



# Effects of functional correction training on injury risk of athletes: a systematic review and meta-analysis

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## ABSTRACT

**Background.** We explored functional correction training using the Functional Movement Screen (FMS<sup>TM</sup>) tool. We also analyzed the effects of training on the injuries of athletes in a systematic review and meta-analysis of non-randomized clinical trials.

**Methodology.** We collected twenty-four articles from PubMed, CENTRAL, Scopus, ProQuest, Web of Science, EBSCOhost, SPORTDiscus, Embase, WanFang, and CNKI that were published between January 1997 to September 2020. Articles were selected based on the following inclusion criteria: randomized and non-randomized controlled trials, studies with functional correction training screened by FMS<sup>TM</sup> as the independent variable, and studies with injury risk to the athlete as the dependent variable. Data conditions included the sample size, mean, standard deviation, total FMS<sup>TM</sup> scores, number of injuries, and asymmetry movement patterns after interventions in the experimental and control groups. Exclusion criteria included: conference abstracts, cross-sectional studies, articles with retrospective study design.

**Results.** Twelve non-randomized trials were included in the meta-analysis. The injury risk ratio of athletes after functional correction training was 0.39 RR (95 CI [1.50–1.93];  $Z = 15.53$ ;  $P < 0.0001$ ;  $I^2 = 2.6\%$ ), indicating an improvement of athletes functional patterns.

**Conclusion.** Grade B evidence indicates that functional correction training based on FMS<sup>TM</sup> may improve the functional patterns of athletes and Grade D evidence indicates that it may reduce the risk of sports injury. However, the true effect is likely to be different from the estimate of the effect. Therefore, further studies are needed to explore the influence of functional correction training on the injury risks of athletes. Protocol registration: CRD42019145287.

Submitted 15 October 2020

Accepted 19 February 2021

Published 25 March 2021

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Academic editor

Antonio Palazón-Bru

Additional Information and  
Declarations can be found on  
page 20

DOI 10.7717/peerj.11089

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**Subjects** Clinical Trials, Evidence Based Medicine, Kinesiology, Orthopedics

**Keywords** Functional movement screen, Functional correction training, Athlete, Injury risk

## INTRODUCTION

The mechanisms of sports injuries in athletes are complex and multifactorial with many potential risk factors for increasing the risk of injury. FMS<sup>TM</sup> is used to evaluate the basic sports patterns of athletes and to screen potential risk factors for injury. It comprises seven basic movements: active straight leg raise, shoulder mobility, trunk stability push-up, trunk rotary stability, in-line lunge, hurdle step and deep squat. Each movement is scored on a scale of 1–3 for a total score of 21 points (Cook, Burton & Hoogenboom, 2006a; Cook, Burton & Hoogenboom, 2006b). FMS<sup>TM</sup> assists in program design by systematically

using corrective exercises to normalize or improve fundamental movement patterns (Cook, 2011; Cook et al., 2014a; Cook et al., 2014b). An earlier study reported that injury prevention and performance enhancement programs should consider including FMS™ or a similar movement screening tool and their associated exercises to normalize dysfunctional movement with the goal of injury reduction and performance improvement (Kiesel, Plisky & Butler, 2011). Therefore, it is important to evaluate the relationship between functional correction training after FMS™ of athletes and sports injuries.

Functional correction training after FMS™ has shown inconsistent results when reported in other populations, including a randomized controlled trial of patients undergoing anterior cruciate ligament reconstruction in whom a set of gradually progressive functional corrective training exercises may significantly improve the function and movement of the knee joint (Chao et al., 2018). Several non-randomized controlled trials of firefighters have shown that personalized corrective exercises can improve FMS™ scores (Basar, 2017; Jafari, Zolaktaf & Ghasemi, 2019). A series of studies by Frost et al. (2012), Frost et al. (2015a), Frost et al. (2015b) and Frost et al. (2015c) reported that the effectiveness of FMS™ training requires the consideration of various factors, such as the number and type of participants, the scoring method (paper or video), the feedback provided during the test, and supervision by a coach. FMS™ may not be a viable tool to assess movement behaviors regardless of whether it is graded qualitatively using composite or task scores or quantitatively via kinematic analyses (Frost et al., 2017; Cornell, 2016) and the effect of functional correction training on firefighters after FMS™ was unclear.

Several non-randomized controlled studies of the functional correction training of athletes (Kiesel, Plisky & Butler, 2011; Kiesel, Butler & Plisky, 2014; Bayati et al., 2019; Campa, Spiga & Toselli, 2019; Riela & Bertollo, 2019; Kovac, 2018) have reported that it may improve their FMS™ scores as well as reduce asymmetry in functional patterns. Additional studies (Xuhua & Ye, 2015; Dinc et al., 2017; Hui & Baoai, 2019) have reported that athletes had significantly improved FMS™ scores and reduced sports injuries. The training of athletes' functional correction after FMS™ may have been effective. However, these findings must be verified since the studies included small sample sizes, some had no control group, and they lacked a strict randomized control design.

The summarized results of systematic reviews and meta-analyses of the total FMS™ score of a mixed population to predict the sports injury risk are contradictory and they do not support the predictive validity of FMS™ (Dorrel et al., 2015; Moran et al., 2017). However, other studies have reported that participants with composite scores equal to or less than 14 had a significantly higher likelihood of an injury compared to those with higher scores (Bonazza et al., 2017). Individuals classified as high risk by FMS™ are 51% more likely to be injured than those classified as having a low risk (Santos Bunn, Rodrigues & Da Silva, 2019). Two studies pertaining to FMS™ and sports injuries of athletes considered the total scores and asymmetry of the FMS™ to be more useful for evaluating the injury risk of older athletes (Moore et al., 2019). Another review reported that the relationship between the FMS™ score and injury is unclear as the heterogeneity of the study populations (type of athletes, age, and sport exposure) and the definition of injury used in the studies made it difficult to draw definitive conclusions (Trinidad-Fernandez, Gonzalez-Sanchez

✉ *Cuesta-Vargas, 2019*). Therefore, there is no clear conclusion about the relationship between FMS<sup>TM</sup> and sports injuries.

Some reviews that analyzed the effects of functional correction training reported that the plan was effective and improved the limitations of exercise patterns (*Minthorn et al., 2015; Kraus et al., 2014*). There is currently no meta-analysis or systematic review of this topic, and establishing the impact of functional correction training on sports injuries of athletes is a challenging and important task. We sought to explore the impact of functional correction training after FMS<sup>TM</sup> screening on the injury risk of athletes and to determine whether functional correction training after FMS<sup>TM</sup> screening could increase total FMS<sup>TM</sup> scores and reduce the incidence of asymmetry in movement patterns of athletes. We hypothesize that functional correction training after FMS<sup>TM</sup> may reduce the sports injury risk in athletes.

## MATERIALS AND METHODS

### Agreement and registration

The systematic review and meta-analysis were performed in accordance with the preferred reporting items for systematic reviews and meta-analyses. We followed the Cochrane Collaboration Handbook while conducting our research (*DerSimonian & Kacker, 2007; Moher et al., 2009*). This systematic review does not include individual patient data; therefore, ethical approval was not required. The research was registered in PROSPERO (Registration no. CRD42019145287).

### Inclusion and exclusion criteria

Participants: Adolescent and adult athletes; males and females.

Interventions: After initial FMS scores were obtained, athletes were prescribed an individualized FMS-score-based training program designed to correct the identified movement deficits. The training program included self-administered trigger point treatments, self and partner stretching of major muscle groups, and strength and stability exercises. The intervention plans were conventional training and functional correction training.

Comparator: Studies were required to have a comparator group that performed conventional training only.

Outcomes: Data indicators were sample size, mean, standard deviation, total FMS<sup>TM</sup> scores, number of athletes with sports injuries, and functional pattern asymmetry after intervention of the experimental and control groups.

Types of studies to be included: Randomized and non-randomized controlled trials were included.

Exclusion criteria: Conference abstracts, cross-sectional studies, and retrospective studies were excluded.

### Article sources, retrieval, and selection

Two authors (S Chen) and (Y Zhao) independently searched the literature. Disagreements over the validity of the findings were solved through consensus and by discussion with

a reference author (C Zhang). Ten electronic databases including PubMed, CENTRAL, Scopus, ProQuest, Web of Science, EBSCOhost, SPORTDiscus, Embase, Wanfang, and CNKI were searched for full texts published between January 1997 and September 2020. The following search terms and MeSH terms were used: functional movement screen OR fms\* OR functional movement screen\* AND injury\* OR injury prediction OR injury risk OR injury prevention screening OR athletic injuries [MeSH] AND functional training OR functional correction training OR corrective exercise training AND sport\* OR athlete\* OR player. Articles written in Chinese were limited to full text. The Chinese version of key words “FMS<sup>TM</sup>, functional training and athletes” were also used. Additionally, the references of the selected articles were searched manually to obtain other potentially related studies. [Table 1](#) shows the systematic search strategy.

### Data extraction and collection procedure

All duplicates were removed before our two investigators (S Chen, Y Zhao) independently screened the titles and abstracts for eligibility. Two investigators independently assessed the full text of the remaining articles for eligibility. The resulting differences were resolved by a reference author (C Zhang). Results provided by each investigator were compared after each stage, and any discrepancies were resolved by discussion. The following data were extracted from the original reports: authors, year, and publication; country; sample characteristics (sample size, age, and sex); functional correction training program; conventional training program; and main results (average values and standard deviations), including total FMS<sup>TM</sup> scores, number of athletes with sports injuries, and functional movement asymmetry after intervention in the experimental group and the control group.

We defined musculoskeletal injuries as sports injuries and they were considered the main outcome as to whether our intervention test reduced the risk of sports injuries. Other additional outcomes were total FMS<sup>TM</sup> score and functional movement asymmetry. Of these, bilateral muscle function asymmetries through FMS<sup>TM</sup> were defined as functional movement asymmetry of the six basic movements: active straight leg raise, shoulder mobility, trunk rotary stability, in-line lunge, hurdle step and deep squat.

