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Literature Review

The association between the functional movement screen outcome and the incidence of musculoskeletal injuries: A systematic review with meta-analysis

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ABSTRACT

Objective: To systematically review the literature investigating the association between the Functional Movement Screening (FMS™) score and musculoskeletal injuries in physical exercise based on relative risk (RR).
Methods: A systematic literature search was carried out in July 2018 in MEDLINE, LILACS, SCOPUS, SPORTDiscus, CINAHL and Web of Science databases. Reference lists were explored to find studies that examined the association between FMS™ and injuries. The following data were extracted from the studies: the participants' profile, sample size, classification of musculoskeletal injuries, follow-up time and RR. Participants with FMS™ score <13–14 were considered as "high risk" depending on used cut-off. The Mantel-Haenszel Test with random-effect model and the RR measure was performed. The Begg Test was used to analyze the publication bias.
Results: A total of 1658 studies were retrieved from the databases and 20 were selected. A meta-analysis of 964 injuries in 2227 high-risk participants and 1719 injuries in 5756 low-risk participants showed that individuals at "high risk" by FMS™ had a RR = 1.51 (95%CI = 1.35–1.69) of developing injuries.
Conclusions: Individuals classified as "high risk" by FMS™ are 51% more likely to be affected by injury than those classified as having low risk, but the level of evidence is very low.

1. Introduction

Musculoskeletal injuries are often seen in physical exercise, especially in those with high training volumes and intensities and in individuals with low levels of aerobic conditioning (Araújo, Sanches, Turi, & Monteiro, 2017). Examples of susceptible groups are athletes of different modalities (soccer, rugby, basketball, and others) (Bardenett et al., 2015; Bond et al., 2017; Gadziński et al., 2017; Schroeder, Wellmann, Stein, & Braumann, 2016) and those in the military (Araújo et al., 2017; O'Brien & Finch, 2014; Taanila et al., 2010, 2015). In this context, evaluation strategies have been implemented and prioritized to detect risk factors for injuries (Finch, Talpey, Bradshaw, Soligard, & Engebretsen, 2016; McCall et al., 2015; O'Brien & Finch, 2014).

Functional Movement Screening ™ (FMS ™) is a low-cost method of evaluation that was developed to assess the fundamental movement patterns of an individual. In FMS™, seven functional tests are performed (deep squat, hurdle step, in-line lunge, shoulder mobility, active straight leg raise, trunk stability push-up and rotary stability test). According to the presence of certain types of movement patterns (deviations), a score that ranges from zero to three points is provided. As described by Cook, Burton, and Hoogenboom (2006), a score of zero represents the presence of pain, a score of 1 is related to a patient having many movement dysfunctions, a score of 2 is related to a patient having few movement dysfunctions, and a score of 3 is related a patient having normal movement patterns (Cook et al., 2006). The FMS™ was developed for personal trainers and physical therapists to identify certain movement patterns and then to prescribe preventive exercises to avoid musculoskeletal injuries. The use of FMS™

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has spread to other sports as well as to military personnel, for whom the risk score is used to rate the risk of musculoskeletal injuries (Bushman et al., 2016; Lisman, O'Connor, Deuster, & Knapik, 2013; Mokha, Sprague, & Gatens, 2016). A more detailed description of FMS™ can be found in the clinical commentary provided by Cook et al., 2006 (Cook et al., 2006).

Previous systematic reviews have concluded that there is insufficient evidence to ensure the efficacy of FMS™ as a method of injury prediction (B. S. Dorrel, Long, Shaffer, & Myer, 2015; McCunn, Aus der Fünten, Fullagar, McKeown, & Meyer, 2015). However, none of the previous reviews performed a relative risk (RR) calculation, which quantifies a risk factor and an outcome in a cohort (Zhang & Yu, 1998). It is obtained by calculating the relationship between the incidence of samples exposed and not exposed to a risk factor, which in this case is the presence or not of a low FMS ™ score (De Oliveira & Parente, 2010). Given the gap in previous meta-analysis that have investigated the RR in FMS ™ studies as a predictor of injury, the aim of this study was to verify the association of the FMS™ injury risk classification with the occurrence of musculoskeletal injuries in physical exercise practitioners (sports and military).

2. Methods

2.1. Protocol and registration

A review protocol was registered in the International Prospective Register of Systematic Reviews (CRD42017071878).

