

# Effectiveness of multicomponent lower extremity injury prevention programmes in team-sport athletes: an umbrella review

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## ABSTRACT

**Objective** To identify which exercise combinations are most effective as part of a lower extremity injury prevention programme for team-sport athletes.

**Design** Umbrella review.

**Data sources** A comprehensive literature search was performed in PubMed, Scopus, Cochrane Library and PEDro databases. Studies published between January 2000 and March 2017 were included in this umbrella review.

**Study eligibility criteria** Moderate to high-quality systematic reviews that investigated the effectiveness of a combination of two or more exercise components, that is, strength, agility, plyometrics, balance, stretching, technique, warm-up and functional activity, regarding injury incidence/rate of lower extremity injuries in team-sport athletes. The methodological quality of the included systematic reviews was independently assessed by two reviewers using the Assessing the Methodological Quality of Systematic Reviews measurement tool and the Grading of Recommendations Assessment, Development and Evaluation guidelines were used to assess the overall quality of evidence for particular outcomes.

**Results** Twenty-four systematic reviews met the inclusion criteria. Multicomponent exercise interventions were effective in reducing the injury incidence/rate of lower extremity, knee, ACL and ankle injuries, but not groin injuries. Strength and balance exercise components were included in 10 of 11 effective injury prevention programmes for the lower extremity, knee, ACL and ankle injuries.

**Summary/conclusion** Lower extremity injury prevention programmes in team sports are effective in preventing lower extremity, knee, ACL and ankle injuries. Lower extremity muscle strength and balance exercises should be prioritised in lower extremity injury prevention programmes for team-sport athletes.

ankle (15% of all reported sports injuries), followed by the knee (3% of all reported sports injuries),<sup>3,4</sup> whereas overuse injuries mostly affect the groin area<sup>5</sup> and represent 5%–10% of all sports-related injuries.<sup>6</sup>

Injury risk factors may have intrinsic (eg, age, sex, general health, physical fitness) and extrinsic (eg, sports venue, equipment and environmental) origins.<sup>7,8</sup> The risk for injuries associated with these intrinsic and extrinsic risk factors can be reduced if athletes complete specific exercise programmes.<sup>9–16</sup> Previous systematic reviews have focused on evaluating the effectiveness of single exercise components (eg, balance) or combinations of two or more exercise components (eg, strength, agility, plyometrics and stretching); however, injury prevention programmes including balance training as a single-component exercise did not reduce the incidence of knee ligament injuries.<sup>10,14</sup> Similarly, stretching did not reduce the incidence of lower extremity sports injuries.<sup>17</sup>

Injury prevention should be a primary goal for team-sport athletes of all ages and participation levels (eg, recreational, semiprofessional, professional) since an injury results in performance disability, loss of playing time, high financial burden for the athlete's employer as well as the healthcare system and an increased risk of reinjury and chronicity.<sup>6</sup> However, it remains unclear which combinations of exercise components are most effective in preventing lower extremity injuries. To identify the most effective exercise combinations, high-level synthesis of the available data, in the form of an umbrella review, is necessary.<sup>18</sup>

The objective of our umbrella review was to identify the most effective combinations of exercise elements for training programmes to prevent lower extremity injuries in team-sport athletes.

## METHODS

This umbrella review was performed according to guidelines established by the working group of Aromataris *et al.*<sup>19</sup> The study is registered in the International Prospective Register of Systematic Reviews (PROSPERO ID CRD42016041667).

## Inclusion criteria

We applied the Assessing the Methodological Quality of Systematic Reviews (AMSTAR) rating system to rate and classify all reviews into low quality (scores of 0 to ≤3 points), moderate quality (3 to ≤7) and high quality (7 to ≤11).<sup>20</sup> Only moderate and

## INTRODUCTION

An average of 8.6 million sports-related injuries were documented per year between 2011 and 2014 in the USA, which equates to an incidence rate of 34 injuries per 1000 persons.<sup>1</sup> The majority of these injuries were lower extremity strains and sprains sustained during basketball, American football and soccer (42%).<sup>1</sup> A similar rate of 26 injuries per 1000 persons was calculated for the European Union, with a peak occurring in the 15–19 years age group.<sup>2</sup> The most common traumatic injuries in team ball sports, such as basketball, volleyball, soccer and field hockey, are ligament injuries of the



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high-quality reviews were included. Reviews were included if published in either English or German between 1 January 2000 and 31 March 2017. The following inclusion criteria were considered according to the Participant-Intervention-Comparison-Outcome process for evidence-based practice.<sup>21</sup>

### Participants

Male and/or female athletes of all ages who participated in team sports at any level (ie, recreational, semiprofessional, professional).

### Interventions

All types of multicomponent exercise interventions to prevent lower extremity injuries. Interventions using protective devices (ie, braces, tapes) or exercise programmes including only one exercise component were excluded (eg, injury prevention programmes using eccentric strength exercises only to prevent hamstring injuries).

### Comparison group

Usual training (no additional training).

### Outcome measures

Injury incidence or injury rate.

### Search strategy

A systematic literature search was performed by one reviewer (RB) in the following electronic databases: PubMed, Scopus, Cochrane Library (Cochrane Database of Systematic Reviews) and Physiotherapy Evidence Database (PEDro). The following search terms were used for PubMed: (athlete OR sportsman OR sportswoman OR sport) AND (prevention OR intervention OR prophylaxis OR avoidance) AND (sport injury OR athletic injury OR sport accident OR sport trauma). Search terms for the Scopus and Cochrane Library databases were: ('injury prevention' AND athlete OR sport). For the PEDro database, the following advanced search for systematic reviews was conducted: (injur\* prevent\* sport\*). An expert in the field of preventive sports medicine (MB) identified through citation tracking any missing but relevant studies on the topic. Duplicates were identified and removed by one reviewer (RB).

Two reviewers (RB and NCC) then independently screened the titles and abstracts of all retrieved studies, and determined the eligibility of the potentially relevant full-text articles. If the decision of eligibility differed, a third reviewer was consulted (NAM) to evaluate the identified articles and reach final consensus on the inclusion of selected articles.