### Quality evaluation

The risk of bias in non-randomized studies was assessed in a manner similar to that used for randomized trials as recommended by the Cochrane Collaboration Handbook for bias assessment of non-randomized studies ([Higgins & Green, 2011](#)). Two researchers were asked to independently evaluate the quality of articles according to 11 factors of the PEDro quality score scales ([PEDro, 2021](#), <https://www.pedro.org.au>). The Spearman rank correlation coefficient was calculated to determine inter-rater reliability of the two researchers (Spearman's  $\rho = 0.779$ ), and a strong level of agreement was found.

The systematic error of 15 articles was assessed using Cochrane's risk of bias tool (RevMan; [Cochrane, 2020](#)). The same researchers independently scored each trial for the risk of bias. In the case of disagreement, a third researcher assessed the questionable item, and agreement was sought by consensus. Each study was graded for the following domains: random sequence generation, allocation concealment, blinding of participants

**Table 1** Search history.**PubMed up to September 2020**

Search: (((((functional movement screen) OR (fms\*)) OR (functional movement screen\*)) AND (((((injury\*) OR (injury prediction)) OR (injury risk)) OR (injury prevention screening)) OR (Athletic injuries[MeSH]))) AND (((functional training) OR (corrective exercise training) OR (functional correction training))) AND ((sport\*) OR (athlet\*) OR (player))) Filters: Free full text, Full text, from 1997–2020

**Scopus up to September 2020**

Search: (((((functional movement screen) OR (fms\*)) OR (functional movement screen\*)) AND (((((injury\*) OR (injury prediction)) OR (injury risk)) OR (injury prevention screening)) OR (Athletic injuries[MeSH]))) AND (((functional training) OR (corrective exercise training) OR (functional correction training))) AND ((sport\*) OR (athlet\*) OR (player))) Filters: Free full text, Full text, from 1997–2020

**Scopus up to September 2020**

TITLE-ABS-KEY ("functional movement screen" OR ("fms\*" OR ("functional movement screen\*" AND ("injury\*" OR ("injury prediction\*" OR ("injury risk\*" OR ("injury prevention screening\*" OR ("Athletic injuries exp" AND ("functional training\*" OR ("corrective exercise training\*" OR ("functional correction training\*" AND ("sport\*" OR ("athlet\*" OR ("player\*"))

**EMbase up to September 2020**

1 "functional movement screen" OR "fms\*" OR "functional movement screen\*".af.  
 2 "injury\*" OR "injury prediction\*" OR "injury risk\*" OR "injury prevention screening\*" OR "Athletic injuries exp".af.  
 3 "functional training\*" OR "corrective exercise training\*" OR "functional correction training".af.  
 4 "sport\*" OR "athlet\*" OR "player".af.  
 5 "functional movement screen" OR "fms\*" OR "functional movement screen\*" AND "injury\*" OR "injury prediction\*" OR "injury risk\*" OR "injury prevention screening\*" OR "Athletic injuries exp" AND "functional training\*" OR "corrective exercise training\*" OR "functional correction training\*" AND "sport\*" OR "athlet\*" OR "player".af.

**Web-science up to September 2020**

# 5 #4 AND #3 AND #2 AND #1  
 # 4 TS=(sport\*) OR TS=(athlet\*) OR TS=(player)  
 # 3 TS=(functional training) OR TS=(corrective exercise training) OR TS=(functional correction training)  
 # 2 TS=(injury\*) OR TS=(injury prediction) OR TS=(injury risk) OR TS=(injury prevention screening) OR TS=(Athletic injuries[MeSH])  
 # 1 TS=(functional movement screen) OR TS=(fms\*) OR TS=(functional movement screen\*)

**EBSOhost up to September 2020**

S1 ((functional movement screen) OR (fms\*)) OR (functional movement screen\*)  
 S2 (((injury\*) OR (injury prediction)) OR (injury risk)) OR (injury prevention screening) OR (Athletic injuries[MeSH])  
 S3 (functional training) OR (corrective exercise training) OR (functional corrective training)  
 S4 (sport\*) OR (athlet\*) OR (player)  
 S5((((functional movement screen) OR (fms\*)) OR (functional movement screen\*)) AND (((((injury\*) OR (injury prediction)) OR (injury risk)) OR (injury prevention screening)) OR (Athletic injuries[MeSH]))) AND (((functional training) OR (corrective exercise training) OR (functional correction training)))) AND (((sport\*) OR (athlet\*) OR (player))

**CENTRAL up to September 2020****ProQuest- Dissertations & Theses****Proquest-Health & Medical Collection**

1 "functional movement screen" OR "fms\*" OR "functional movement screen"  
 2 "injury\*" OR "injury prediction\*" OR "injury risk\*" OR "injury prevention screening\*" OR "Athletic injuries[MeSH]"  
 3 "functional training\*" OR "corrective exercise training\*" OR "functional corrective training"  
 4 "sport\*" OR "athlet\*" OR "player"  
 5 "functional movement screen" OR "fms\*" OR "functional movement screen\*" AND "injury\*" OR "injury prediction\*" OR "injury risk\*" OR "injury prevention screening\*" OR "Athletic injuries[MeSH]" AND "functional training\*" OR "corrective exercise training\*" OR "functional correction training\*" AND "sport\*" OR "athlet\*" OR "player"

**SPORTDiscus up to September 2020**

S1 ((functional movement screen) OR (fms\*)) OR (functional movement screen\*)  
 S2 (((injury\*) OR (injury prediction)) OR (injury risk)) OR (injury prevention screening) OR (Athletic injuries[MeSH])  
 S3 (functional training) OR (corrective exercise training) OR (functional corrective training)  
 S4 (sport\*) OR (athlet\*) OR (player)  
 S5((((functional movement screen) OR (fms\*)) OR (functional movement screen\*)) AND (((((injury\*) OR (injury prediction)) OR (injury risk)) OR (injury prevention screening)) OR (Athletic injuries[MeSH]))) AND (((functional training) OR (corrective exercise training) OR (functional correction training)))) AND (((sport\*) OR (athlet\*) OR (player))

**CNKI up to September 2020**

FMS, functional training, athletes

**WANFANG up to September 2020**

FMS, functional training, athletes

and personnel, blinding of outcome assessment, incomplete outcome data, selective reporting, and other bias. Each domain was rated as having a low or high risk of bias. In the case of insufficient reported information or information with a questionable interpretation that was unclear, the risk of bias for this item was rated as unclear.

### Effect index and data aggregation method

Meta-analyses were performed with R3.3.2. The random effects method or the fixed-effects method was used depending on the heterogeneity (*DerSimonian & Kacker, 2007*). The risk ratio (RR) was used to combine the athletes' sports injuries and asymmetry of functional patterns after intervention. The mean difference (MD) was used to combine the athletes' total FMS<sup>TM</sup> scores. A 95% confidence interval (CI) was also used. The effect sizes of the results were evaluated as follows: large effect size, >0.8; medium effect size, 0.5–0.79; and small effect size, 0.00–0.49 (*Higgins & Green, 2011*). The heterogeneity of results across studies was evaluated using the I<sup>2</sup> statistic as follows: may not be important, 0–40%; moderate heterogeneity, 30–60%; substantial heterogeneity, 50–90%; and considerable heterogeneity, 75–100% (*Higgins & Thompson, 2002*). Additionally, the adopted significance level was  $P \leq 0.05$ . The publication bias was tested using Egger's linear regression (*Sterne, Egger & Smith, 2001*). Finally, a sensitivity analysis was performed by eliminating the research literature item-by-item and calculating the combined value of the remaining literature to determine if the results changed.

### Level of evidence

The quality of the evidence associated with the meta-analysis results was assessed using the Grading of Recommendations Assessment, Development and Evaluation approach (GRADE) (*Guyatt et al., 2011a; Guyatt et al., 2011b; Guyatt et al., 2011c; Guyatt et al., 2011d; GRADEproGDT, 2020*).