2.2. Inclusion criteria

In this meta-analysis, cohort studies were included that met the following inclusion criteria (Moola et al., 2015):

2.2.1. Population

Participants who perform physical exercises, such as athletes of different modalities and military of different specialties, were included.

2.2.2. Exposure of interest (independent variable)

We considered as "exposed" the participants who practiced physical activities and whose FMS™ score was evaluated.

2.2.3. Injury (outcome or dependent variable)

We included studies that met at least one of the following criteria for definition of injury: I) the injury was associated with athletic participation or military exercises; II) there was a need for health care; and III) there was time lost with restricted participation for at least 24 h. The included studies should meet at least one of these criteria.

2.3. Data sources

A systematic literature search without language or time filters was conducted in July 2018 in the following databases: National Library of Medicine (MEDLINE), Latin American and Caribbean Health Sciences Literature (LILACS), CINAHL (EBOSCOhost), SCOPUS, SPORTDiscus and Web of Science. The following keywords were used as descriptors of the Medical Subject Headings (MeSH) or text words: injury prediction, injury risk, injury, relative risk, movement analysis, functional movement screen and their synonyms. The search phrase was obtained using the "AND" logic operators between the descriptors and "OR" between the synonyms. Additionally, reference lists and other sources were explored to find studies that quantitatively examined the association between FMS™ and musculoskeletal injuries.

2.4. Study selection

The selection of studies was performed by two independent evaluators (P.S.B and A.I.R). Disagreements were decided by a third researcher (E.B.S). In this meta-analysis, we included cohort studies that assessed the association of the FMS™ risk score with the occurrence of musculoskeletal injuries during physical exercises (sports and military) by using RR to analyze the data or cohort studies that presented a 2×2 table that allowed the calculation of the RR. Studies were excluded if they were revisions or designed with normality, reliability, or an intervention and studies without full-text.

2.5. Data collection process

The following data were extracted from the selected studies by two independent evaluators (P.S.B and A.I.R): the profile of the participants, sample size, classification of musculoskeletal injuries, follow-up time, FMS™ cutoff point and RR provided by the author or calculated in the present review through the 2×2 Contingency Tables. Disagreements were decided by a third researcher (E.B.S). Some authors were contacted to get information missing from the articles.

2.6. Risk of bias

Based on the cohort design of the included studies, the Newcastle-Ottawa Scale (NOS) was used to analyze the risk of bias (ROB) (Deeks et al., 2003; Wells et al., 2000). Two independent evaluators performed the ROB analysis (P.S.B and A.I.R). The disagreements were decided by a third evaluator (E.B.S). The three domains of NOS were evaluated: (I) **selection**: (1) representativeness of the exposed cohort, (2) selection of the unexposed cohort, (3) evaluation of the exposure, and (4) absence of baseline cases; (II) **comparison**: (5) pairing of major variables and (6) pairing of other variables; and (III) **outcomes**: (7) outcome evaluation, (8) sufficient follow-up time; and (9) adequacy of the cohort follow-up. For each item in the domains, one star was provided. For a study to be classified as low risk, it had to have at least five stars and at least one star in the "comparison" domain. Studies with more than five stars but without a "comparison" domain score received an "uncertain" risk. Finally, studies with four stars or less were considered to be at high risk of bias.

Funnel plots were developed to detect publication bias in the meta-analysis.

2.7. Data analysis

Statistical analysis was performed by an independent evaluator (E.B.S). The RevMan5.3 program was utilized to develop forest plots. RevMan5.3 is freely available at link: http://community.cochrane.org/tools/review-production-tools/revman-5. The aim was to perform a meta-analysis of the injury incidences in high-risk and low-risk groups. We selected the following parameters for the analysis: dichotomous variable, Mantel-Haenszel statistical method, random effects analysis model (in order to correct the heterogeneity found if $I^2 \geq 25\%$), and fixed effect analysis if $I^2 < 25\%$ (Moola et al., 2015), and RR effect measure with 95% CI for the studies and meta-analysis, and ordered it according to the weight of the studies. Subgroup analysis by profile of participants (athletes x military), injury definition criteria and FMS™ cutoff point were performed independently in order to verify the degree of confounding generated by these variables. The StatsDirect program

(version 3) was utilized to develop the funnel plot and the quantitative analysis of publication bias by the Begg Test and Mazumbar rank correlation. Kendall's statistic with tau continuity correction was performed. The significance level adopted was $P \leq 0.05$.

