preventive effect of the shinguard law with respect to lower leg injuries, underlining the relevance of rule modification as an effective preventive measure at a group or societal level.

Effectiveness of an intervention programme based on health communication

Chapter 5 describes a study evaluating the effectiveness and reach of a nationwide intervention to increase voluntary helmet use in adult Dutch recreational skiers and snowboarders (DRSS). Main motive for developing this intervention programme was low and inconsistent helmet use in this population. The in-season intervention ‘Use your head, wear a helmet’ was first implemented nationwide in the 2010/2011-winter sport season. Multiple intervention components were included, implemented at an individual level within the setting of Dutch indoor ski halls (i.e. ‘strongman game’ machine, informative flyers), and at a national level using health communication elements (i.e. informative website, press release, website banners and advertisements). A prospective single-cohort study was used to evaluate the impact of intervention exposure on determinants of

helmet use (i.e. risk perception, knowledge, attitudes) and self-reported helmet use using online questionnaires. A random sample of 363 DRSS from an existing Dutch panel participated in this study. A second independent sample of 363 DRSS was used to assess intervention reach. Multiple regression analyses were used to evaluate the effect of intervention exposure on individual changes in outcome measures over the intervention season.

Intervention exposure had a significant, positive effect on self-reported helmet use in DRSS ($\beta=0.23$; 95% CI 0.017 to 0.44). Subgroup analyses revealed that this effect was found only in female DRSS, young skiers, and intermediate skiers. No significant, positive associations were found between intervention exposure and any of the determinants of helmet use. However, subgroup analyses revealed intervention effects on risk perception and knowledge in specific subpopulations. Overall intervention reach was 28.1%, with differences found between skiers and snowboarders. This study showed that a nationwide intervention programme could be successful to influence preventive behaviour. Differences in intervention reach and effectiveness between subgroups of a target population should be considered when developing and evaluating interventions.

Use of eHealth: an app-based neuromuscular training programme to prevent ankle sprains

Both eHealth and mHealth are regarded as practical tools in the dissemination of preventive measures and interventions. For this purpose the Dutch 'Versterk je enkel' app ('Strengthen your ankle' app; free of charge) was developed, including an efficacious NMT programme for the prevention of ankle sprain recurrences. This study evaluated the implementation effectiveness of this app in the Netherlands within its practical context, using the Reach Effectiveness Adoption Implementation Maintenance (RE-AIM) Framework.

Data for the evaluation of the app were objectively registered through Google Analytics and analysed after follow-ups of 18 months (iOS version) and 15 months (Android version), respectively. Users questionnaires provided a qualitative view of the objectively assessed measures (n=82) to gain insight into the demographics of users, users' reasons to download the app, app-user experience, and use of the embedded preventive programme.

App reach was low, with 2.6% of the projected target population. User ratings for the app's relevancy, clarity, usefulness, appeal, information and reliability were high. However, app usage indicated that compliance with

the embedded programme was low. Although the app was well received by the users, targeted efforts will be required to ensure proper uptake and usage of the app by the target population. This may in general hold true for eHealth and mHealth efforts aimed at athlete care and injury prevention.

Conclusions

Main objective of this thesis was to gain insight into the effectiveness of intervention strategies to translate and implement available evidence on sport injury prevention to a broad practical context. Results presented in this thesis indicate that a range of potentially relevant intervention strategies is available to support and strengthen implementation efforts. However, not all strategies are based on sufficient evidence or are relevant for all sport injury contexts. Results showed that the majority of evidence targeted behavioural modifications in individuals. Additional research is needed to build on the evidence base for specific intervention strategies, including rule and regulation changes, policies, product and other contextual modifications. Although the evidence base of these strategies is lagging compared to other strategies, the available evidence is promising and provides new opportunities for sport injury prevention. This is especially true as these strategies rely less on behavioural modification on the part of the individual athlete and have the potential to reach and affect large populations. Moreover, additional (subgroup) analyses can yield information on essential intervention components and contexts, which can be translated into more usable interventions without impacting effectiveness. Joined efforts of science and practice are needed to understand the working mechanisms of effective interventions, support effective implementation through evidence-based interventions that are adopted and complied with, and to stimulate practice-driven research that fits the needs of specific sport injury contexts.