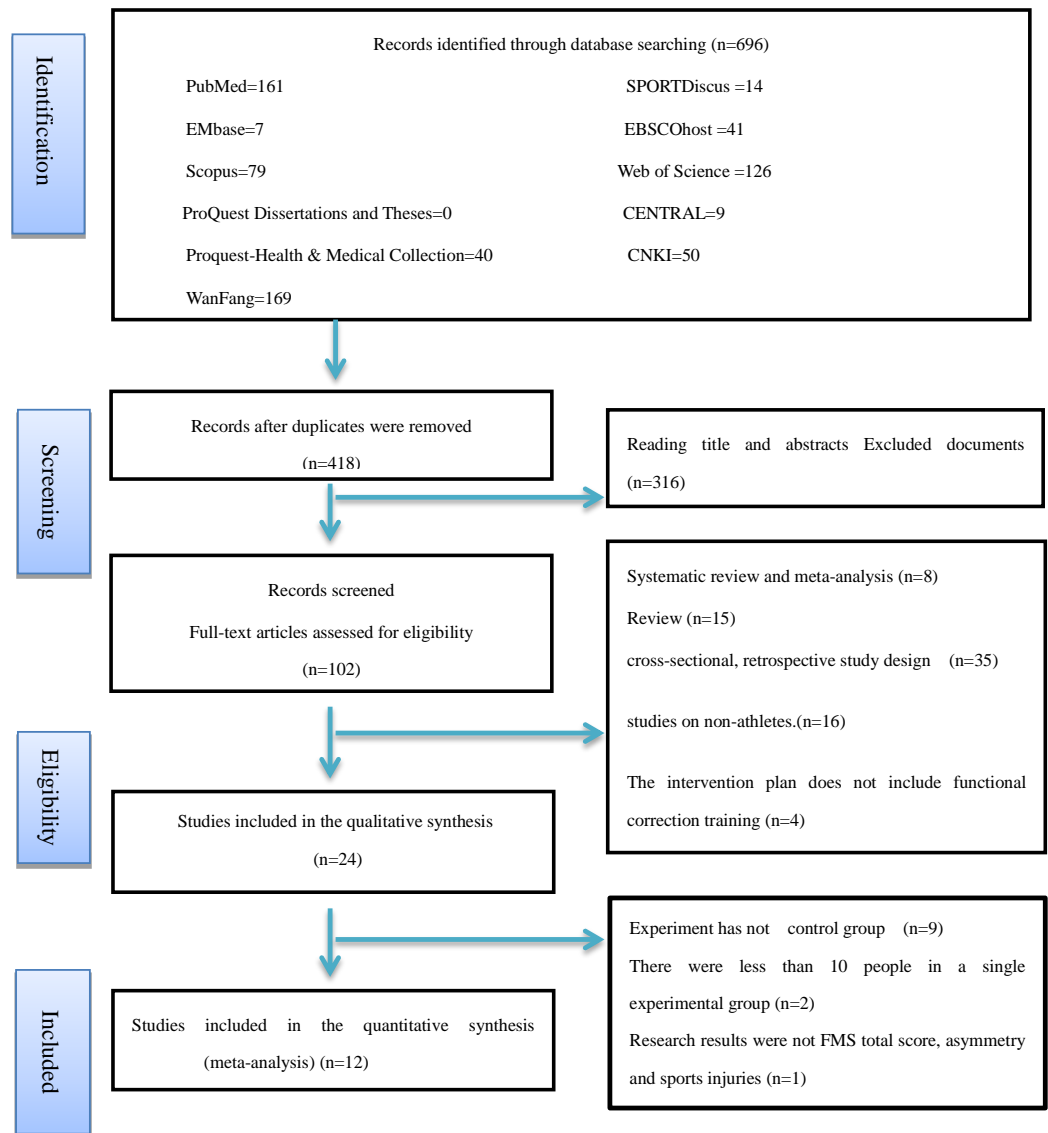
## RESULTS

### Study selection

We excluded 594 of the 696 articles identified in the initial literature search. Further screening was conducted according to the aforementioned inclusion criteria and quality assessments. Discrepancies were resolved through third-party mediation. Twenty-four articles met the inclusion criteria and included in the systematic review and 12 were selected for this meta-analysis. None of the included studies were a randomized controlled trial. [Figure 1](#) shows the systematic search strategy and selection process.

### Study characteristics

The study included a total of 538 participants; 258 were included in the experimental group and 280 in the control group. Detailed information regarding the training status is shown in [Tables 2–4](#). The age of the participants ranged from 9.6 to 26.5 years; the average ages of the experimental group and control group were  $18.56 \pm 4.17$  years and  $19.04 \pm 4.92$  years, respectively. The shortest experiment time was 6 weeks and the longest was 20 weeks. The average experiment time was  $9.33 \pm 4.32$  weeks. The shortest intervention frequency



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

Full-size DOI: [10.7717/peerj.11089/fig-1](https://doi.org/10.7717/peerj.11089/fig-1)

was twice per week, and the maximum was six times per week. The average intervention frequency was  $3.42 \pm 1.39$  times per week. Finally, the shortest duration of each session was 15 min, the longest was 60 min, and the average was  $36.36 \pm 16.75$  min. The included studies were published between January 1997 and September 2020. The sports included for research were baseball (*Song et al., 2014*), table tennis (*Kangkang & Zhuhan, 2016*), volleyball (*Xuhua & Ye, 2015*), free kicking (*Bodden, Needham & Chockalingam, 2015*), basketball (*Klusemann et al., 2012; Hui & Baoai, 2019*), soccer (*Dinc et al., 2017; Campa, Spiga & Toselli, 2019; Riela & Bertollo, 2019; Schneider et al., 2019*), tennis (*Yildiz, Pinar & Gelen, 2019*), netball (*Kovac, 2018*), and wrestling (*Bayati et al., 2019*). Three studies were not included in the meta-analysis for the following reasons: one was missing data

regarding the total FMS<sup>TM</sup> scores and sports injury but included data regarding the strength and flexibility of the athletes (Song et al., 2014), and two studies had single-group sample sizes fewer than 10 people and very low quality assessment scores (the PEDro quality scale score for physical therapy was only 4 points) (Kim et al., 2014; Armstrong et al., 2019). Furthermore, some studies used a single-group pre-test design method to perform functional correction training for athletes and found that they had a positive impact on the FMS<sup>TM</sup> scores, asymmetric events, and sports injuries (Kiesel, Plisky & Butler, 2011; Lee, Zhang & Lee, 2015; Garbenyté-Apolinskienė et al., 2018; Tejani et al., 2019; Boucher et al., 2018; Baron et al., 2019; Huebner et al., 2019; Bayrakdar, Kilin & Boz, 2020). These studies did not meet the inclusion criteria and were excluded from this report.

The standard function correction program, first classified according to the screening results, and then from basic flexibility to basic stability, and finally retraining the action mode. This procedure includes self-managed trigger point therapy; self-based and partner-based stretching exercises for the major muscle groups; and strength, stability, and flexibility exercises. It uses elastic bands, medicine balls, and foam rollers. In 12 studies, after FMS<sup>TM</sup> screening, the researchers developed a functional correction training program (including personalized correction training) as an intervention. Some of these studies used mixed interventions, including strength, stability, and jumping (including functional training) of the upper and lower limbs with bare hands or instruments and the Wrestling+ warm-up program (similar functional correction training) (Klusemann et al., 2012; Bayati et al., 2019). One study did not report whether the intervention plan was supervised by coaches or researchers (Dinc et al., 2017). Two studies (Dinc et al., 2017; Bayati et al., 2019) did not provide any FMS<sup>TM</sup> assessor qualification information or reliability tests. All experimental groups performed functional correction and conventional training or warm-up activities, and the control groups performed either conventional training or warm-up activities. Two non-randomized trials (Xuhua & Ye, 2015; Hui & Baoai, 2019) used scoring thresholds to divide the subjects into a high-risk group (total FMS<sup>TM</sup> score  $\leq 14$ ) and low-risk group (total FMS<sup>TM</sup> score  $\geq 14$ ) prior to the test and interventions (Kiesel, Plisky & Voight, 2007). Our report includes four trials.

The numbers of athletes in the experimental and control groups with sports injuries and pattern asymmetry during the intervention period were reported after FMS<sup>TM</sup> (Xuhua & Ye, 2015; Hui & Baoai, 2019; Dinc et al., 2017; Bodden, Needham & Chockalingam, 2015; Campa, Spiga & Toselli, 2019; Kangkang & Zhuhang, 2016). Dinc et al. (2017) did not report the number of athletes with sports injuries; instead, a selection of injuries causing an inability to perform athletic activities for more than three weeks was reported.

### Research bias

The risk of bias was analyzed and a high risk of bias was associated with blinding procedures (Figs. 2 and 3). Participant blinding was only described in one study (Campa, Spiga & Toselli, 2019). Four studies included random grouping; however, they did not provide any specific methods. Blinding of the outcome assessors was performed in two studies (Campa, Spiga & Toselli, 2019; Riela & Bertollo, 2019). The outcome evaluators of the other four studies were not blinded, as repeated measurement reliability, inter-rater reliability, and



**Table 2** Base line characteristics of included studies.

References	Sports	n, gender	Age mean (SD)	Experimental group Intervention	Dose	n, gender	Age mean (SD)	Control group Intervention	Dose	Outcomes Measurement item Results between groups
<i>Bodden, Neadham &amp; Chockalingam, 2015</i> United Kingdom	Martial arts	12, Males	24.31 ± 4.46	Corrective exercise program Certified coach implementation	frequency/s, <sup>?</sup> 4 times/w 8 weeks	12, Males	24.13 ± 4.46	Routine training	8 weeks	FMS <sup>TM</sup> scores :EG 15.34 ± 1.43 CG 13.24 ± 0.8 Asymmetry Number of patients Total number EG 2 13 CG 4 12
<i>Klusemann et al., 2012</i> Australia;	Basketball	13, Males and females	14.6 ± 1 15 ± 1	Strength, stability and jumping (including functional training) of upper and lower limbs with bare hands or instruments Coach supervision	frequency/s, 60 min 2 times/w 6 weeks	13, Males and females	14.6 ± 1 15 ± 1	Daily training without resistance	6 weeks	FMS <sup>TM</sup> scores :EG 16 ± 2 CG 14 ± 1 20-m sprint :EG 3.56 ± 0.21 CG 3.50 ± 0.22 Vertical jump : EG 46 ± 6 CG 44 ± 9
<i>Campa, Spiga &amp; Toselli, 2019</i> Italy	Soccer	32, Males	15.93 ± 0.4	Corrective exercise program Professional trainer guidance	2 times/w 20 weeks	30, Males	15.81 ± 0.63	Routine training	20 weeks	FMS <sup>TM</sup> scores :EG 14.59 ± 0.87 CG 13.13 ± 1.3 Asymmetry Number of patients Total number EG 19 32 CG 22 30
<i>Yildiz, Pinar &amp; Gelen, 2019</i> Turkey	Tennis	10 Males	9.6 ± 0.7	Functional training (for problems such as muscle imbalance) Coach supervision	3 times/w 8 weeks	10, males	9.6 ± 0.7	Routine training	8 weeks	FMS <sup>TM</sup> scores : EG 19.3 ± 0.8 CG 10.3 ± 1.6 10-m acceleration: EG 4.44 ± 0.20 CG 3.64 ± 0.3 Counted movement jump: EG 28.9 ± 1.90 CG 22.4 ± 3.6
<i>Riela &amp; Bertollo, 2019</i> Italy	Soccer	15, Males	23.8 ± 4.6	Warm up (functional correction training) Professional trainer guidance	3 times/w 8 weeks	15, Males	24.78 ± 4.6	Regular warm up	8 weeks	FMS <sup>TM</sup> scores EG 16.33 ± 0.79 CG 14.21 ± 1.1
<i>Bayati et al., 2019</i> Guilan	Wrestling	12 ?	16.16 ± 0.7	Wrestling+ <sup>?</sup> injury prevention program Coach supervision	3 times/w 12 weeks	12 ?	16.41 ± 0.79	Regular warm up	12 weeks	FMS <sup>TM</sup> scores : EG 17.08 ± 0.42 CG 15.47 ± 0.58

**Notes.**

(A) EG, experimental group; CG, next step. (B) Armstrong's research results only provide histograms and lack data.