2.8. Level of evidence

An independent evaluator (F.O.M) assessed the quality of the evidence associated with the result of the meta-analysis using the Grading of Recommendations Assessment, Development and Evaluation approach (GRADE) (Guyatt, Oxman, Kunz, Brozek, et al., 2011; Guyatt, Oxman, Kunz, Woodcock, Brozek, Helfand, Alonso-Coello, Falck-Ytter et al., 2011; Guyatt, Oxman, Kunz, Woodcock, Brozek, Helfand, Alonso-Coello, Glasziou, et al., 2011; Guyatt, Oxman, Montori, et al., 2011).

3. Results

3.1. Overview

The flow diagram of the included studies is presented in Fig. 1. A total of 1658 articles were identified in this meta-analysis (1656 were retrieved in the databases and two were manually located). Then, 524 duplicates were removed, and 1074 studies failed to meet the inclusion criteria and were excluded. After reading 60 full-texts, a total of 40 full-texts were excluded from the analysis: one study evaluated the association between FMS™ score and sports performance; five were review or editorial studies; two evaluated other injury prediction methods; five were cross-sectional studies; three used a retrospective design; 10 consisted of unpublished works; one used a modified FMS™ protocol; and 13 studies did not provide the 2×2 table or the incidence of injuries, making it impossible to include them in the meta-analysis. The list of excluded studies with reasons is in the Supplementary Material. Among the prospective studies that did not provide the 2×2 table ($n = 13$), two studies consisted of samples with military and 11 with athletes. Five calculated the area under the receiver operating characteristic curve (ROC); two calculated OR and the others have used other types of analysis, such as Pearson Correlation, and difference of FMS™ score between injured and non-injured groups. In nine studies (69.23%) there was no association between the FMS™ score and the occurrence of injuries.