Samenvatting

Ready? Blessurepreventieve kennis vertalen naar de praktijk

Regelmatig sporten en bewegen heeft positieve gevolgen voor de gezondheid, zowel voor het individu als voor de volksgezondheid in het algemeen. Mede daarom wordt een actieve leefstijl gestimuleerd. Een nadeel van sport en bewegen is echter de kans om geblesseerd te raken. Preventie van sportblessures is belangrijk om de positieve gezondheidseffecten van sport en bewegen te behouden en te vergroten.

Er is veel wetenschappelijke kennis over de effectiviteit van blessurepreventieve maatregelen in de sport, waaronder het gebruik van persoonlijke beschermingsmiddelen en specifieke trainingsvormen. Het blijkt echter lastig om deze kennis te vertalen naar de dagelijkse praktijk. Cijfers over sportblessures in Nederland laten over de afgelopen jaren een stijging zien in de kans op een sportblessure. Dit kan wijzen op een niet optimaal gebruik van blessurepreventieve maatregelen. Om dit te verbeteren is niet alleen kennis nodig over de effectiviteit van blessurepreventieve maatregelen, maar ook over strategieën om deze kennis op grote schaal 'aan de man/vrouw' te brengen. Implementatie van blessurepreventieve maatregelen vereist een (blijvende) gedragsverandering van sporters: zij moeten bekend zijn met effectieve blessurepreventieve maatregelen én deze op een juiste manier (gaan) gebruiken. Hiervoor moet de inzet van alle mogelijke, relevante interventiestrategieën worden overwogen. Dit betreft onder andere training, voorlichting, spelregelwijzigingen en aanpassingen van sportomgeving en sportaccommodaties.

Het belangrijkste doel van dit onderzoek is inzicht krijgen in de effectiviteit van strategieën om wetenschappelijke kennis over blessurepreventie naar de praktijk te vertalen en te implementeren. De kern van het proefschrift bestaat uit twee delen. In het eerste deel ('Set?') wordt bestaande kennis over wat werkt in sportblessurepreventie geanalyseerd om inzicht te krijgen in relevante interventiestrategieën en essentiële elementen van effectieve interventies. Hiertoe zijn twee systematische reviews uitgevoerd. Deel 2 ('Go!') beschrijft effect- en procesevaluaties van drie interventies in Nederland, gericht op het bevorderen van het gebruik van effectieve blessurepreventieve maatregelen via verschillende interventiestrategieën.

Set? Wat werkt in sportblessurepreventie

Interventiestrategieën voor sportblessurepreventie

Een systematische review werd uitgevoerd om inzicht te krijgen in interventiestrategieën die in de wetenschappelijke literatuur zijn gebruikt om sportblessures te voorkomen, en om mogelijke gaten in de kennis zichtbaar te maken (*Hoofdstuk 2*). Een aangepaste versie van de Haddon matrix is gebruikt om de literatuur in te delen in 20 mogelijk relevante strategieën voor sportblessurepreventie. Deze strategieën grijpen in voor ('pre-event'), tijdens ('event') of na het blessuremoment ('post-event'), en richten zich op het direct beïnvloeden van het gedrag van het individu, de sportactiviteit (door in te grijpen op regelgeving of sportmateriaal) of de fysieke of sociaal-culturele omgeving waarin wordt gesport. Relevante wetenschappelijke literatuur werd gezocht in vijf elektronische bestanden. De 155 studies die werden meegenomen in de review voldeden aan de volgende eisen: het onderzoek maakte gebruik van een controlegroep of -conditie, prospectieve dataverzameling en een kwantitatieve blessure-uitkomstmaat. De meeste studies evalueerden het blessurepreventieve effect van interventies die direct gericht waren op gedragsverandering van het individu. Dit gebeurde vooral in de 'pre-event' fase via trainingsprogramma's om de belastbaarheid van het individu te vergroten. Ook waren veel studies gericht op het gebruik van sportmateriaal in de 'event' fase (brace, tape, beschermingsmaterialen). Het gebruik van de Haddon matrix maakte ook duidelijk dat specifieke strategieën nog niet of onvoldoende zijn geëvalueerd in de wetenschappelijke literatuur, namelijk interventies die aangrijpen op regelgeving, voorlichting, training van psychologische en cognitieve vaardigheden en het aanpassen van de sportomgeving. Slechts enkele studies waren gericht op het voorkomen van herhaalde blessures (recidieven) in de 'post-event' fase. Aanvullend onderzoek naar de effectiviteit van deze interventiestrategieën is gewenst.

De systematische review heeft geresulteerd in een overzicht van relevante interventiestrategieën die gebruikt kunnen worden bij het ontwikkelen en inzetten van blessurepreventieve interventies in de praktijk. Hierbij moet wel rekening worden gehouden met het specifieke blessureprobleem en de omstandigheden.