**Table 3** Base line characteristics of included studies.

References	Sports	n, gender	Age mean (SD)	Experimental group Intervention	Dose	n, gender	Age mean (SD)	Control group Intervention	Dose	Outcomes Measurement item Results between groups
<a href="#">Dinc et al., 2017</a> Turkey	Soccer	24, Males	16.13 ± 0.38	Corrective exercise program	2 times/w 12weeks	43, Males	16.42 ± 0.24	Routine training	12 weeks	FMS <sup>TM</sup> scores: EG 16.79 ± 1.61 CG 15.33 ± 1.19 Sports injury (injury stop >3 weeks) Number of patients Total number EG 6 24 CG 31 43
<a href="#">Song et al., 2014</a> Korea	Baseball	31, Males	17 ± 1.06	FMS training program	3 times/w 16 weeks	31, Males	16.62 ± 0.94	Routine training	16 weeks	Strength (Back Muscle Strength): EG 144.93 ± 20.67 CG 137.74 ± 20.5 Strength squat (1RM): EG 161.08 ± 35.06 CG 129.68 ± 26.82
<a href="#">Schneider et al., 2019</a> Germany	Soccer	23, Males	11.87 ± 0.87	Individualized multimodal training intervention on warm up Coach supervision	2 times/w 12 weeks	22, Males	10.84 ± 1.18	Regular soccer practice	12 weeks	FMS <sup>TM</sup> scores : EG 14.30 ± 1.43 CG 13.16 ± 2.44
<a href="#">Kangkang &amp; Zhuang, 2016</a> China	Table tennis	20, Males and females	?	Pre-class function plan × 4 + personalized correction training × 1 (supervised by author and fitness coach)	5 times/w 6 weeks	20, Males and females	?	Routine training	6 weeks	FMS <sup>TM</sup> scores: EG 15.15 ± 1.27 CG 13.15 ± 1.35 Asymmetry, Number of patients Total number EG 1 20 CG 9 20
<a href="#">Hui &amp; Baoai, 2019</a> China	Basketball	High-risk 8, males Low risk 8, males	21.75 ± 1.28 21.50 ± 0.76	Dynamic stretching and personalized correction training	6 times/w 8 weeks	High-risk 8, males Low risk 8, males	21.78 ± 1.48 21.71 ± 1.49	Routine training	8 weeks	FMS <sup>TM</sup> scores (High-risk group): EG 14.00 ± 1.31 CG 12.44 ± 1.01 (Low risk group): EG 16.25 ± 1.75 CG 15.42 ± 0.78 High-risk Number of patients Total number EG 3 8 CG 5 8 Low-risk EG 1 8 CG 2 8
<a href="#">Kovac, 2018</a> South Africa	Netball	10, Females	20 ± 1.5	Corrective exercise program instructed and supervised by the researcher.	3 times/ 6 weeks	19, Females	19.8 ± 1.5	Routine training	6 weeks	FMS <sup>TM</sup> scores : EG 14.55 ± 1.6 CG 13.55 ± 2.4 Drop vertical jump: EG 2.155 ± 0.95 CG 1.9 ± 0.86

**Notes.**

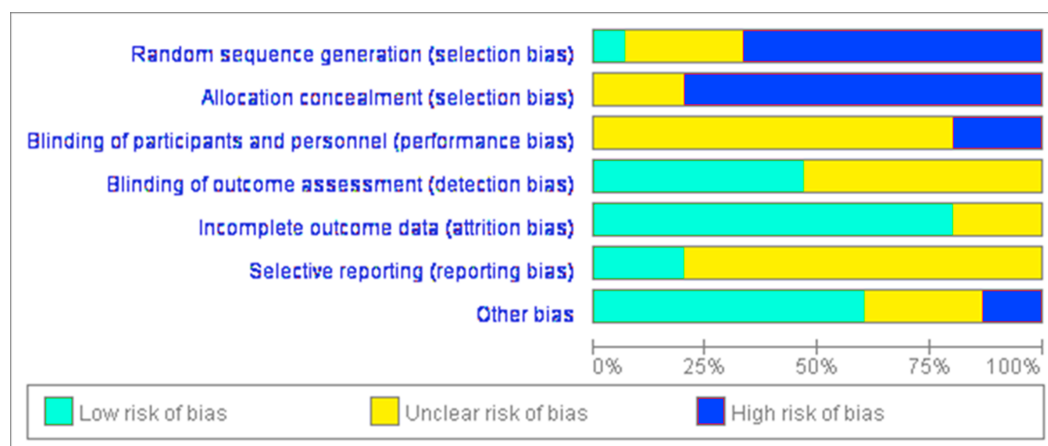
(A) EG, experimental group; CG, next step. (B) Armstrong's research results only provide histograms and lack data.

**Table 4** Base line characteristics of included studies.

References	Sports	n, gender	Age mean (SD)	Experimental group Intervention	Dose	n, gender	Age mean (SD)	Control group Intervention	Dose	Outcomes Measurement item Results between groups
<i>Armstrong et al., 2019</i> USA	Basketball	6, Males	20.04 ± 1.4	Corrective exercise program	4 times/w 4 weeks	7, Males	20.04 ± 1.4	Pre-practice dynamic warm-up	4 times/w 4 weeks	Incomplete data
<i>Xuhua &amp; Ye, 2015</i> China	Volleyball	High-risk 15, females Low risk 13, females	20.92 ± 3.26 21.47 ± 3.16	Rehabilitation physical training (correction training)	6 times/ 6 weeks	High-risk 14, females Low risk 12, females	21.56 ± 3.58 21.20 ± 3.32	Routine training	6 weeks	FMS <sup>TM</sup> scores (High-risk group) EG 14.80 ± 1.21 CG 12.21 ± 1.05 (Low risk group): EG 17.23 ± 2.05 CG 15.33 ± 1.30 High-risk Number of patients Total number EG 3 15 CG 8 14 Low-risk EG 1 13 CG 2 12 Squat (High-risk) :EG 115 ± 12.11 CG 112 ± 18.78 (low-risk) :EG 118 ± 6.15 CG 115 ± 18.7
<i>Kim et al., 2014</i> Korea	Javelin	4, Males 2, Females	Males 22 ± 1.15 Females 22 ± 1.41	Weight, Javelin specific, core, FMS training Performed by researchers	?/8weeks	2, Males 2, females	Males 26 ± 4.24 Females 26.5 ± 1.41	Routine training	8 weeks	Difference CG-EG FMS score (points): CG 0.30 ± 1.07 EG -1.03 ± 1.37 throwing performances: CG 9.6 ± 1.10 EG 5.8 ± 2.64

**Notes.**

(A) EG, experimental group; CG, next step. (B) Amstrong's research results only provide histograms and lack data.



**Figure 2** Assessment of bias risk for included studies (risk of bias graph).

Full-size DOI: [10.7717/peerj.11089/fig-2](https://doi.org/10.7717/peerj.11089/fig-2)

high-precision professional electronic instruments were used to record data (Song *et al.*, 2014; Kim *et al.*, 2014; Klusemann *et al.*, 2012; Yildiz, Pinar & Gelen, 2019). The selection bias ratings remained unclear due to either insufficient or unclear information. A low risk of bias attributable to the blinding of outcome assessment, reporting, and other bias was observed throughout the studies.

We used the PEDro physical therapy quality scale to evaluate article quality and the primary difference between randomized and non-randomized trials (Table 5). Some studies included athletes who were randomly divided into groups in a blinded manner (Bodden, Needham & Chockalingam, 2015; Kovac, 2018; Campa, Spiga & Toselli, 2019; Riela & Bertollo, 2019). Some studies did not conduct random grouping of athletes, therefore, there was no score for this item. In some studies, the coaches, raters, and participants were not blinded, therefore, scores were not obtained for questions related to those items. Among the 15 studies, the average score was 5.5 with an overall quality of the literature of average.

## Result integration

We verified the effects of functional correction training on sports injuries of athletes based on the sports injury RR, total FMS<sup>TM</sup> score, and functional pattern asymmetry. There was no heterogeneity in the hazard ratio of the influence of functional correction training on athletes' sports injuries (RR, 0.39; 95% CI [0.24–0.65];  $Z = -3.57$ ;  $P = 0.0003$ ;  $I^2 = 0.0\%$ ) (Fig. 4); therefore, the fixed-effects model was used to combine the effect sizes. The incidence of sports injuries in the experimental group was lower than that of the control group, and the injury risk in the experimental group decreased by 60%. The effect sizes were combined to measure the influence of functional correction training on the total FMS<sup>TM</sup> scores (MD, 1.72; 95% CI [1.50–1.93];  $Z = 15.53$ ;  $P < 0.0001$ ;  $I^2 = 2.6\%$ ) (Fig. 5). As there was low heterogeneity, the fixed-effects model was used to combine the effect sizes. All results had large effect sizes with significant differences as compared

**Table 5** Quality assessment results of included studies using the PEDro quality scales. The purpose of the PEDro scale is to help the users of the PEDro database rapidly identify which of the known or suspected randomized clinical trials (i.e., RCTs or CCTs) archived in the database are likely to be internally valid (criteria 2–9), and could have sufficient statistical information to make their results interpretable (criteria 10–11). An additional criterion (criterion 1) that relates to the external validity (or “generalizability” or “applicability” of the trial) has been retained so that the Delphi list is complete, but this criterion will not be used to calculate the PEDro score reported on the PEDro web site.