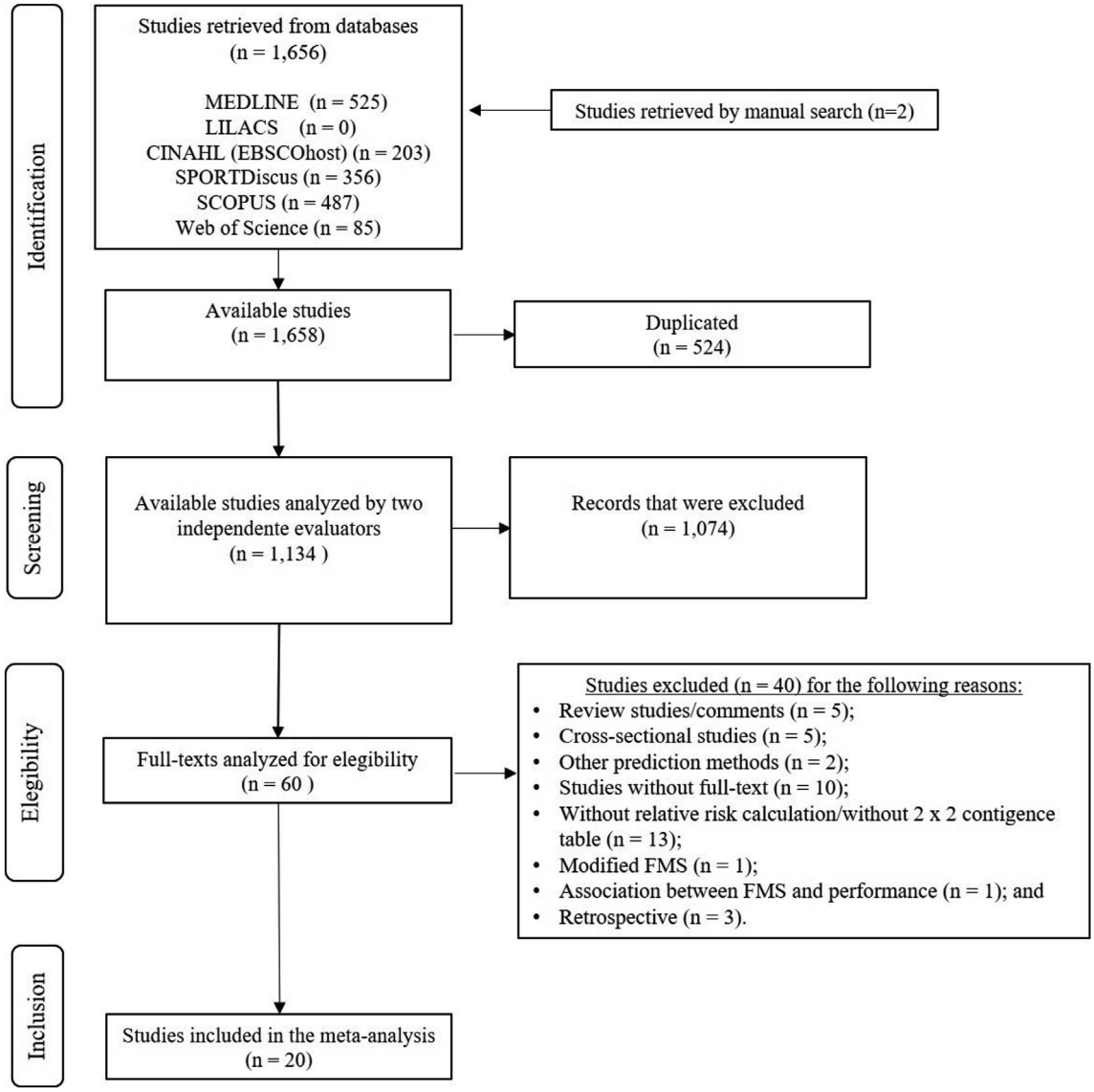

Fig. 1. Preferred reporting items for systematic reviews and **meta-analysis** (PRISMA); flow diagram of search results (Moher, Liberati, Tetzlaff, Altman, & Grp, 2009).

Table 1
Characteristics of the included studies.

Study	Sample	Injury Classification	Follow-up	Results	Cut-off point (FMS™)
Bushman et al. (2016)	n = 2476 physically active male soldiers; Age = 18–57 yr.	All inpatient and outpatient medical encounters for OI, TI, or AI found in soldiers' electronic medical records. The injuries were diagnosed according to ICD.	6 months	RR = 1.60 and 95% CI = 1.45–1.78 (any injury); RR = 1.84 and 95% CI = 1.63–2.09 (OI); RR = 1.26 and 95% CI = 1.03–1.54 (TI).	14
McGill et al. (2015)	n = 53 male police officers; Age = 37.9 ± 5 yr.	Any back injury not due to any specific acute incidents such as travel, slips, falls and other accidental mechanisms.	5 years	RR = 0.84 and 95% CI = 0.31–2.31	14
O'Connor et al. (2011)	n = 874 male marine officer candidates; Age = 18–30 yr (SC = 21.7 ± 2.6 yr; LC = 23.0 ± 2.6 yr).	Medical care providers who were not part of the investigation recorded all medical encounters using the military's electronic medical record system. Injury types included 1) OI, 2) TI, 3) AI, and 4) serious injury.	6 (n = 427) or 10 weeks (n = 447), according to the course (SD or LD).	SC: RR = 1.91 and 95% CI = 1.21–3.01 LC: RR = 1.65 and 95% CI = 1.05–2.59	14
Zarei et al. (2015)	n = 105 Iranian soldiers.	Musculoskeletal injuries that led to the removal of functions for at least 24 h.	7 months	RR* = 4.90 and 95% CI = 2.49–9.64)	14
Everard et al. (2018)	n = 132 entry level male soldiers; Age = 22.4 ± 4.2yr.	Any physical damage to the body which was secondary to physical training and required medicalc are one or more times during the study period. It resulted in at least one day of missed training.	16 weeks.	RR* = 1.19 and 95% CI = 0.60–2.35	14
Knapik et al. (2015)	n = 1045 American Coast Guard cadets (770 male and 275 female) Age = 18–22 yr.	Any physical damage to the body that resulted in clinic visit and that was suspected to have been caused by Summer Warfare Annual Basic (SWAB) training.	8 weeks.	RR = 1.33 and 95% CI = 1.04–1.60	14
Cosio-Lima et al. (2016).	n = 31 male Maritime Security Response candidates (MSRT) Age = 28 ± 4 yr.	Any physical damage to the body that resulted in a clinic visit and that was suspected to have been caused by MSRT physical training.	2 months	RR = 1.87 and 95% CI = 1.04–3.34	14
Alemany et al. (2017)	n = 2153 U.S. army soldiers; Age = 26.8 ± 5.6 years old.	All inpatient and outpatient medical encounters with an ICD diagnosis code consistent with recommended definitions of military injury. Diagnoses included: OI-related musculoskeletal conditions identified from the ICD-9 CM code series 710 to 739; and TI identified in the ICD-9 code series 800 to 999.	6 months	RR = 1.58 and 95% CI = 1.39–1.78	14
Kiesel et al. (2014)	n = 238 professional football players; Age = NR.	An injury was defined as a musculoskeletal injury (excluding contusion) resulting in any time loss from either practice or preseason games.	One preseason	RR = 1.87 and 95% CI = 1.20–2.96	14
Chorba et al. (2010)	n = 38 female collegiate athletes of various modalities; Age = 19.24 ± 1.2 yr.	A musculoskeletal injury that met the following criteria: (1) The injury occurred as a result of participation in a training or competition; (2) health care was needed.	One season	RR = 1.89 and 95% CI = 0.993–3.60	14
Mokha et al. (2016)	n = 84 (20 men) players of different modalities; Age = 20.4 ± 1.3yr (men) and 19.1 ± 1.2yr (women).	An musculoskeletal injury met the following criteria: (1) the injury occurred as a result of participation in an organized intercollegiate practice, strength and conditioning session, or competition setting; (2) the injury required attention or the athlete sought medical care; and (3) the injury resulted in modified training for at least 24 h or required protective splinting or taping for continued sport participation. .	One season	RR* = 0.68 and 95% CI = 0.39–1.19	14
Dossa et al. (2014)	n = 20 hockey players. Idade = 16–20 yr.	An injury was defined as any condition which occurred during a game or practice which resulted in a player missing at least one game. Injuries were those resulting from sports participation or training.	One season (2013 –2014)	RR* = 1.50 and 95% CI = 0.64–3.54	14
Martin et al. (2017)	n = 27 high school cricket players (fast/pace powers); Age = 13–18 years old.	An injury was defined as injury of any body region, sustained while participating in a sporting activity, that resulted in loss of at least one day of training or play or that occurred during	One season	RR = 0.59 and 95% CI = 0.16–2.20	14