### Methodological quality evaluation

Two reviewers (RB and KN) independently assessed the methodological quality of the included systematic reviews using the AMSTAR tool. If the assessment was unclear, consensus was either reached by discussion or with the help of a third reviewer (NAM). The AMSTAR checklist is a reliable and valid instrument, which assesses the risk of systematic review bias.<sup>22</sup> It comprises 11 different domains that are answered with the following options: 'yes'; 'no'; 'cannot answer'; and 'not applicable'; only a 'yes' answer is nominated with a score of 1 point.

To assess the overall quality of evidence of all included systematic reviews, we applied an adapted form of the Grading of Recommendations Assessment, Development and Evaluation (GRADE) principles.<sup>23</sup> There are five GRADE categories: high; moderate; low; very low; and no evidence from systematic

**Table 1** Description of study outcomes and exercise elements

Study outcomes	Description
Lower extremity injuries	Lower limb injuries, all sports injuries, all injuries
Groin injuries	Groin injuries
Knee injuries	Knee joint injuries, acute knee injuries, undefined knee injuries
ACL injuries	ACL injuries, non-contact ACL injuries
Ankle injuries	Acute ankle injuries, ankle sprains, undefined ankle injuries
Exercise elements	
Strength	Eccentric or concentric strength training, weight training, core stability or power training
Agility	Sport cord drills, sports-specific drills or running techniques
Plyometric	Jumping and rebounding exercises
Balance	Proprioception, neuromuscular training with wobble boards or balance mats, dynamic stability, body control or one-leg coordination
Stretching	Flexibility exercises
Technique	Single-leg jumps with focus on leg alignment, jumping and landing techniques, and neuromuscular control during landing manoeuvres
Warm-up	Aerobic exercises, muscle activation or unspecified basic warm-up (ie, jogging, trunk twists, jumping jacks)
Functional activities	Unspecified exercises for the lower and upper extremities

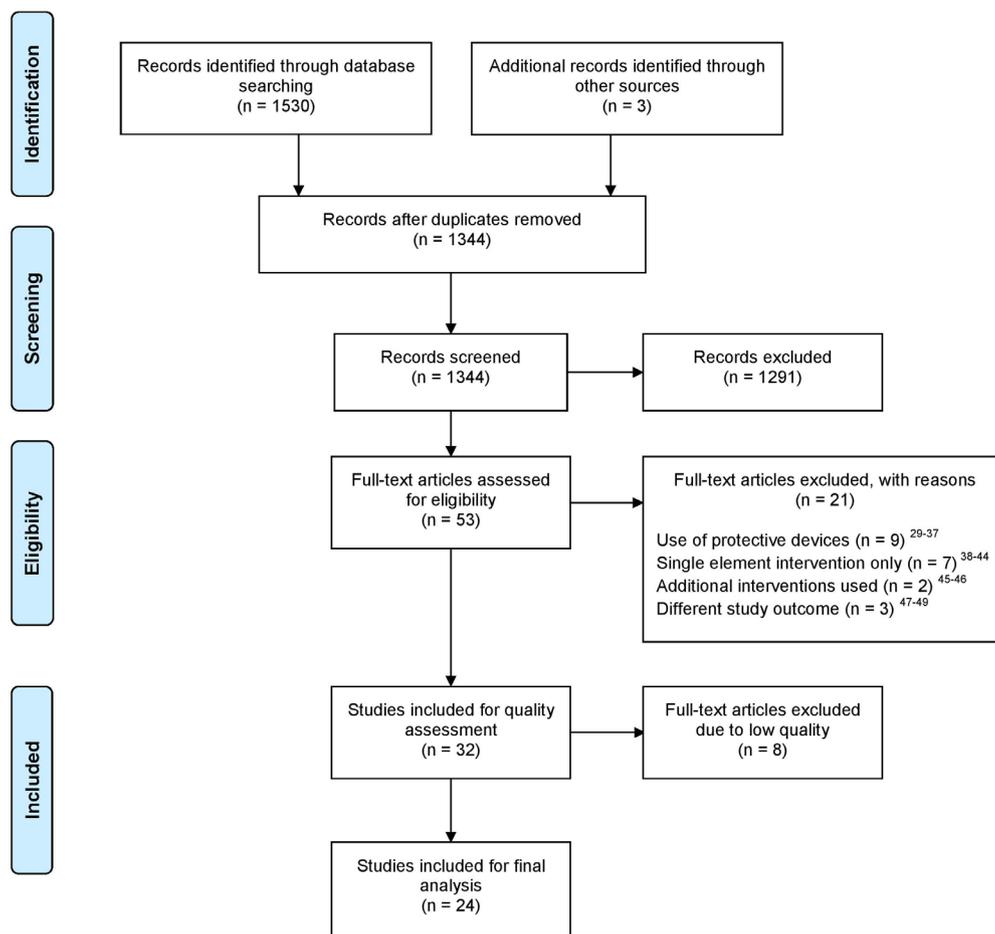
review. A high GRADE defines a systematic review or meta-analysis consisting of at least two high-quality primary studies. A moderate GRADE defines a review including at least one high-quality primary study or at least two moderate-quality primary studies. Low GRADE defines a review on only moderate-quality primary studies and/or inconsistent results in the primary studies. Very low GRADE refers to 'no medium to high quality systematic review identified on this topic'. If the authors of the systematic review did not assess the quality of the primary studies (ie, no risk of bias assessment was conducted), they were classified as 'no evidence from systematic review' and the GRADE system was not applied.

### Data extraction and analysis

Two reviewers (RB and BF) used a standardised data extraction form as part of the established umbrella review protocol to collect data from the included reviews.<sup>19</sup> A third reviewer (NAM) was consulted when any ambiguity arose during this process. All data were stored and managed in Microsoft Excel 2010.