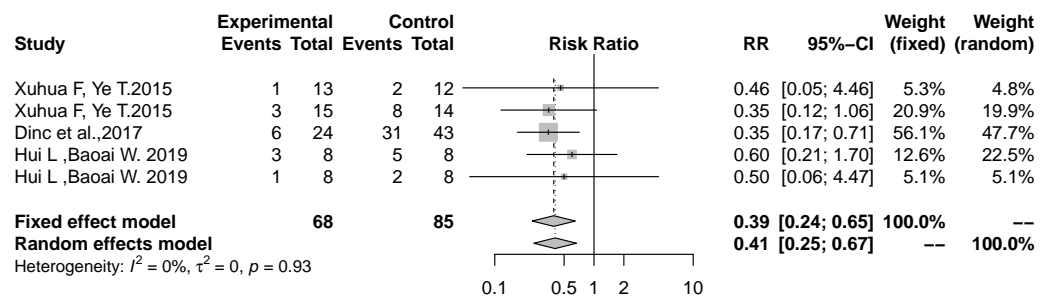
Author	1	2	3	4	5	6	7	8	9	10	11	scale	PEDro Scoring item
<i>Dinc et al. (2017)</i>	Y	N	N	Y	N	N	N	Y	Y	Y	Y	5	1. eligibility criteria were specified
<i>Bodden, Needham &amp; Chockalingam (2015)</i>	Y	N	N	Y	N	N	?	Y	Y	Y	Y	5	2. subjects were randomly allocated to groups
<i>Campa, Spiga &amp; Toselli (2019)</i>	Y	Y	N	Y	N	N	Y	Y	Y	Y	Y	7	3. allocation was concealed
<i>Kovac (2018)</i>	Y	Y	N	Y	N	N	N	Y	Y	Y	Y	6	4. the groups were similar at baseline regarding the most important prognostic indicators
<i>Riela &amp; Bertollo (2019)</i>	Y	Y	?	Y	N	N	Y	Y	Y	Y	Y	7	5. there was blinding of all subjects
<i>Song et al. (2014)</i>	Y	N	N	Y	N	N	N	Y	Y	Y	Y	5	6. there was blinding of all therapists who administered the therapy
<i>Schneider et al. (2019)</i>	Y	N	N	Y	N	N	?	Y	Y	Y	Y	5	7. there was blinding of all assessors who measured at least one key outcome
<i>Xuhua &amp; Ye (2015)</i>	Y	N	N	Y	N	N	?	Y	Y	Y	Y	5	8. measures of at least one key outcome were obtained from more than 85% of the subjects initially allocated to groups
<i>Kangkang &amp; Zhuhang (2016)</i>	Y	N	N	Y	N	N	N	Y	Y	Y	Y	5	9. all subjects for whom outcome measures were available received the treatment or control condition as allocated or, where this was not the case, data for at least one key outcome was a analyses by “intention to treat
<i>Klusemann et al. (2012)</i>	Y	Y	N	Y	N	N	?	N	Y	Y	Y	5	10. the results of between-group statistical comparisons are reported for at least one key outcome
<i>Bayati et al. (2019)</i>	Y	N	N	Y	N	N	?	Y	Y	Y	Y	5	11. the study provides both point measures and measures of variability for at least one key outcome
<i>Yildiz, Pinar &amp; Gelen (2019)</i>	Y	N	?	Y	N	N	?	Y	Y	Y	Y	5	
<i>Hui &amp; Baoai (2019)</i>	Y	N	N	Y	N	N	N	Y	Y	Y	Y	5	
<i>Kim et al. (2014)</i>	Y	N	N	?	N	N	N	Y	Y	Y	Y	4	
<i>Armstrong et al. (2019)</i>	Y	Y	N	?	N	N	N	Y	Y	N	Y	4	

	Random sequence generation (selection bias)	Allocation concealment (selection bias)	Blinding of participants and personnel (performance bias)	Blinding of outcome assessment (detection bias)	Incomplete outcome data (attrition bias)	Selective reporting (reporting bias)	Other bias
Armstrong, et al.,2019	?	-	-	?	+	?	-
Bayati et al.,2019	-	-	-	?	+	?	?
Bodden et al.,2015	-	-	?	?	+	?	?
Campa et al., 2018	+	?	?	+	+	?	+
Dinc et al.,2017	-	-	?	?	+	?	?
Hui L et al.,2019	-	-	?	?	+	?	?
Kangkang Z et al.,2016	-	-	?	?	+	+	+
Kim H et al.,2014	-	-	?	+	+	?	-
Klusemann et al.,2012	?	-	?	+	?	?	+
Kovac D et al.,2018	?	?	?	+	+	+	+
Riela LA et al.2019	?	?	?	+	+	?	+
Schneider et al.2019	-	-	-	?	+	?	+
Song HS et al.,2014	-	-	?	+	?	?	+
Xuhua F et al.,2015	-	-	?	?	+	+	+
Yildiz S et al.,2018	-	-	?	+	?	?	+

**Figure 3** Assessment of bias risk for included studies (risk of bias summary).

Full-size  DOI: 10.7717/peerj.11089/fig-3

with those of the control group and the functional patterns of athletes were optimized according to Cohen's interpretation standard.



**Figure 4** Forest plot of athletes' sports injuries.

Full-size DOI: [10.7717/peerj.11089/fig-4](https://doi.org/10.7717/peerj.11089/fig-4)

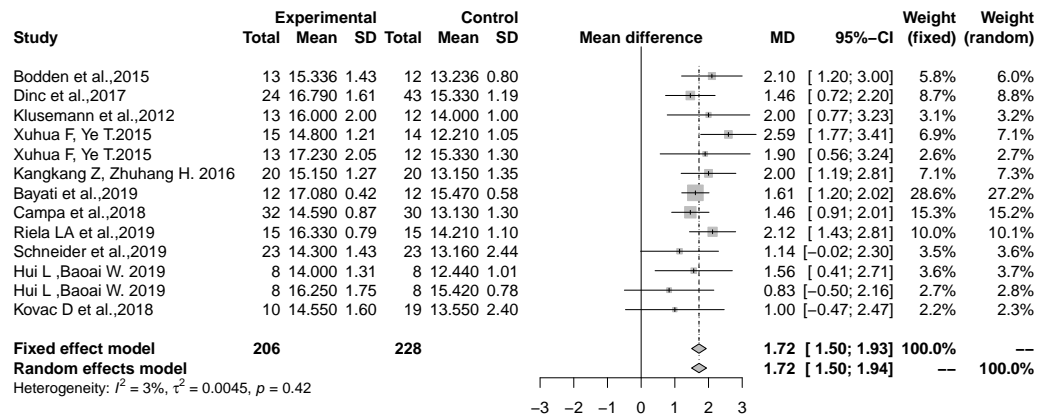
The hazard ratio of the influence of functional correction training on the pattern of asymmetry of athletes showed large heterogeneity (RR, 0.45; 95% CI [0.13–1.50];  $Z = -1.3$ ;  $P = 0.19$ ;  $I^2 = 65.2\%$ ) (Fig. 6). Therefore, the random effects model was used to combine the effects and no significant difference was observed when compared with the control group. One study considered that the age of the athlete may explain heterogeneity in the prospective prediction of injury risk by FMS<sup>TM</sup> (Moore et al., 2019) and reported that asymmetry determined by FMS<sup>TM</sup> is more useful for evaluating the injury risk of senior athletes. Another study included soccer players aged  $15.89 \pm 0.53$  years (Campa, Spiga & Toselli, 2019), and two studies included adult-free combat athletes (Bodden, Needham & Chockalingam, 2015) and a national table tennis team (Kangkang & Zhuhan, 2016). The incidence rates of model asymmetry for adults were lower than that of the younger soccer players. Therefore, our research results are in line with their results. However, a subgroup analysis to determine the source of heterogeneity was impossible as only three cases were included in the sample. Additionally, the total FMS<sup>TM</sup> score was not necessarily improved, and a score of 21 was not the goal. Instead, the focus was the identification of asymmetries (Cook et al., 2014b). Further studies are needed to explore the influence of functional correction training on the model asymmetry of athletes.

### Publication bias and sensitivity analysis

The publication bias associated with the influence of functional correction training on athletes' total FMS<sup>TM</sup> scores was not significant (Egger's linear regression,  $t = -0.096$ ;  $df = 11$ ;  $P = 0.92 > 0.05$ ) (Fig. S1). The sensitivity analysis indicated that the hazard ratios for athletic injuries and total FMS<sup>TM</sup> scores after functional correction training were consistent with those without stratification, with very robust results (Figs. S2–S5). The results of the sensitivity analysis of athletes' asymmetry were slightly different than those before stratification and were not sufficiently stable.

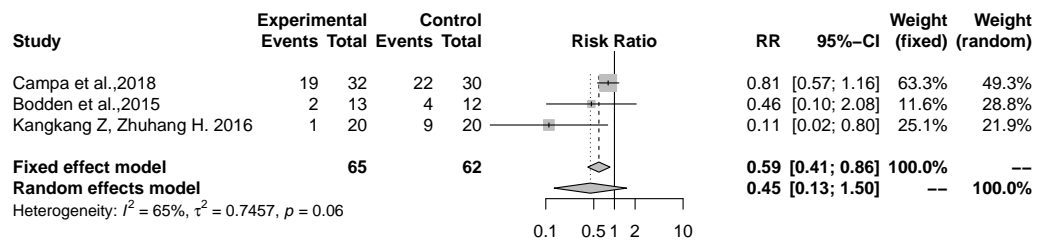
### Level of evidence

The included studies were non-randomized controlled trials, and the level of evidence using GRADE instruments was low (Tables 6 and 7). Altogether, these studies provided a very low level of evidence of the injury risk ratio and asymmetry model of the athlete. The other prevalent outcome showed a moderate level of evidence of athletes' total FMS<sup>TM</sup> scores.



**Figure 5** Forest plot of the effect size of the athletes' total FMS™ score.

Full-size DOI: 10.7717/peerj.11089/fig-5



**Figure 6** Forest plot of the athletes' asymmetry functional patterns.

Full-size DOI: 10.7717/peerj.11089/fig-6

## DISCUSSION

Our review explored the influence of functional correction training based on FMS™ on the sports injury risk of athletes. The results showed that the injury risk of the experimental group was reduced by 60% after functional correction training, the effect on the total scores of FMS™ was large, and significantly different from that of the control group. Results of the sensitivity analysis were very robust, and the possibility of publication bias influencing the athletes' total FMS™ scores was very low.