(*continued on next page*)

Table 1 (*continued*)

Study	Sample	Injury Classification	Follow-up	Results	Cut-off point (FMS™)
		a sporting activity that required medical attention.			
Smith and Hanlon (2016)	n = 89 senior male soccer players; Age = 23.2 ± 4.4 years old.	Criteria proposed by Hagglund et al. (Hägglund et al., 2005).	One season	RR* = 0.76 and 95% CI = 0.36–1.61	14
Clay et al. (2016).	n = 37 female collegiate rower; Age = above than 18 years old	Injury was defined as any event that prevented athletic participation for at least one day.	One season	RR* = 1.49 and 95% CI = 0.998–2.33	14
Hotta et al. (2015)	n = 84 competitive male runners; Age = 20.0 ± 1.1 years old	A musculoskeletal injury that met the following criteria: (1) the injury occurred as a result of participating in a practice or race in track and field (trauma injuries, such as sprains, were excluded) and (2) the injury was sufficiently severe to prevent participation for at least 4 weeks.	6 months	RR* = 2.62 and 95% CI = 0.91–1.94	14
Duke et al. (2017)	n = 68 male rugby union players; Age = 22.0 ± 3.0 years old.	Any physical complaint that was sustained by a player during a rugby match or rugby training, irrespective of need for medical attention with time-loss from rugby activities that results in a player being unable to take a full part in future rugby training or match plat.	3 months	RR* = 1.52 and 95% CI = 1.19–1.94	14
Dorrel et al. (2018)	n = 257 collegiate athletes (men = 176, women = 81) of several modalities (football, volleyball, baseball, softball, basketball, soccer, tennis and track and field). Age = 18–24 yr.	Only practice– and competition-related injuries were included. For this research project, injury was defined as an altered state of practice or competition, and SI was defined as an altered state of practice or competition that lasted for at least 3 weeks.	One season	RR = 1.25 and 95% CI = 0.95–1.66.	15
Tee et al. (2016)	n = 62 professional rugby union players	Only severe injuries were considered. A severe injury was defined as an injury that caused a player to be excluded from matches and/or practice for a period of 28 days or more.	6 months	RR* = 3.05 and 95% CI = 1.57–5.89	13
Letafatkar et al. (2014)	n = 100 physically active (50 females and 50 males) students; Age = 22.5 ± 2.9yr.	Any acute lower extremity injury that occurred and kept the athlete out of participation for one or more full consecutive exposures was counted as an injury.	One season	RR* = 1.29 and 95% CI = 0.81–2.05	17

ICD = International Code of Diseases; OI = overuse injury; TI = Traumatic injury; AI = all injuries or any injury; yr = years old; 95% CI = 95% Confidence Interval; CP = Cutting Point; NR = not reported; SD = short duration; LD = long duration; RR = relative risk; RR* = RR not provided in the article but calculated in the present systematic review with data from Table 2x2 provided.