Injury incidences/rates were analysed separately for five lower extremity injury categories: (1) lower extremity injuries; (2) groin injuries; (3) knee injuries; (4) ACL injuries; and (5) ankle injuries. This categorisation was defined based on the terms mainly used to describe lower extremity injuries in the included systematic reviews/meta-analyses and primary studies. A detailed description of each injury category is listed in [table 1](#).

We defined eight exercise element categories according to the common terms found ([table 1](#)): (1) strength; (2) agility; (3) plyometric; (4) balance; (5) stretching; (6) technique; (7) warm-up; and (8) functional activities. Terms 1–5 were previously adopted from one of the included meta-analyses that tested the effectiveness of each exercise component on ACL injury prevention.<sup>15</sup> Terms 6–8 were included because they represent frequent exercise concepts. Term 6, technique, encompassed a correct lower extremity alignment technique while performing demanding weight-bearing tasks (eg, single-leg jumps with a focus on leg



**Figure 1** Flow chart of the study selection process.

alignment; jumping and landing techniques; neuromuscular control during landing).<sup>24-27</sup> Term 7, warm-up, included aerobic exercises, muscle activation or non-specific basic warm-up exercises such as jogging, trunk twists and jumping jacks. Term 8, functional activities, comprised all non-specific exercise elements for lower and upper extremities as part of the injury prevention programmes found in the studies included in this umbrella review.

Characteristics of the selected systematic reviews/meta-analyses including the AMSTAR and GRADE scores, number of participants, combination of exercise elements, heterogeneity between primary studies ( $I^2$ ) as well as results, findings and authors' conclusions are presented in online e-Supplement 1. Within each review/meta-analysis one<sup>28</sup> to ten<sup>11</sup> different combinations of exercise elements were presented.

A summary of the effectiveness of exercise element combinations was made for each injury category, including the mean methodological quality (summary of AMSTAR scores divided by the number of systematic reviews including the exercise element combinations to strengthen the overall results) and overall results. We used a traffic light system to visually summarise the effectiveness of each exercise element combination in reducing the injury incidence/rate per injury category. A green light was set for studies with effective overall results (ie, agreement on the effectiveness of exercise element combinations). An orange light was indicative of studies with inconsistent overall results (ie, disagreement on the effectiveness of exercise element combinations), and a red

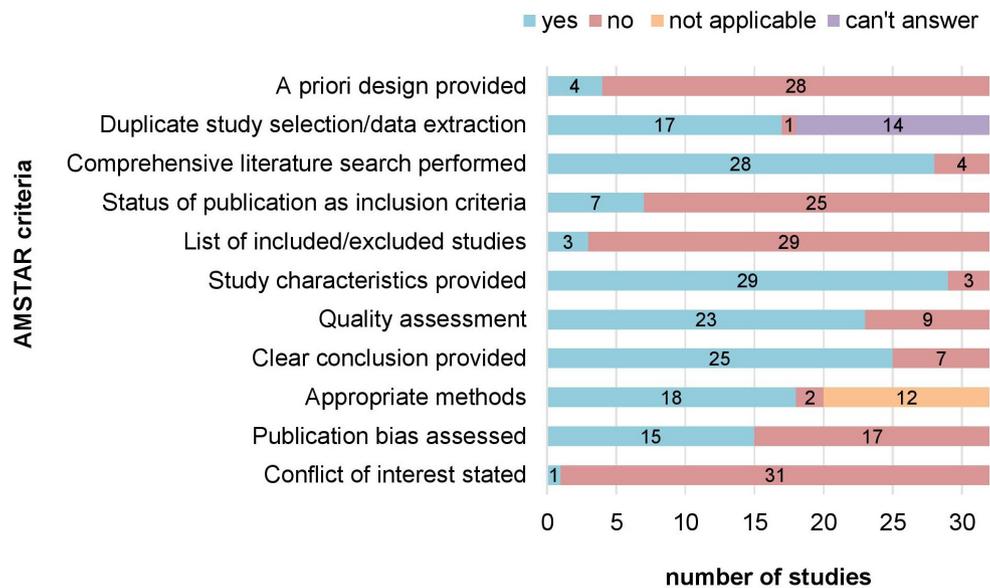
light of ineffective overall results (ie, agreement on the ineffectiveness of exercise element combinations).<sup>19</sup>

## RESULTS

Our database search identified a total of 1530 records with three additional studies found by our content expert (MB) (figure 1). After duplicates were removed, 1344 records were screened for titles and abstracts. A further 1291 studies were excluded, mainly because the study outcome did not match the one defined at the outset of our review. Of 53 full-text articles evaluated, 21 systematic reviews were excluded for various reasons (figure 1: Eligibility).<sup>29-49</sup> The 32 remaining systematic reviews were evaluated for methodological quality.

### Methodological quality evaluation

The overall methodological quality of the 32 included reviews is summarised in figure 2. Eight reviews had a total AMSTAR score of  $\leq 3$  and were excluded.<sup>50-57</sup> For the remaining 24 reviews,<sup>6 9-11 13-17 24 28 58-70</sup> the following AMSTAR criteria were under-reported: using the status of publication as an inclusion criterion<sup>11 29 56-58 61 64</sup>; providing an a priori design<sup>6 12 17 64</sup>; listing all included and excluded primary studies<sup>9 10 17</sup>; and stating a conflict of interest.<sup>30</sup> The majority ( $n=17$ ) of the 24 included systematic reviews were based on high-quality primary studies (ie, high GRADE) for the outcome of lower extremity, knee, ACL and ankle injuries. Two systematic reviews were of moderate



**Figure 2** Overall results of the Assessing the Methodological Quality of Systematic Reviews (AMSTAR) checklist (n=32).

GRADE regarding the outcome of ACL injuries<sup>24 68</sup> and four systematic reviews were of low GRADE regarding the outcome of lower extremity, groin and ACL injuries<sup>6 13 64 67</sup>; one systematic review did not assess the quality of the primary studies regarding the outcome of ACL injuries.<sup>16</sup>

### Effectiveness of exercise element combinations

Twenty-six primary studies were included in the analysed systematic reviews.