A previous review had no consistent conclusion regarding the total FMS™ score and the risk of subsequent injuries for athletes and mixed populations (Dorrel et al., 2015; Moran et al., 2017; Bonazza et al., 2017; Santos Bunn, Rodrigues & Da Silva, 2019; Moore et al., 2019). This review summarized the functional correction training after FMS™ with the RR for athletes' injuries, total FMS™ scores, and asymmetry. We provided standardized evidence and clarified that functional correction training after FMS™ can effectively enhance the functional patterns of athletes.

The positive effects of functional correction training after FMS™ on sports injuries may be due to several factors. First, using FMS™, athletes may discover weaknesses and perform corrections by focusing on their trunk pillar strength, joint flexibility, and joint stability to ensure effectiveness. Second, intervention training includes myofascial therapy,



**Table 6** Summary of findings.

Outcomes	Anticipated absolute effects* (95% CI)		Relative effect (95% CI)	No. of participants (studies)	Setting: sports injury Comparison: conventional training	Certainty of the evidence (GRADE)	Comments
	Risk with conventional training	Risk with functional correction training					
<b>Study population</b>							
sports injury risk of athletes (injury risk) follow up: mean 6–12 weeks	565 per 1,000	<b>222 per 1,000</b> (135 to 366)	<b>RR</b> <b>0.3932</b> (0.2386 to 0.6482)	153 (5 observational studies)		⊕○○○ VERY LOW <sup>a,b,c,d</sup>	The injury risk ratio of athletes after functional correction training was 0.3932 RR (95% CI, 0.2386–0.6482; Z = -3.57; P = 0.0003; I <sup>2</sup> = 0.0%). It was found that functional correction training could reduce the injury risk by 60% in the experimental groups as compared with the control groups.
	0 per 1,000	<b>0 per 1,000</b> (0 to 0)					
<b>Study population</b>							
New outcome (model asymmetry of athletes) assessed with: Functional movement screen follow up: mean 6–20 weeks	565 per 1,000	<b>252 per 1,000</b> (75 to 849)	<b>RR</b> <b>0.4460</b> (0.1323 to 1.5033)	127 (3 observational studies)		⊕○○○ VERY LOW <sup>a,d,e,f</sup>	The hazard ratio of the influence of functional correction training on the pattern of asymmetry of athletes showed large heterogeneity (RR, 0.446; 95% CI, 0.1323–1.5033; Z = -1.3; P = 0.1928; I <sup>2</sup> = 65.2%), and no significant difference was observed when compared with the control group.
	<b>Moderate</b> 0 per 1,000	<b>0 per 1,000</b> (0 to 0)					
Total FMS score of athlete assessed with: Functional Movement Screen Scale from: 0 to 21 follow up: range 6 weeks to 20 weeks	The mean total FMS score of athlete was <b>13.89 MD</b>	<b>MD 1.7165 MD higher</b> (1.4999 higher to 1.9333 higher)	–	434 (13 observational studies)		⊕⊕⊕○ MODERATE <sup>g,h</sup>	The influence of functional correction training on the athletes' total FMS <sup>TM</sup> scores was 1.7165 MD (95% CI, 1.4999–1.9330; Z = 15.53; P < 0.0001; I <sup>2</sup> = 2.6%), indicating effective improvement of athletes' functional patterns.

\*The risk in the intervention group (and its 95% confidence interval) is based on the assumed risk in the comparison group and the relative effect of the intervention (and its 95% CI).  
CI: Confidence interval; RR: Risk ratio; MD: Mean difference

**GRADE Working Group grades of evidence**  
**High certainty:** We are very confident that the true effect lies close to that of the estimate of the effect  
**Moderate certainty:** We are moderately confident in the effect estimate: The true effect is likely to be close to the estimate of the effect, but there is a possibility that it is substantially different  
**Low certainty:** Our confidence in the effect estimate is limited: The true effect may be substantially different from the estimate of the effect  
**Very low certainty:** We have very little confidence in the effect estimate: The true effect is likely to be substantially different from the estimate of effect

**Notes.****Explanations**<sup>a</sup>All included studies were not randomized.<sup>b</sup>Researchers may have different definition of sports injury/injuries.<sup>c</sup>Sample size was small. According to the graph in the GRADE guidelines: 6. Rating the quality of evidence—imprecision, set RRR=30%, both injury risk ratio and asymmetry movement patterns of athletes that event rate of the control group was 0.56, at least 500–1,000 samples were required.<sup>d</sup>The publication bias test was not completed because the sample sizes used to determine the sports injury risk and model asymmetry were fewer than 10.<sup>e</sup>Only one study implemented randomization.<sup>f</sup>The hazard ratio of the influence of functional correction training on patterns of athletes' asymmetry had large heterogeneity (RR, 0.446; 95% CI [0.1323–1.5033]; z = -1.3; P = 0.1928; I<sup>2</sup> = 65.2%).<sup>g</sup>66% of subjects were not randomly allocated to a group.<sup>h</sup>The influence of functional correction training on the athletes' total FMS<sup>TM</sup> scores was 1.7165 (95% CI [1.4999–1.9330]; Z = 15.53; P < 0.0001; I<sup>2</sup> = 2.6%), Confidence interval exceeded 1.

**Table 7 GRADE evidence profile.**

No of studies	Study design	Risk of bias	Certainty assessment			Other considerations	No. of patients		Relative (95% CI)	Effect Absolute (95% CI)	Certainty	Importance
			Inconsistency	Indirectness	Imprecision		functional correction training	conventional training				
sports injury risk of athletes (follow up: mean 6-12 weeks)												
5	observational studies	serious <sup>a,b</sup>	not serious	not serious	serious <sup>c</sup>	publication bias strongly suspected strong association all plausible residual confounding would reduce the demonstrated effect <sup>d</sup>	14/68 (20.6%)	48/85 (56.5%) 0.0%	<b>RR 0.3932</b> (0.2386 to 0.6482)	<b>343 fewer per 1,000</b> (from 430 fewer to 199 fewer) <b>0 fewer per 1,000</b> (from 0 fewer to 0 fewer)	⊕○○○ VERY LOW	CRITICAL
New outcome (follow up: mean 6-20 weeks; assessed with: Functional movement screen)												
3	observational studies	very serious <sup>e</sup>	serious <sup>f</sup>	not serious	serious <sup>e</sup>	publication bias strongly suspected all plausible residual confounding would reduce the demonstrated effect <sup>d</sup>	22/65 (33.8%)	35/62 (56.5%) 0.0%	<b>RR 0.4460</b> (0.1323 to 1.5033)	<b>313 fewer per 1,000</b> (from 490 fewer to 284 more) <b>0 fewer per 1,000</b> (from 0 fewer to 0 fewer)	⊕○○○ VERY LOW	CRITICAL
Total FMS score of athlete (follow up: range 6 weeks to 20 weeks; assessed with: Functional Movement Screen; Scale from: 0 to 21)												
13	observational studies	serious <sup>g</sup>	not serious	not serious	serious <sup>h</sup>	very strong association all plausible residual confounding would reduce the demonstrated effect	206	228	–	<b>MD 1.7165 MD higher</b> (1.4999 higher to 1.9333 higher)	⊕⊕⊕○ MODERATE	IMPORTANT

**Notes.**

CI, Confidence interval; RR, Risk ratio; MD, Mean difference.

Explanations

<sup>a</sup>All included studies were not randomized.

<sup>b</sup>Researchers may have different definition of sports injury/injuries.

<sup>c</sup>Sample size was small. According to the graph in the GRADE guidelines: 6. Rating the quality of evidence—imprecision, set RRR=30%, both injury risk ratio and asymmetry movement patterns of athletes that event rate of the control group was 0.56, at least 500-1,000 samples were required.

<sup>d</sup>The publication bias test was not completed because the sample sizes used to determine the sports injury risk and model asymmetry were fewer than 10.

<sup>e</sup>Only one study implemented randomization.

<sup>f</sup>The hazard ratio of the influence of functional correction training on patterns of athletes' asymmetry had large heterogeneity (RR, 0.446; 95% CI [0.1323–1.5033];  $z = -1.3$ ;  $P = 0.1928$ ;  $I^2 = 65.2\%$ ).

<sup>g</sup>66% of subjects were not randomly allocated to a group.

<sup>h</sup>The influence of functional correction training on the athletes' total FMS<sup>TM</sup> scores was 1.7165 (95% CI [1.4999–1.9330];  $Z = 15.53$ ;  $P < 0.0001$ ;  $I^2 = 2.6\%$ ), Confidence interval exceeded 1.

dynamic stretching, core stability training, resistance strength training, and combined neuromuscular training. This may improve the imbalance of the muscle groups and the energy transmission effect of the body's kinetic chain (Cook, 2011; Cook et al., 2014a; Cook et al., 2014b). Third, functional correction training includes core stability exercises. Enhancing core stability through exercise is common to musculoskeletal injury prevention programs. Core stabilization relies on instantaneous integration among passive, active, and neural control subsystems. Neuromuscular control is critical in coordinating this complex system for dynamic stabilization (HuxelBliven & Anderson, 2013). Fourth, these interventions aim to stimulate the activation of the muscles of the natural nucleus to improve the relationship between the main muscular function and the fundamental movement (Cook & Fields, 1997; Kiesel, Plisky & Butler, 2011). Additionally, an 8-week program with the foam roll has been reported as effective in increasing range of motion in the stand and reach test (Junker & Stöggl, 2019). The theory that functional correction training programs should consist of functional movements related with core stability and shoulder and hamstring flexibility improvement is supported by a study that reported improved strength and flexibility in 62 elite male high school baseball players after participating in a correction training program (Song et al., 2014). Therefore, functional correction training may effectively reduce the risk of sports injury.

This was the first study to evaluate the impact of functional correction training after FMS™ on athletes' sports injury risk by including non-randomized controlled trials. Grade B evidence indicates that functional correction training based on FMS™ could improve athletes' functional patterns and Grade D evidence indicates that functional correction training may reduce the risk of sports injuries in athletes. The evidence found in this review is reliable and significant for evidence-based clinical practice.