Essentiële elementen van effectieve interventies

Beschikbare wetenschappelijk kennis over blessurepreventie zou meer ingezet moeten worden om essentiële elementen van effectieve interventies te identificeren. Inzicht is gewenst in onderdelen die (voornamelijk) bijdragen aan het preventieve effect van een interventie, en welke specifieke doelgroep vooral profiteert van de interventie. *Hoofdstuk 3* beschrijft als voorbeeld een systematische review naar de effectiviteit van een neuromusculair trainingsprogramma (NMT) ter preventie van enkeldistorsies. In drie elektronische bestanden is gezocht naar relevante wetenschappelijke studies die gebruik maakten van (gerandomiseerd) onderzoek met een controlegroep, of van observationeel onderzoek met een voor- en nameting ('pretest-posttest design'). In totaal werden 30 studies meegenomen in het onderzoek. Van al deze studies werd de methodologische kwaliteit (bias) gescoord. De variatie bleek groot in zowel de kwaliteit van de studies (de kwaliteitsscore varieerde van 47% tot 100%) als in de gevonden preventieve effecten. Beide factoren bleken onafhankelijk van elkaar te zijn. Alleen studies van hoge kwaliteit zijn meegenomen in de meta-analyses.

De analyses lieten zien dat NMT effectief is ter preventie van enkeldistorsies (relatief risico (RR)=0,60; 95% betrouwbaarheidsinterval (BI) 0,51-0,71). NMT bestond bij circa de helft van de studies alleen uit een vorm van balanstraining. In de overige studies was dit aangevuld met andere trainingvormen en/of voorlichting (multi-component programma's). Subgroepanalyses toonden aan dat balanstraining op zich effectief is om enkeldistorsies te voorkomen, met of zonder het gebruik van een balansbord/oefentol. Dit werd gevonden bij interventies die specifiek gericht waren op de preventie van enkeldistorsies (RR=0,58; 95% BI 0,48-0,72) en bij interventies gericht op de preventie van onderbeenblessures/alle blessures (RR=0,71; 95% BI 0,52-0,97). Bij multi-component programma's kon de effectiviteit alleen aangetoond worden bij interventies gericht op de preventie van onderbeenblessures/alle blessures (RR=0,55; 95% BI 0,41-0,74). Ook bleek NMT alleen effectief ter preventie van recidieve enkeldistorsies. Er is onvoldoende bewijs voor het preventieve effect van NMT bij nieuwe enkeldistorsies en binnen een algemene sportpopulatie. Balanstraining lijkt een essentieel element te zijn van NMT ter preventie van enkelblessures. Voor de praktijk betekent dit dat balanstraining in ieder geval onderdeel moet zijn van een programma ter preventie van enkeldistorsies, indien gewenst aangevuld met balansbord-oefeningen of overige elementen.

Dit onderzoek toont aan dat beschikbare kennis gebruikt kan worden om te komen tot efficiëntere interventies zonder verlies aan effectiviteit, met mogelijk meer draagvlak (therapietrouw) onder de doelgroep en andere belanghebbenden.

Go! Blessurepreventieve interventies in Nederland

Evaluatie van diverse interventiestrategieën

Om blessures te voorkomen moet kennis over wat werkt in sportblessurepreventie toegepast worden in de praktijk. Het tweede deel van dit proefschrift beschrijft daarom effect- en procesevaluaties van drie blessurepreventieve interventies. Deze interventies zijn in Nederland geïmplementeerd als onderdeel van (inter)nationaal beleid ter preventie van sportblessures om het gebruik van blessurepreventieve maatregelen te bevorderen. Elke interventie maakte hierbij gebruik van een andere strategie: spelregelwijziging, voorlichting en de inzet van eHealth (een app).