Ten systematic reviews evaluated eight different exercise element combinations, of which three exercise element combinations were effective in reducing the lower extremity injury incidence/rate (table 2). These effective injury prevention programmes encompassed three different combinations: strength, plyometric, balance, stretching, warm-up; strength, agility, plyometric, balance; and the combination of balance, stretching and warm-up exercises.

For the groin, there were no effective exercise element combinations identified in five systematic reviews (table 2).

Eight systematic reviews reported two combinations of exercise elements as effective in preventing knee injuries (table 2). These effective injury prevention programmes encompassed two different exercise combinations: strength, agility, balance, stretching, technique; and strength, agility, balance, warm-up.

From a total of 10 exercise element combinations focused on reducing ACL injuries, two different exercise combinations were considered effective: strength, plyometric, balance, stretching, warm-up; and strength, agility, balance, warm-up (table 2).

Four combinations of exercise elements were effective in preventing ankle injuries (table 2); these injury prevention programmes included the exercise elements of strength, agility, plyometrics, balance, stretching, technique and warm-up.

Overall, there were 11 combinations of exercise elements that were effective in reducing the injury incidences/rates. Strength and balance exercises were included in 10 effective injury prevention programmes. For lower extremity injuries, balance exercises were included in all three effective injury prevention programmes. Strength, plyometrics, stretching and warm-up exercises were included in two programmes. For knee injuries, strength, balance and agility exercises were included in all three effective injury

prevention programmes. Stretching, technique and warm-up exercises were included in two programmes. For ACL injuries, the two effective injury prevention programmes included strength, balance and warm-up exercises. Strength was included in all four effective ankle injury prevention programmes. Balance, agility and stretching exercises were included in three effective ankle injury prevention programmes.

### DISCUSSION

Based on 24 moderate to high-quality systematic reviews and meta-analyses, we found that multicomponent exercise interventions were effective in reducing the injury incidence/rate of lower extremity, knee, ACL and ankle injuries, but not of groin injuries. The most frequent elements of a neuromuscular training programme were a combination of strength and balance exercises.

Several meta-analyses included in this umbrella review showed a beneficial effect of multicomponent exercise programmes for different outcomes (ie, lower extremity, knee, ACL and ankle injuries).<sup>10 13–17</sup> The combination of strength and balance exercises enhanced the effect of an injury prevention programme.<sup>17</sup> Strengthening and proximal control exercises (eg, exercises involving segments proximal to the knee joint) were associated with a reduction in ACL injuries.<sup>14</sup> On the other hand, injury prevention programmes including balance exercises compared with programmes without balance exercises did not reveal any additional effect in reducing ACL injuries.<sup>14 16</sup> However, the authors of the systematic reviews did claim the importance of balance exercises in combination with other types of exercises for reducing ACL injuries.<sup>14 16</sup>

In contrast to strength and balance exercises, the exercise components stretching, agility, plyometrics and technique were less frequent in programmes aimed at reducing lower extremity, knee, ACL and ankle injury incidence/rate. According to a meta-analysis included in this umbrella review, stretching added no beneficial effect in decreasing sports injuries.<sup>17</sup> Several other studies<sup>31–34 71 72</sup> also found limited evidence to support the benefits of stretching before or after training for injury prevention. Stretching increases flexibility,<sup>73</sup> which is an important quality in specific team sports and playing positions (eg, an ice hockey goalkeeper needs more hip flexibility compared with a field player). Yet higher flexibility

Table 2 Summary of findings for each outcome

References	Combination of exercise elements										Mean methodological quality (AMSTAR)	Effectiveness of exercise element combinations (traffic light indicator*)	
	Strength	Agility	Plyometrics	Balance	Stretching	Technique	Warm-up	Functional activity					
Lower extremity injuries													
van Beijsterveldt, Steffen, Soligard, Longo, Owwoeye, Hammes, Gatterer, Grooms; included in SRs 9; 10; 17; 57; 64–66; 70	x	x	x	x							x		Inconsistent
Pasanen included in SRs 10; 17; 59	x		x	x	x						x		Effective
Emery and Meeuwisse included in SRs 17; 65; 66; 70	x	x	x	x	x								Inconsistent
LaBella included in SRs 9; 17; 65	x	x	x	x									Effective
Olsen included in SRs 10; 50; 65; 66	x	x	x	x							x		Inconsistent
Emery included in SRs 10; 17; 65; 66	x	x		x	x						x		Effective
Bixler included in SR 60					x						x		Inconsistent
Wederkopp included in SRs 60; 65; 66					x						x		Inconsistent
Groin injuries													
van Beijsterveldt, Steffen, Soligard included in SRs 6; 9	x	x	x	x							x		Ineffective
Engelbreten included in SRs 6; 59; 64	x			x							x		Ineffective
Holmich included in SRs 6; 59; 64	x			x									Ineffective
Wederkopp included in SRs 6; 17; 59				x							x		Ineffective
Knee injuries													
van Beijsterveldt, Steffen, Soligard included in SRs 9; 62	x	x	x	x							x		Inconsistent
LaBella included in SR 9	x	x	x	x									Inconsistent
Emery and Meeuwisse included in SR 62	x	x	x	x							x		Effective
Gilchrist included in SRs 9; 10; 59; 62	x	x	x	x									Inconsistent
Olsen included in SRs 10; 17; 60	x	x		x							x		Effective
Engelbreten, Kiani, Walden included in SRs 9; 62; 64; 65	x			x							x		Inconsistent
ACL injuries													
van Beijsterveldt, Steffen, Grooms included in SRs 9; 11; 14; 15; 58; 61; 62; 67; 69	x	x	x	x							x		Inconsistent
Gilchrist, Heidt, Mandelbaum included in SRs 9; 11; 13–17; 24; 59; 61; 62; 65; 67–69	x	x	x	x							x		Inconsistent
Pasanen included in SRs 11; 14; 61; 69	x		x	x							x		Effective
LaBella included in SRs 9; 11; 14; 15; 69	x	x	x	x									Inconsistent
Olsen included in SRs 11; 14; 15; 24; 61; 69	x	x	x	x							x		Effective
Myklebust included in SRs 11; 14–16; 24; 61; 67–69	x		x	x							x		Inconsistent
Hewett included in SRs 11; 13–16; 24; 61; 65; 67–69	x		x	x							x		Inconsistent
Kiani, Walden included in SRs 11; 14; 15; 17; 61; 62; 65; 67; 69	x		x	x							x		Inconsistent
Pfeiffer included in SRs 9; 11; 13–16; 61; 65; 67–69		x		x									Inconsistent
Petersen included in SRs 11; 13–16; 24; 61; 67–69		x	x	x									Inconsistent
Ankle injuries													
van Beijsterveldt, Steffen, Soligard included in SRs 9; 63	x	x	x	x							x		Inconsistent