### Strengths and limitations

Our review had some limitations. First, some relevant literature may have been overlooked despite a search of ten online databases. Second, the methodological limitations of this review include the small sample sizes evaluated within the retained studies, no differentiation among sports, allocation concealment, and evaluator blindness, which may have resulted in an overestimation of the effects of the intervention. Third, because the sample sizes used to determine the sports injury risk and model asymmetry were fewer than 10, the publication bias test was not completed. Fourth, some studies did not define whether the coaches supervised or corrected the training quality or whether joint intervention was used. Fifth, FMS™ was limited by its inability to test a single construct from a composite set of scores. The total FMS™ score of our study was only used to show whether the functional model could be improved. Thus, our findings should be carefully interpreted.

## CONCLUSIONS

Grade B evidence indicates that functional correction training based on FMS™ could improve the functional patterns of athletes, and Grade D evidence indicates that it may reduce the risk of sports injury. The true effect is likely to be different from the estimate

of effect. Therefore, further studies are needed to explore the influence of functional correction training on the injury risks of athletes.

## ACKNOWLEDGEMENTS

We would like to thank Professors Li Shuping, Huang Zhijian, and Yu Lianghua for their guidance and suggestions in the process of writing the paper. We would also like to thank Editage for their editing work for this article.

## ADDITIONAL INFORMATION AND DECLARATIONS

### Funding

This study was financed by grants from the Teaching Research Project of Hubei University (No.201978), and the Open Project of the Key Laboratory of the State Sports General Administration (No. 2017C17). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

### Grant Disclosures

The following grant information was disclosed by the authors:

Teaching Research Project of Hubei University: 201978.

Open Project of the Key Laboratory of the State Sports General Administration: 2017C17.

### Competing Interests

The authors declare there are no competing interests.

### Author Contributions

- Junxia Chen conceived and designed the experiments, performed the experiments, analyzed the data, prepared figures and/or tables, authored or reviewed drafts of the paper, and approved the final draft.
- Chunhe Zhang conceived and designed the experiments, performed the experiments, analyzed the data, authored or reviewed drafts of the paper, and approved the final draft.
- Sheng Chen and Yuhua Zhao performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.
- performed the experiments, analyzed the data, prepared figures and/or tables, and approved the final draft.

### Data Availability

The following information was supplied regarding data availability:

The raw data collected in this systematic review and meta-analysis are available in the [Supplementary Files](#).

### Supplemental Information

Supplemental information for this article can be found online at <http://dx.doi.org/10.7717/peerj.11089#supplemental-information>.

## REFERENCES

- Armstrong K, McDevitt B, Baumann K, O'Reilly L, Ramos Y, Reyes C. 2019.** Movement capability changes in collegiate basketball players following a corrective exercise programme. Available at <https://digitalcommons.linfield.edu/cgi/viewcontent.cgi?article=1431&context=symposium>.
- Baron J, Bieniec A, Swinarew AS, Gabryś T, Stanula A. 2019.** Effect of 12-week functional training intervention on the speed of young footballers. *International Journal of Environmental Research and Public Health* 17:160 DOI 10.3390/ijerph17010160.
- Basar MJ. 2017.** The influence of corrective exercises on functional movement screen and physical fitness performance in Army ROTC Cadets. Theses and dissertations, Available at <https://ir.library.illinoisstate.edu/etd/652>.
- Bayati R, Majelan ASHamsi, Mirzaei B, Barbas I. 2019.** The effect of 12 weeks of wrestling+ warm-up program on functional movement screen scores in cadet wrestlers. *Annals of Applied Sport Science* 7:39–47 DOI 10.29252/aassjournal.7.1.39.
- Bayrakdar A, Kılın H, Boz P. 2020.** The effect of functional movement screen and lower extremity training on hamstring/quadriceps ratio in football players. *Physical Education of Students* 2:80–85 DOI 10.15561/20755279.2020.0202.
- Bodden JG, Needham RA, Chockalingam N. 2015.** The effect of an intervention program on functional movement screen test scores in mixed martial arts athletes. *The Journal of Strength & Conditioning Research* 29:219–225 DOI 10.1519/JSC.0b013e3182a480bf.
- Bonazza NA, Smuin D, Onks CA, Silvis ML, Dhawan A. 2017.** Reliability, validity, and injury predictive value of the functional movement screen: a systematic review and meta-analysis. *The American Journal of Sports Medicine* 45:725–732 DOI 10.1177/0363546516641937.
- Boucher BK, Rich AJ, Gobert D, Gardner B, Metzner P, King C, Buse M. 2018.** The effectiveness of a functional movement assessment and 4-week exercise training program for female high school athletes. *Journal of Strength and Conditioning Research* 35:102–110 DOI 10.1519/JSC.0000000000002549.
- Campa F, Spiga F, Toselli S. 2019.** The effect of a 20-week corrective exercise program on functional movement patterns in youth elite male soccer players. *Journal of Sport Rehabilitation* 28:746–751 DOI 10.1123/jsr.2018-0039.
- Chao WC, Shih JC, Chen KC, Wu CL, Wu NY, Lo CS. 2018.** The effect of functional movement training after anterior cruciate ligament reconstruction: a randomized controlled trial. *Journal of Sports Rehabilitation* 27:541–545 DOI 10.1123/jsr.2017-0022.
- Cochrane . 2020.** RevMan computer program, version 5.4. The Cochrane Collaboration. Available at <https://www.cochrane.org/zh-hans/join-cochrane>.
- Cook G. 2011.** Movement: functional movement systems. In: *Screening-assessment-corrective strategies*. Bucuresti: Lotus Publishing.
- Cook G, Burton L, Hoogenboom B. 2006a.** Pre-participation screening: the use of fundamental movements as an assessment of function - part 1. *North American Journal of Sports Physical Therapy* 1:62–72.

- Cook G, Burton L, Hoogenboom B. 2006b.** Pre-participation screening: the use of fundamental movements as an assessment of function - part 2. *North American Journal of Sports Physical Therapy* 1:132–139.
- Cook G, Burton L, Hoogenboom BJ, Voight M. 2014a.** Functional movement screening: the use of fundamental movements as an assessment of function-part 1. *International Journal of Sports Physical Therapy* 9:396–409.
- Cook G, Burton L, Hoogenboom BJ, Voight M. 2014b.** Functional movement screening: the use of fundamental movements as an assessment of function-part 2. *International Journal of Sports Physical Therapy* 9:549–563.
- Cook G, Fields K. 1997.** Functional training for the torso. *Strength and Conditioning* 19(2):129–132.
- Cornell DJ. 2016.** Influence of a corrective exercise training program on measures of functional movement among active-duty firefighters. PhD dissertation, University of Wisconsin, Milwaukee, USA. Available at <https://dc.uwm.edu/cgi/viewcontent.cgi?article=2134&context=etd&httpsredir=1&referer=>.
- DerSimonian R, Kacker R. 2007.** Random-effects model for meta-analysis of clinical trials: an update. *Contemporary Clinical Trials* 28:105–114 DOI 10.1016/j.cct.2006.04.004.
- Dinc E, Kilinc BE, Bulat M, Erten YT, Bayraktar B. 2017.** Effects of special exercise programs on functional movement screen scores and injury prevention in pre-professional young football players. *Journal of Exercise Rehabilitation* 13:535–540 DOI 10.12965/jer.1735068.534.
- Dorrel BS, Long T, Shaffer S, Myer GD. 2015.** Evaluation of the functional movement screen as an injury prediction tool among active adult populations: a systematic review and meta-analysis. *Sports Health* 7:532–537 DOI 10.1177/1941738115607445.
- Frost DM, Beach TAC, Callaghan JP, McGill SM. 2012.** Using the functional movement screen to evaluate the effectiveness of training. *Journal of Strength and Conditioning Research* 26:1620 DOI 10.1519/JSC.0b013e318234ec59.
- Frost DM, Beach TAC, Callaghan JP, McGill SM. 2015a.** Exercise-based performance enhancement and injury prevention for firefighters: contrasting the fitness- and movement-related adaptations to two training methodologies. *Journal of Strength and Conditioning Research* 29(9):2441–2459 DOI 10.1519/JSC.0000000000000923.
- Frost DM, Beach TAC, Callaghan JP, McGill SM. 2015b.** FMSTM scores change with performers' knowledge of the grading criteria- are whole-body movement screens capturing dysfunction? *Journal of Strength and Conditioning Research* 29:3037–3044 DOI 10.1097/JSC.0000000000000211.
- Frost DM, Beach TAC, Campbell TL, Callaghan JP, McGill SM. 2015c.** An appraisal of the Functional Movement Screen grading criteria -Is the composite score sensitive to risky movement behavior? *Physical Therapy in Sport* 16:324–330 DOI 10.1016/j.ptsp.2015.02.001.
- Frost DM, Beach TA, Campbell TL, Callaghan JP, McGill SM. 2017.** Can the Functional Movement Screen™ be used to capture changes in spine and knee motion control following 12 weeks of training? *Physical Therapy in Sports* 23:50–57 DOI 10.1016/j.ptsp.2016.06.003.