Twenty studies involving a total of 7983 participants met the inclusion criteria for the meta-analysis. All of the studies had been published (or accepted for publication) in peer-reviewed scientific journals. The characteristics of the included studies are described in Table 1. Eight studies included military samples (Alemany et al., 2017; Bushman et al., 2016; Cosio-Lima et al., 2016; Everard, Lyons, & Harrison, 2018; Knapik, Cosio-Lima, Reynolds, & Shumway, 2015; McGill et al., 2015; O'Connor, Deuster, Davis, Pappas, & Knapik, 2011; Zarei, Asady Samani, & Reisi, 2015), and twelve studies included athletes of rowing (Clay, Mansell, & Tierney, 2016), hockey (Dossa, Cashman, Howitt, West, & Murray, 2014), cricket (Martin, Olivier, & Benjamin, 2017), soccer (Smith & Hanlon, 2016), run (Hotta et al., 2015), rugby (Duke, Martin, & Gaul, 2017), volleyball (Mokha et al., 2016), football (Kiesel, Butler, & Plisky, 2014), basketball (Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010), collegiate athletes (Dorrel, Long, Shaffer, & Myer, 2018) and physically active students (Letafatkar, Hadadnezhad, Shojaedin, & M, 2014) (Table 1).

The injury definition ranged across the studies. Most of the studies applied one (J A Alemany et al., 2017; Bushman et al., 2016; McGill et al., 2015), two (Chorba et al., 2010; Clay et al., 2016; Cosio-Lima et al., 2016; Duke et al., 2017; Hotta et al., 2015; Kiesel et al., 2014; Knapik et al., 2015; Letafatkar et al., 2014; O'Connor et al., 2011; Zarei et al., 2015) or three criteria (Dorrel et al., 2018a; Dossa et al., 2014; Everard et al., 2018; Martin et al., 2017; Mokha et al., 2016; Smith & Hanlon, 2016; Tee, Klingbiel, Collins, Lambert, & Coopoo, 2016) proposed by Hägglund, Waldén, Bahr, and Ekstrand (2005).

Several studies classified as "high-risk", participants those who presented obtained FMS™ values below 14 points. However, three studies used different cut-off points: 13 points (Tee et al., 2016), 15 points (Dorrel et al., 2018) and 17 points (Letafatkar et al., 2014).

3.2. Meta-analysis

The meta-analysis of 964 injuries in 2227 high-risk participants and 1719 injuries in 5756 low-risk participants (athletes and military) showed that individuals who were considered to be at "high risk" according to FMS™ had a RR = 1.51 (95% CI = 1.35–1.69) to develop injuries (Fig. 2). Considering only athletes (Fig. 3), an analysis of 194 injuries in 405 high-risk participants and 255 injuries in 727 low-risk participants showed that individuals who were considered to be at "high risk" according to FMS™ a RR = 1.41 (95% CI = 1.15–1.73) to develop injuries. Considering only the military, an analysis of 771 injuries in 1821 high-risk participants and 1454 injuries in 5029 low-risk participants showed that military members who were considered to be at "high risk" according to FMS™ had a RR = 1.59 (95% CI = 1.39–1.81) to develop injuries