Continued

Table 2 Continued

References	Combination of exercise elements										Mean methodological quality (AMSTAR)	Effectiveness of exercise element combinations (traffic light indicator*)	
	Strength	Agility	Plyometrics	Balance	Stretching	Technique	Warm-up	Functional activity					
Pasanen included in SR 10	x		x	x	x		x					7	Effective
LaBella included in SR 9	x	x	x	x								6	Ineffective
Olsen included in SRs 10; 17; 60	x	x		x			x					7	Effective
Engelbreten included in SRs 59; 63; 64	x			x			x					6.7	Inconsistent
Emery and Meeuwisse included in SR 63	x	x		x			x					6	Effective
Heidt included in SR 63	x	x	x	x	x		x					6	Effective

\* Representing the effectiveness of the exercise element combination in reducing the injury incidence/rate applied in per injury category. AMSTAR, Assessing the Methodological Quality of Systematic Reviews; SR, systematic review.

was not associated with a lower risk of injuries.<sup>71</sup> Thus, the component stretching may not add much additional benefit to a lower extremity injury prevention programme.

Our finding of no beneficial effect of prevention programmes with and without plyometric exercises on ACL injuries supports previous research.<sup>14</sup> However, this area is not unanimous, and it is possible that plyometric exercises may be effective for ACL injury prevention.

No subgroup analysis within a meta-analysis to assess the specific effectiveness of agility exercises was conducted. Only one systematic review included in this umbrella review claimed the importance of agility exercises incorporated into a multicomponent injury prevention programme to reduce the risk of ACL injuries in female athletes.<sup>24</sup> It has been shown that a combination of agility and plyometric exercises contributed to a risk reduction that was associated with knee valgus angles and moments.<sup>4</sup> A combination of plyometric and agility exercises might therefore protect the knee joint during dynamic movements<sup>14</sup> and be beneficial in reducing ACL injuries when included in injury prevention programmes.

Technique exercises described in the included reviews focused on leg alignment during landing manoeuvres following a jump. Technique exercises may be less important because jumping was not a usual action in all the team sports considered in this umbrella review (ie, floorball and soccer). Nevertheless, landing technique exercises have been successfully applied to decrease knee varus/valgus moments<sup>27</sup>; various studies used visual feedback and/or education on dangerous knee postures to modify landing manoeuvres.<sup>25-27 74 75</sup> However, the authors might not have classified that as an exercise itself, which might lead to a reporting bias of technique exercises, and is therefore considered as less important in this umbrella review.

There are two types of injuries that require differentiation based on their occurrence: traumatic and overuse. All articles considered in this umbrella review focused on traumatic injuries. Therefore, making any conclusions about the effects of injury prevention programmes on reducing the rate of overuse injuries is not justified. It was previously reported that groin injuries are mainly overuse in origin<sup>5</sup> and represent a serious problem in many sports.<sup>76 77</sup> However, a recent meta-analysis, included in our umbrella review,<sup>6</sup> reported a total number of groin injuries that was very low in comparison to other injury types. Despite the relatively large sample size, there were only traumatic injuries examined, which may indicate a reporting bias. It is important to systematically assess all overuse injuries in addition to traumatic injuries in future primary studies. Detailed prevalence data of overuse injuries may support the development of overuse-specific prevention programmes.

### Strengths and limitations

Our umbrella review ensured a high-level synthesis of the evidence<sup>18</sup> regarding injury prevention programmes in team-sport athletes and allowed to identify the most frequent exercise combinations for lower extremity injury prevention.

Due to study participant heterogeneity, it was not possible to stratify the main findings by age, sex, type of sports and level of play. One problem inherent in a study of this kind is the definition of outcomes assessed in the reviews. For example, various reviews used the outcome knee injuries, whereas others specifically used the outcome ACL injuries. We presume that some reviews with the outcome knee injuries might also have included ACL injuries. However, this did not influence the outcome of this umbrella review because ACL injuries were considered as knee ligament injuries. Some reviews used different exercise descriptions or

poorly reported the type of exercise element in the prevention programmes. This may have led to a misclassification of exercise elements. Various authors classified jumping as plyometrics, which can also be interpreted as landing technique exercises. We also speculate that participants in the primary studies may have been trained to focus on leg alignment during landing, while alignment during landing was not considered as an exercise itself. Therefore, there is a risk for reporting bias.

Many of the reviews included in our umbrella review included the same primary studies and concluded on the same available data, which reveals a large overlap among published systematic reviews and meta-analyses. What appears to be a large number of primary studies and evidence could partly be due to an over-publication of systematic reviews and meta-analyses on the topic of injury prevention. We encountered some reporting bias within the reviews and primary studies regarding a detailed description of the types of intervention and degree of compliance. Therefore, we could not formulate recommendations for specific exercise modalities (eg, contraction type, load or execution speed when performing strength exercises). A systematic documentation of prevention programmes including the target group, a detailed exercise description using the frequency, intensity/type, time principles, and description of delivery agents should be considered in future studies to enhance generalisability and reproducibility.<sup>78</sup> Particularly for groin injuries, improved reporting of prevalence data is required. More high-quality intervention studies are also needed to accurately evaluate the effectiveness of multicomponent programmes for specifically preventing traumatic as well as overuse injuries.