Effectiviteit van spelregelwijziging

Hoofdstuk 4 beschrijft een onderzoek naar het blessurepreventieve effect van een spelregelwijziging bij voetbal. In 1990 introduceerde de internationale voetbalbond FIFA een nieuwe spelregel die het gebruik van scheenbeschermers in wedstrijden verplicht stelde om onderbeenblessures te voorkomen. In Nederland is deze wijziging voor alle amateurspelers ingevoerd in het seizoen 1999/2000. Tijdtrendanalyses (over de periode 1986-2010) zijn gebruikt voor de analyse van gegevens over voetbalblessures behandeld op spoedeisende hulpafdelingen van Nederlandse ziekenhuizen. Alle blessures van voetballers van 6-65 jaar zijn meegenomen in de analyses, waarbij onderbeenblessures die door scheenbeschermers voorkomen kunnen worden, zijn onderscheiden van overige blessures. Uit de resultaten bleek dat het aantal onderbeenblessures bij voetbal significant afnam in de periode na introductie van de nieuwe spelregel (1996-2000: -20%; 2001-2005: -25%) in tegenstelling tot het aantal overige voetbalblessures. Dit effect was duidelijker zichtbaar in de weekenden (op wedstriiddagen) bij zowel mannen als vrouwen. Het beschikbare bewijs duidt op een relatie tussen de spelregelwijziging en een afname in het aantal onderbeenblessures, al kan op basis van het onderzoeksdesign geen directe oorzaak-gevolg relatie aangetoond worden. Het onderzoek laat zien dat een spelregelwijziging op (inter)nationaal ingezet kan worden om sportblessures te voorkomen.

Effectiviteit van voorlichting

Hoofdstuk 5 beschrijft een onderzoek naar de effectiviteit en het bereik van een landelijke interventie om vrijwillig helmgebruik bij Nederlandse recreatieve skiërs en snowboarders (NRSS) te bevorderen. De belangrijkste reden om deze interventie te ontwikkelen was het lage en inconsequente gebruik van helmen door deze doelgroep. De interventie 'Gebruik je kop, helm op' ging van start tijdens het wintersportseizoen van 2010/2011 en bestond uit meerdere elementen. In indoor skihallen werden NRSS bereikt via een 'Kop van Jut' en informatiefolders en op nationaal niveau door gezondheidsvoorlichting (via een informatieve website, persbericht, banners op websites en advertenties). Een prospectief onderzoek met herhaalde metingen binnen één groep, direct voor en na het wintersportseizoen van 2010/2011, evalueerde het effect van blootstelling aan de interventie op (determinanten van) zelf-gerapporteerd helmgebruik. Er werd gebruik gemaakt van een random steekproef van 363 NRSS uit een bestaand Nederlands onderzoekspanel. Gegevens werden verzameld met behulp van online vragenlijsten. Een tweede onafhankelijke steekproef van 363 NRSS werd gebruikt om het bereik van de interventie vast te stellen direct na afloop van het wintersportseizoen. Multipele regressieanalyses zijn gebruikt om de associatie vast te stellen tussen blootstelling aan de interventie en individuele veranderingen in de uitkomstmaten (risicoperceptie, kennis, attitude, helmgebruik) gedurende het seizoen.

Blootstelling aan de interventie had een significant en positief effect op helmgebruik onder NRSS ($\beta=0,23$; 95% BI=0,017-0,44). Subgroepanalyses lieten zien dat dit effect alleen aanwezig was bij vrouwelijke NRSS, jonge skiërs, en bij skiërs van middelmatig niveau. Er werd geen significant effect gevonden tussen blootstelling aan de interventie en de determinanten van helmgebruik. Wel toonden subgroepanalyses interventie-effecten aan in specifieke subpopulaties op respectievelijk risicoperceptie en kennis. In totaal werd 28,1% van de NRSS met de interventie bereikt. Het bereik verschilde tussen skiërs, snowboarders en NRSS die actief waren in beide sporten. Het onderzoek heeft aangetoond dat een landelijke interventie succesvol kan zijn in het beïnvloeden van preventief gedrag. Bij de ontwikkeling en evaluatie van interventies moet rekening worden gehouden met verschillen tussen relevante subgroepen in bereik en effectiviteit.

Gebruik van eHealth

Zowel eHealth als mHealth worden gezien als relevante technologieën om de implementatie van preventieve maatregelen te verbeteren. Met dit doel is de gratis app 'Versterk je enkel' ontwikkeld. De app bevat een effectief bewezen NMT programma ter preventie van recidieve enkeldistorsies. Een procesevaluatie is uitgevoerd om inzicht te krijgen hoe de app en het daarin opgenomen programma in de praktijk werden gebruikt. Google Analytics werd ingezet voor objectieve data over het gebruik van de app gedurende een periode van respectievelijk 18 maanden (de iOS versie) en 15 maanden (Android versie) vanaf lancering van de app. Ook zijn vragenlijsten uitgezet onder app-gebruikers om inzicht te krijgen in hun kenmerken, redenen om de app te downloaden, waardering van de app en de mate waarin het ingebedde NMT programma werd gebruikt (n=82). Het bereik van de app binnen de potentiële doelgroep van sporters met enkeldistorsie in Nederland, bleek laag (2,6%). De app werd hoog gewaardeerd: gebruikers vonden de app relevant, duidelijk, nuttig, aansprekend, informatief en betrouwbaar. Het ingebedde programma werd vaak niet gebruikt zoals deze was bedoeld (lage therapietrouw). De app is een praktische manier om effectieve interventies te verspreiden. Het onderzoek laat echter zien dat gerichte acties nodig zijn voor de implementatie van een app om de doelgroep te bereiken en hun gedrag te veranderen.