- Garbenytė-Apolinskienė T, Šiupšinskas L, Salatkaitė S, Gudas R, Radvila R. 2018. The effect of integrated training program on functional movements patterns, dynamic stability, biomechanics, and muscle strength of lower limbs in elite young basketball players. *Sport Sciences for Health* 14:245–250 DOI 10.1007/s11332-017-0409y.
- GRADEpro GDT. 2020. Online computer program. Available at <https://gdt.gradeapro.org/app>.
- Guyatt GH, Oxman AD, Kunz R, Brozek J, Alonso-Coello P, Rind D, Devereaux PJ, Montori VM, Freyschuss B, Vist G, Jaeschke R, Williams Jr JW, Murad MH, Sinclair D, Falck-Ytter Y, Meerpohl J, Whittington C, Thorlund K, Andrews J, Schünemann HJ. 2011. GRADE guidelines 6. Rating the quality of evidence—imprecision. *Journal of Clinical Epidemiology* 64:1283–1293 DOI 10.1016/j.jclinepi.2011.01.012.
- Guyatt GH, Oxman AD, Kunz R, Brozek J, Helfand M, Alonso-Coello P, Glasziou P, Jaeschke R, Akl EA, Norris S, Vist G, Dahm P, Shukla VK, Higgins J, Falck-Ytter Y, Schünemann HJ, GRADE Working Group. 2011b. GRADE guidelines: 7. Rating the quality of evidence—inconsistency. *Journal of Clinical Epidemiology* 64:1294–1302 DOI 10.1016/j.jclinepi.2011.03.017.
- Guyatt GH, Oxman AD, Kunz R, Woodcock J, Brozek J, Helfand M, Alonso-Coello P, Falck-Ytter Y, Jaeschke R, Vist G, Akl EA, Post PN, Norris S, Meerpohl J, Shukla VK, Nasser M, Schünemann HJ, GRADE Working Group. 2011c. GRADE guidelines: 8. Rating the quality of evidence—indirectness. *Journal of Clinical Epidemiology* 64:1303–1310 DOI 10.1016/j.jclinepi.2011.04.014.
- Guyatt GH, Oxman AD, Montori V, Vist G, Kunz R, Brozek J, Alonso-Coello P, Djulbegovic B, Atkins D, Falck-Ytter Y, Williams Jr JW, Meerpohl J, Norris SL, Akl EA, Schünemann HJ. 2011d. GRADE guidelines: 5. Rating the quality of evidence—publication bias. *Journal of Clinical Epidemiology* 64:1277–1282 DOI 10.1016/j.jclinepi.2011.01.011.
- Higgins JP, Green S. Cochrane Collaboration. 2011. *Cochrane handbook for systematic reviews of interventions, version 5.1.0.2011*. The Cochrane Collaboration. Available at <https://handbook.cochrane.org> (accessed on March 2011).
- Higgins JP, Thompson SG. 2002. Quantifying heterogeneity in a meta-analysis. *Statistics in Medicine* 21:1539–1558 DOI 10.1002/sim.1186.
- Huebner BJ, Plisky PJ, Kiesel KB, Schwartzkopf-Phifer K. 2019. Can injury risk category be changed in athletes? An analysis of an injury prevention system. *International Journal of Sports Physical Therapy* 14(1):127–134.
- Hui L, Baoai W. 2019. Functional movement screen and rehabilitation training of basketball player. *Sport Science Research* 40:81–85.
- HuxelBliven KC, Anderson BE. 2013. Core stability training for injury prevention. *Sports Health* 5(6):514–522 DOI 10.1177/1941738113481200.
- Jafari M, Zolaktaf V, Ghasemi G. 2019. Functional movement screen composite scores in firefighters: effects of corrective exercise training. *Journal of Sports Rehabilitation* 29:102–106 DOI 10.1123/jsr.2018-0080.

- Junker D, Stöggel T. 2019.** The training effects of foam rolling on core strength endurance, balance, muscle performance and range of motion: a randomized controlled trial. *Journal of Sports Science and Medicine* **18**(2):229–238.
- Kangkang Z, Zhuhang H. 2016.** The application research of the top level table tennis athlete in the functional movement screen test. Theses and dissertations, Beijing Sport University, Beijing, China. Available at <http://istic.wanfangdata.com.cn/Search/Detail?uniqueId=VEjVajaRtUMHEf3oHTVF%2B1QH3PrHAUsarfpKpdDOb7E%3D>.
- Kiesel KB, Butler RJ, Plisky PJ. 2014.** Prediction of injury by limited and asymmetrical fundamental movement patterns in American football players. *Journal of Sports Rehabilitation* **23**:88–94 DOI [10.1123/jsr.2012-0130](https://doi.org/10.1123/jsr.2012-0130).
- Kiesel K, Plisky P, Butler R. 2011.** Functional movement test scores improve following a standardized off-season intervention program in professional football players. *Scandinavian Journal of Medicine & Science in Sports* **21**:287–292 DOI [10.1111/j.1600-0838.2009.01038](https://doi.org/10.1111/j.1600-0838.2009.01038).
- Kiesel K, Plisky PJ, Voight ML. 2007.** Can serious injury in professional football be predicted by a preseason functional movement screen? *North American Journal of Sports Physical Therapy* **2**:147–158.
- Kim H, Lee Y, Shin I, Kim K, Moon J. 2014.** Effects of 8 weeks' specific physical training on the rotator cuff muscle strength and technique of javelin throwers. *Journal of Physical Therapy Science* **26**:1553–1556 DOI [10.1589/jpts.26.1553](https://doi.org/10.1589/jpts.26.1553).
- Klusemann MJ, Pyne DB, Fay TS, Drinkwater EJ. 2012.** Online video-based resistance training improves the physical capacity of junior basketball athletes. *The Journal of Strength & Conditioning Research* **26**:2677–2684 DOI [10.1519/JSC.0b013e318241b021](https://doi.org/10.1519/JSC.0b013e318241b021).
- Kovac D. 2018.** The effect of a six-week functional movement intervention on dynamic knee stability and physical performance in female netball players. Theses and Dissertations, Stellenbosch University. Available at <https://scholar.sun.ac.za>.
- Kraus K, Schütz E, Taylor WR, Doyscher R. 2014.** Efficacy of the functional movement screen: a review. *Journal of Strength & Conditioning Research* **28**:3571–3584 DOI [10.1519/JSC.0000000000000556](https://doi.org/10.1519/JSC.0000000000000556).
- Lee J-W, Zhang S-A, Lee J-K. 2015.** Effects of combined training on the FMS score in woman rugby national players. *Journal of the Korean Society of Industry-Academia Technology* **11**:7439–7446 DOI [10.5762/KAIS.2015.16.11.7439](https://doi.org/10.5762/KAIS.2015.16.11.7439).
- Minthorn LM, Fayson SD, Stobierski LM, Welch CE, Anderson BE. 2015.** The functional movement screen's ability to detect changes in movement patterns after a training intervention. *Journal of Sport Rehabilitation* **24**(3):322–326 DOI [10.1123/jsr.2013-0146](https://doi.org/10.1123/jsr.2013-0146).
- Moher D, Liberati A, Tetzlaff J, Altman D. 2009.** Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *PLOS Medicine* **6**:e1000097 DOI [10.1371/journal.pmed.1000097](https://doi.org/10.1371/journal.pmed.1000097).
- Moore E, Chalmers S, Milanese S, Fuller JT. 2019.** Factors influencing the relationship between the functional movement screen and injury risk in sporting populations: a systematic review and meta-analysis. *Sports Medicine* **49**:1449–1463 DOI [10.1007/s40279-019-01126-5](https://doi.org/10.1007/s40279-019-01126-5).



- Moran RW, Schneiders AG, Mason J, Sullivan SJ. 2017.** Do Functional Movement Screen (FMS<sup>TM</sup>) composite scores predict subsequent injury? A systematic review with meta-analysis. *British Journal of Sports Medicine* 51:1661–1669 DOI 10.1136/bjsports-2016-096938.
- PEDro. 2021.** PEDro scale. Available at <https://www.pedro.org.au/english/downloads/pedro-scale/>.
- Riela LA, Bertollo M. 2019.** The effectiveness of eight weeks of a movement-based program on functional movement patterns in male professional soccer players. *Journal of Physical Education and Sport* 19:1976–1983 DOI 10.7752/jpes.2019.s5294.
- Santos Bunn P, Rodrigues AI, Da Silva EB. 2019.** The association between the functional movement screen outcome and the incidence of musculoskeletal injuries: a systematic review with meta-analysis. *Physical Therapy in Sport* 35:146–158 DOI 10.1016/j.ptsp.2018.11.011.
- Schneider J, Wiegand Y, Braumann KM, Wollesen B. 2019.** Functional and motor deficits in youth soccer athletes—an explorative, quasi-experimental study. *Deutsche Zeitschrift für Sportmedizin* 70:14–20 DOI 10.5960/dzsm.2018.358.
- Song HS, Woo SS, So WY, Kim KJ, Lee J, Kim JY. 2014.** Effects of 16-week functional movement screen training program on strength and flexibility of elite high school baseball players. *Journal of Exercise Rehabilitation* 10:124–130 DOI 10.12965/jer.140101.
- Sterne JA, Egger M, Smith GD. 2001.** Investigating and dealing with publication and other biases in meta-analysis. *BMJ* 323:101–105 DOI 10.1136/bmj.323.7304.101.
- Tejani AS, Middleton EF, Huang M, Dimeff RJ. 2019.** Implementing a standardized interventional exercise regimen to improve functional movements in female collegiate athletes. *International Journal of Sports Physical Therapy* 14:117–126.
- Trinidad-Fernandez M, Gonzalez-Sanchez M, Cuesta-Vargas AI. 2019.** Is a low Functional Movement Screen score ( $\leq 14/21$ ) associated with injuries in sport? A systematic review and meta-analysis. *BMJ Open Sport & Exercise Medicine* 5:e000501 DOI 10.1136/bmjsem-2018-000501.
- Xuhua F, Ye T. 2015.** The experimental study of intervention on the prevention and treatment of sports injury and improvement of athletic performance by functional movement screen (FMS<sup>TM</sup>) and rehabilitation training volleyball players. Theses and dissertations, Shanghai Institute of Physical Education, Shanghai, China. Available at <https://kns.cnki.net/kcms/detail/detail.aspx?dbcode=CDFD&dbname=CDFDLAST2016&filename=1015626460.nh&v=loyN%25mmd2BfiOykjXdCZ4qyPlgIcIprQelqPzuikzVWPSAZd%25mmd2FF56vWA6QEBSVgnyct14>.
- Yildiz S, Pinar S, Gelen E. 2019.** Effects of 8-week functional vs. traditional training on athletic performance and functional movement on prepubertal tennis players. *The Journal of Strength & Conditioning Research* 33:651–661 DOI 10.1519/JSC.0000000000002956.