## CONCLUSIONS

Multicomponent lower extremity exercise programmes were effective in preventing lower extremity, knee, ACL and ankle injuries in the team sports of soccer, floorball, Australian and American football, basketball, handball and volleyball for all age levels and sex.

### What is already known

- ▶ There is a large number of systematic reviews available on the effectiveness of injury prevention programmes for the lower extremity in team-sport athletes.
- ▶ Injury prevention programmes reduce the risk of traumatic injuries of the lower extremity in athletes.
- ▶ Multicomponent prevention programmes are more effective compared with single element prevention programmes.

### What are the new findings

- ▶ In 10 of 11 effective injury prevention programmes regarding lower extremity, knee, ACL and ankle injuries, strength and balance are considered the most important exercise elements for team-sport athletes.
- ▶ Agility and plyometric exercises might be beneficial in reducing the ACL injury incidence/rate when performed in combination with strength and balance exercises as part of an injury prevention programme.
- ▶ Due to the heterogeneity of methodological descriptions in the reviews, it is impossible to draw conclusions about the specific intervention(s) for each exercise category as well as the frequency and intensity of an injury prevention programme.

Muscle strength and balance exercises seem to be the most frequent components in a lower extremity injury prevention programme.

**Contributors** RB: conception and design, literature search, methodological quality assessment, data extraction, data analysis, data interpretation, drafting of the manuscript, revision/editing of the manuscript, final approval of the manuscript, agreement to be accountable for all aspects of the work. BF: data extraction, critical revision of the manuscript, final approval of the manuscript, agreement to be accountable for all aspects of the work. NCC and MB: literature search, critical revision of the manuscript, final approval of the manuscript, agreement to be accountable for all aspects of the work. NAM: conception and design, disagreement solving, critical revising of the manuscript, final approval of the manuscript, agreement to be accountable for all aspects of the work. KN: conception and design, methodological quality assessment, data analysis, data interpretation, critical revision of the manuscript, final approval of the manuscript, agreement to be accountable for all aspects of the work.

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## REFERENCES

- 1 Sheu Y, Chen LH, Hedegaard H. Sports- and recreation-related injury episodes in the United States, 2011–2014. *Natl Health Stat Report* 2016;1–12.
- 2 EuroSafe: Injuries in the European Union. Summary on injury statistics 2012–2014. [http://www.bridge-health.eu/sites/default/files/EuropeSafe\\_Master\\_R4\\_SinglePage\\_12102016%20%281%29.pdf](http://www.bridge-health.eu/sites/default/files/EuropeSafe_Master_R4_SinglePage_12102016%20%281%29.pdf) (accessed 8 Nov 2017).
- 3 Ter Stege MH, Dallinga JM, Benjaminse A, et al. Effect of interventions on potential, modifiable risk factors for knee injury in team ball sports: a systematic review. *Sports Med* 2014;44:1403–26.
- 4 Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: summary and recommendations for injury prevention initiatives. *J Athl Train* 2007;42:311–9.
- 5 Pettersson M, Lorentzon R. Ice hockey injuries: a 4-year prospective study of a Swedish elite ice hockey team. *Br J Sports Med* 1993;27:251–4.
- 6 Esteve E, Rathleff MS, Bagur-Calafat C, et al. Prevention of groin injuries in sports: a systematic review with meta-analysis of randomised controlled trials. *Br J Sports Med* 2015;49:785–91.
- 7 Meeuwisse WH. Assessing causation in sport injury: a multifactorial model. *Clin J Sport Med* 1994;4:166–70.
- 8 Bahr R, Holme I. Risk factors for sports injuries—a methodological approach. *Br J Sports Med* 2003;37:384–92.
- 9 Herman K, Barton C, Malliaras P, et al. The effectiveness of neuromuscular warm-up strategies, that require no additional equipment, for preventing lower limb injuries during sports participation: a systematic review. *BMC Med* 2012;10:75.
- 10 Hübscher M, Zech A, Pfeifer K, et al. Neuromuscular training for sports injury prevention: a systematic review. *Med Sci Sports Exerc* 2010;42:413–21.
- 11 Myer GD, Sugimoto D, Thomas S, et al. The influence of age on the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: a meta-analysis. *Am J Sports Med* 2013;41:203–15.
- 12 Rössler R, Donath L, Verhagen E, et al. Exercise-based injury prevention in child and adolescent sport: a systematic review and meta-analysis. *Sports Medicine* 2014;44:1733–48.
- 13 Sadoghi P, von Keudell A, Vavken P. Effectiveness of anterior cruciate ligament injury prevention training programs. *J Bone Joint Surg Am* 2012;94:769–76.
- 14 Sugimoto D, Myer GD, Foss KD, et al. Specific exercise effects of preventive neuromuscular training intervention on anterior cruciate ligament injury risk reduction in young females: meta-analysis and subgroup analysis. *Br J Sports Med* 2015;49:282–9.
- 15 Taylor JB, Waxman JP, Richter SJ, et al. Evaluation of the effectiveness of anterior cruciate ligament injury prevention programme training components: a systematic review and meta-analysis. *Br J Sports Med* 2015;49:79–87.
- 16 Yoo JH, Lim BO, Ha M, et al. A meta-analysis of the effect of neuromuscular training on the prevention of the anterior cruciate ligament injury in female athletes. *Knee Surg Sports Traumatol Arthrosc* 2010;18:824–30.
- 17 Laursen JB, Bertelsen DM, Andersen LB. The effectiveness of exercise interventions to prevent sports injuries: a systematic review and meta-analysis of randomised controlled trials. *Br J Sports Med* 2014;48:871–7.
- 18 Ioannidis J. Next-generation systematic reviews: prospective meta-analysis, individual-level data, networks and umbrella reviews. *Br J Sports Med* 2017;51:1456–8.
- 19 Aromataris E, Fernandez R, Godfrey CM, et al. Summarizing systematic reviews: methodological development, conduct and reporting of an umbrella review approach. *Int J Evid Based Healthc* 2015;13:132–40.