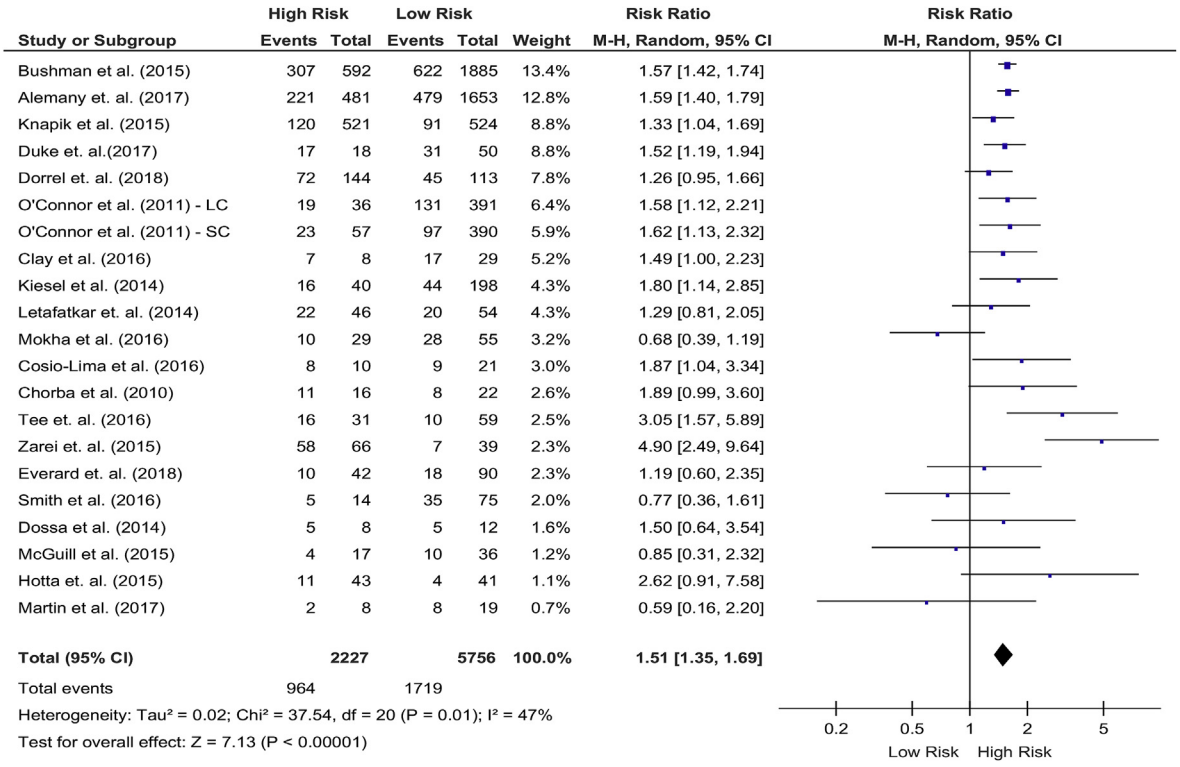

Fig. 2. Forest plot of the results from a random-effects meta-analysis shown as the relative risk (RR) with a 95% CI to analyze the studies that used FMS™ for injury prediction in athletes and military participants. For each study, the squares represent the risk ratio of each study and the horizontal lines are the lower and upper limits of the 95% CI. The size of each square is indicative of the relative weight that the study carried in the meta-analysis.