Conclusies

Doel van het onderzoek was inzicht krijgen in de effectiviteit van interventiestrategieën voor het vertalen en implementeren van wetenschappelijke kennis over blessurepreventie naar de praktijk, en op die manier ervoor zorgen dat meer sportblessures voorkomen worden. Een groot aantal interventiestrategieën is beschikbaar en mogelijk relevant voor de praktijk. Uit het onderzoek wordt duidelijk dat de meeste blessurepreventieve interventies in wetenschappelijke studies vooral gericht zijn op de sporter zelf en het direct veranderen van zijn/haar blessurepreventieve gedrag. Niet alle interventiestrategieën zijn voldoende empirisch onderbouwd of geschikt voor alle sporten en sporters. Er blijkt vooral meer onderzoek nodig te zijn naar de inzet en de effectiviteit van strategieën die ingrijpen op spelregelwijzigingen, beleid en aanpassingen van sportproducten en/of sportomgeving om blessures te voorkomen. De inzet van deze strategieën is veelbelovend om blessures te voorkomen, vooral omdat de focus hierbij minder ligt op het direct beïnvloeden van het individuele gedrag en omdat een potentieel grote groep bereikt kan worden. Daarnaast toont het onderzoek aan dat aanvullende analyses van onderzoeksgegevens inzicht kunnen geven in essentiële componenten van effectieve interventies

en in subpopulaties die hiervan het meest kunnen profiteren. Beschikbare wetenschappelijke kennis over blessurepreventie kan daarmee bijdragen aan de ontwikkeling van efficiëntere interventies zonder verlies aan effectiviteit, met mogelijk meer draagvlak (therapietrouw) onder de primaire doelgroep en overige belanghebbenden. Er ligt een gezamenlijke uitdaging voor wetenschap en praktijk om meer inzicht te krijgen in effectieve (elementen van) interventies en te sturen op het inzetten van veelbelovende interventiestrategieën. Dit alles moet ingezet worden vanuit een praktijkgerichte vraag, binnen een relevante sportcontext en begeleid met wetenschappelijk onderzoek.

Ready, set, go ... Thanks!

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About the author

Ingrid Vriend was born in Woerden, lived in Uffelte and Drachten on her way to Amsterdam to study Human Movement Sciences at the VU University. Health sciences, health promotion, sport and epidemiology were the central topics in her study and research internships. Together with a study on wheelchair efficiency and a great experience being part of the klapskate research team in Inzell, the interest for practice-based research was there to stay. She acquired her master degree in 1997, after which she spent a year working as an assistant teacher at VU University. In 1998, she was happy to start working at the Consumer Safety Institute (VeiligheidNL), being actively involved in the development and evaluation of interventions on sport injury prevention and work-related safety behaviour, and in nationwide policies on sport injury prevention. She completed her master's degree in Epidemiology in 2007. In 2015 she was offered the opportunity to combine her work at VeiligheidNL with a PhD position at the Department of Public & Occupational Health and the Amsterdam Public Health research institute of VU University Medical Center. This turned out to be an optimal combination of science and practice, and a great research experience. In the mean time she enjoys being a mum, sports, and travelling to many great places.

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Award

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[Thesis, back cover]

Preventive interventions targeting the problem of sport injuries are needed. Especially as sport injuries have the potential to decrease an active lifestyle and sport participation, which are related to enjoyment, social interaction, maintenance and improvement of health. The problem of sport injuries can be reduced if evidence-based preventive measures (such as helmets and preventive training programmes) are successfully used in daily practice. However, effective implementation is considered an important challenge. Knowledge is required on strategies to reach the target population and affect their preventive behaviour. This thesis describes a range of potentially relevant intervention strategies that should be considered to translate and implement available scientific evidence on sport injury prevention to broad practice. Dutch examples are included on how different strategies can contribute to sport injury prevention.