- 20 Sharif MO, Janjua-Sharif FN, Sharif FN, *et al.* Systematic reviews explained: AMSTAR-how to tell the good from the bad and the ugly. *Oral Health Dent Manag* 2013;12:9–16.
- 21 Miller SA, Forrest JL. Enhancing your practice through evidence-based decision making: PICO, learning how to ask good questions. *Journal of Evidence Based Dental Practice* 2001;1:136–41.
- 22 Shea BJ, Hamel C, Wells GA, *et al.* AMSTAR is a reliable and valid measurement tool to assess the methodological quality of systematic reviews. *J Clin Epidemiol* 2009;62:1013–20.
- 23 Moe RH, Haavardsholm EA, Christie A, *et al.* Effectiveness of nonpharmacological and nonsurgical interventions for hip osteoarthritis: an umbrella review of high-quality systematic reviews. *Phys Ther* 2007;87:1716–27.
- 24 Grindstaff TL, Hammill RR, Tuzson AE, *et al.* Neuromuscular control training programs and noncontact anterior cruciate ligament injury rates in female athletes: a numbers-needed-to-treat analysis. *J Athl Train* 2006;41:450–6.
- 25 Oñate JA, Guskiewicz KM, Marshall SW, *et al.* Instruction of jump-landing technique using videotape feedback: altering lower extremity motion patterns. *Am J Sports Med* 2005;33:831–42.
- 26 Milner CE, Fairbrother JT, Srivatsan A, *et al.* Simple verbal instruction improves knee biomechanics during landing in female athletes. *Knee* 2012;19:399–403.
- 27 Myer GD, Ford KR, Hewett TE. Rationale and clinical techniques for anterior cruciate ligament injury prevention among female athletes. *J Athl Train* 2004;39:352–64.
- 28 Al Attar WS, Soomro N, Pappas E, *et al.* How effective are F-marc injury prevention programs for soccer players? A systematic review and meta-analysis. *Sports Med* 2016;46:205–17.
- 29 Sugimoto D, Myer GD, Bush HM, *et al.* Compliance with neuromuscular training and anterior cruciate ligament injury risk reduction in female athletes: a meta-analysis. *J Athl Train* 2012;47:714–23.
- 30 Sugimoto D, Myer GD, Foss KD, *et al.* Dosage effects of neuromuscular training intervention to reduce anterior cruciate ligament injuries in female athletes: meta- and sub-group analyses. *Sports Med* 2014;44:551–62.
- 31 Lewis J. A systematic literature review of the relationship between stretching and athletic injury prevention. *Orthop Nurs* 2014;33:312–20.
- 32 Small K, Mc Naughton L, Matthews M. A systematic review into the efficacy of static stretching as part of a warm-up for the prevention of exercise-related injury. *Res Sports Med* 2008;16:213–31.
- 33 Thacker SB, Gilchrist J, Stroup DF, *et al.* The impact of stretching on sports injury risk: a systematic review of the literature. *Med Sci Sports Exerc* 2004;36:371–8.
- 34 Weldon SM, Hill RH, Hrh WSM. The efficacy of stretching for prevention of exercise-related injury: a systematic review of the literature. *Man Ther* 2003;8:141–50.
- 35 Aaltonen S, Karjalainen H, Heinson A, *et al.* Prevention of sports injuries: systematic review of randomized controlled trials. *Arch Intern Med* 2007;167:1585–92.
- 36 Abernethy L, Bleakley C. Strategies to prevent injury in adolescent sport: a systematic review. *Br J Sports Med* 2007;41:627–38.
- 37 Grimm NL, Shea KG, Leaver RW, *et al.* Efficacy and degree of bias in knee injury prevention studies: a systematic review of RCTs. *Clin Orthop Relat Res* 2013;471:308–16.
- 38 Handoll HH, Rowe BH, Quinn KM, *et al.* Interventions for preventing ankle ligament injuries. *Cochrane Database Syst Rev* 2001;3:CD000018.
- 39 Leppänen M, Aaltonen S, Parkkari J, *et al.* Interventions to prevent sports related injuries: a systematic review and meta-analysis of randomised controlled trials. *Sports Med* 2014;44:473–86.
- 40 McGuire T. Sports injuries in high school athletes: a review of injury-risk and injury-prevention research. *Clin J Sports Med* 2006;16:488–99.
- 41 Thacker SB, Stroup DF, Branche CM, *et al.* Prevention of knee injuries in sports. A systematic review of the literature. *J Sports Med Phys Fitness* 2003;43:165.
- 42 Verhagen EA, van Mechelen W, de Vente W. The effect of preventive measures on the incidence of ankle sprains. *Clin J Sport Med* 2000;10:291–6.
- 43 Verhagen EA, Bay K. Optimising ankle sprain prevention: a critical review and practical appraisal of the literature. *Br J Sports Med* 2010;44:1082–8.
- 44 Goode AP, Reiman MP, Harris L, *et al.* Eccentric training for prevention of hamstring injuries may depend on intervention compliance: a systematic review and meta-analysis. *Br J Sports Med* 2015;49:349–56.
- 45 Hibbert O, Cheong K, Grant A, *et al.* A systematic review of the effectiveness of eccentric strength training in the prevention of hamstring muscle strains in otherwise healthy individuals. *N Am J Sports Phys Ther* 2008;3:67–81.
- 46 Schiftan GS, Ross LA, Hahne AJ. The effectiveness of proprioceptive training in preventing ankle sprains in sporting populations: a systematic review and meta-analysis. *J Sci Med Sport* 2015;18:238–44.
- 47 Goldman EF, Jones DE. Interventions for preventing hamstring injuries. *Cochrane Database Syst Rev* 2010;20:CD006782.
- 48 Olsen L, Scanlan A, MacKay M, *et al.* Strategies for prevention of soccer related injuries: a systematic review. *Br J Sports Med* 2004;38:89–94.
- 49 Whittaker JL, Small C, Maffey L, *et al.* Risk factors for groin injury in sport: an updated systematic review. *Br J Sports Med* 2015;49:803–9.
- 50 Barenco NC, Meneses-Echavez JF, Ramirez-Vélez R, *et al.* The impact of the FIFA 11+ training program on injury prevention in football players: a systematic review. *Int J Environ Res Public Health* 2014;11:11986–2000.
- 51 Frisch A, Croisier JL, Urhausen A, *et al.* Injuries, risk factors and prevention initiatives in youth sport. *Br Med Bull* 2009;92:95–121.
- 52 Hewett TE, Myer GD. Reducing knee and anterior cruciate ligament injuries among female athletes. *J Knee Surg* 2005;18:82–8.
- 53 Hewett TE, Ford KR, Myer GD. Anterior cruciate ligament injuries in female athletes: Part 2, a meta-analysis of neuromuscular interventions aimed at injury prevention. *Am J Sports Med* 2006;34:490–8.
- 54 Kirkendall DT, Junge A, Dvorak J. Prevention of football injuries. *Asian J Sports Med* 2010;1:81–92.
- 55 Michaelidis M, Koumantakis GA. Effects of knee injury primary prevention programs on anterior cruciate ligament injury rates in female athletes in different sports: a systematic review. *Phys Ther Sport* 2014;15:200–10.
- 56 Noyes FR, Barber-Westin SD. Neuromuscular retraining intervention programs: do they reduce noncontact anterior cruciate ligament injury rates in adolescent female athletes? *Arthroscopy* 2014;30:245–55.
- 57 Noyes FR, Barber Westin SD. Anterior cruciate ligament injury prevention training in female athletes: a systematic review of injury reduction and results of athletic performance tests. *Sports Health* 2012;4:36–46.
- 58 Alentorn-Geli E, Mendiguchía J, Samuelsson K, *et al.* Prevention of non-contact anterior cruciate ligament injuries in sports. Part II: systematic review of the effectiveness of prevention programmes in male athletes. *Knee Surg Sports Traumatol Arthrosc* 2014;22:16–25.
- 59 Andrew N, Gabbe BJ, Cook J, *et al.* Could targeted exercise programmes prevent lower limb injury in community Australian football? *Sports Med* 2013;43:751–63.
- 60 Fradkin AJ, Gabbe BJ, Cameron PA. Does warming up prevent injury in sport? The evidence from randomised controlled trials? *J Sci Med Sport* 2006;9:214–20.
- 61 Gagnier JJ, Morgenstern H, Chess L. Interventions designed to prevent anterior cruciate ligament injuries in adolescents and adults: a systematic review and meta-analysis. *Am J Sports Med* 2013;41:1952–62.
- 62 Grimm NL, Jacobs JC, Kim J, *et al.* Anterior cruciate ligament and knee injury prevention programs for soccer players: a systematic review and meta-analysis. *Am J Sports Med* 2015;43:2049–56.
- 63 Grimm NL, Jacobs JC, Kim J, *et al.* Ankle injury prevention programs for soccer athletes are protective: a level-I meta-analysis. *J Bone Joint Surg Am* 2016;98:1436–43.
- 64 Porter T, Rushton A. The efficacy of exercise in preventing injury in adult male football: a systematic review of randomised controlled trials. *Sports Med Open* 2015;1:4.
- 65 Rössler R, Donath L, Verhagen E, *et al.* Exercise-based injury prevention in child and adolescent sport: a systematic review and meta-analysis. *Sports Med* 2014;44:1733–48.
- 66 Soomro N, Sanders R, Hackett D, *et al.* The efficacy of injury prevention programs in adolescent team sports: a meta-analysis. *Am J Sports Med* 2016;44:2415–24.
- 67 Stevenson JH, Beattie CS, Schwartz JB, *et al.* Assessing the effectiveness of neuromuscular training programs in reducing the incidence of anterior cruciate ligament injuries in female athletes: a systematic review. *Am J Sports Med* 2015;43:482–90.
- 68 Stojanovic MD, Ostojic SM. Preventing ACL injuries in team-sport athletes: a systematic review of training interventions. *Res Sports Med* 2012;20:223–38.
- 69 Sugimoto D, Myer GD, McKeon JM, *et al.* Evaluation of the effectiveness of neuromuscular training to reduce anterior cruciate ligament injury in female athletes: a critical review of relative risk reduction and numbers-needed-to-treat analyses. *Br J Sports Med* 2012;46:979–88.
- 70 van Beijsterveldt AM, van der Horst N, van de Port IG, *et al.* How effective are exercise-based injury prevention programmes for soccer players? A systematic review. *Sports Med* 2013;43:257–65.
- 71 Shrier I. Stretching before exercise does not reduce the risk of local muscle injury: a critical review of the clinical and basic science literature. *Clin J Sport Med* 1999;9:221–7.
- 72 Witvrouw E, Mahieu N, Danneels L, *et al.* Stretching and injury prevention: an obscure relationship. *Sports Med* 2004;34:443–9.
- 73 Bandy WD, Irion JM, Briggler M. The effect of time and frequency of static stretching on flexibility of the hamstring muscles. *Phys Ther* 1997;77:1090–6.
- 74 Hewett TE, Myer GD, Ford KR, *et al.* Mechanisms, prediction, and prevention of ACL injuries: Cut risk with three sharpened and validated tools. *J Orthop Res* 2016;34:1843–55.
- 75 Sugimoto D, Alentorn-Geli E, Mendiguchía J, *et al.* Biomechanical and neuromuscular characteristics of male athletes: implications for the development of anterior cruciate ligament injury prevention programs. *Sports Med* 2015;45:809–22.
- 76 Bahr R. No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. *Br J Sports Med* 2009;43:966–72.
- 77 Clarsen B, Myklebust G, Bahr R. Development and validation of a new method for the registration of overuse injuries in sports injury epidemiology: the Oslo Sports Trauma Research Centre (OSTRC) overuse injury questionnaire. *Br J Sports Med* 2013;47:495–502.
- 78 O'Brien J, Donaldson A, Barbery G, *et al.* The three must-do's of intervention reporting: enhancing sports injury prevention research. *Br J Sports Med* 2014;48:1267–9.