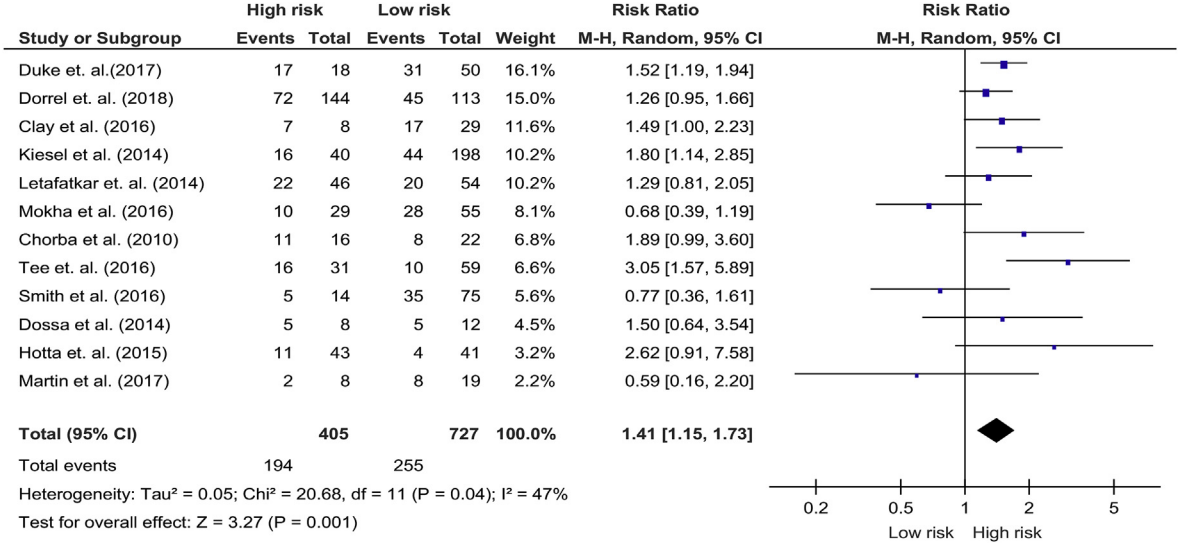

Fig. 3. Forest plot of the results from a random-effects meta-analysis shown as the relative risk (RR) with 95% CIs to analyze the studies that used FMS™ for injury prediction in athletes. For each study, the squares represent the risk ratio of the "high risk" group according to FMS, intersecting it as the lower and upper limits of the 95% CI. The size of each square is indicative of the relative weight that the study carried in the meta-analysis.

(Fig. 4). Among studies that adopted two criteria for the definition of injuries (I: the injury was associated with athletic participation or military exercises; and III: there was time lost with restricted participation for at least 24 h), an analysis of 150 injuries in 271 high-risk participants and 205 injuries in 602 low-risk participants showed that participants who were considered to be at "high risk" according to FMS™ had a RR = 1.43 (95% CI = 1.06–1.92) to develop injuries, with heterogeneity (I^2) = 67% (Fig. 5). Among studies that have adopted the three criteria to define the injuries (Fig. 6), there is a RR = 1.17 (95% CI = 0.80–1.70). Considering studies that have adopted at least the third criterion (Fig. 7), there is a RR = 1.44 (95% CI = 1.05–1.99), with I^2 = 67%. Among studies that used the 14-point cut-off to categorize subjects at high risk (≤14) or low risk (>14) (Fig. 8) the RR = 1.52 and 95% CI = 1.35–1.71), while among studies with another cut-off points the RR was 1.43 (95% CI = 1.14–1.78 (Fig. 9). On the other hand, studies that used the 14-

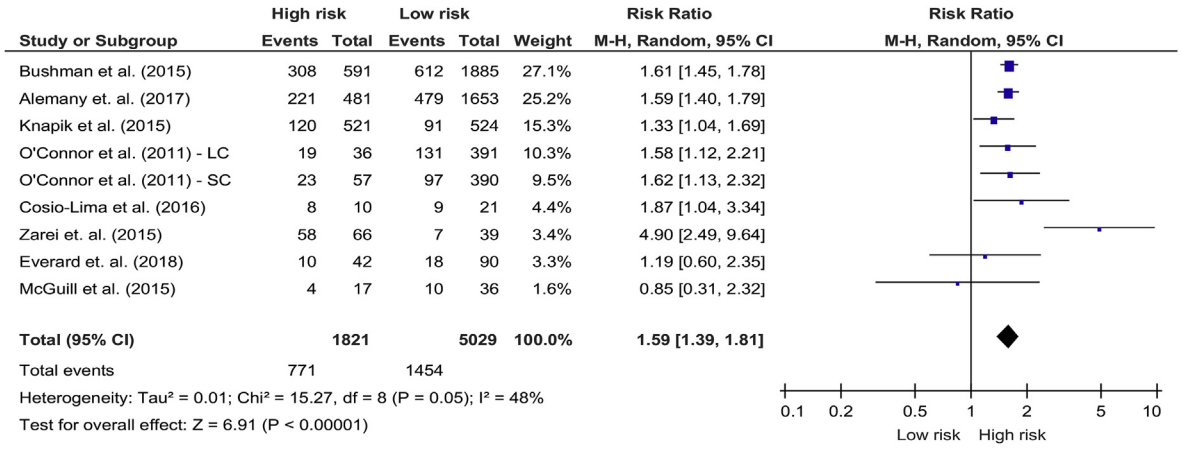

Fig. 4. Forest plot of the results from a random-effects meta-analysis shown as the relative risk (RR) with 95% CIs to analyze the studies that used FMS™ for injury prediction in the military. For each study, the squares represent the risk ratio of the "high risk" group in FMS, intersecting it as the lower and upper limits of the 95% CI. The size of each square is indicative of the relative weight that the study carried in the meta-analysis.

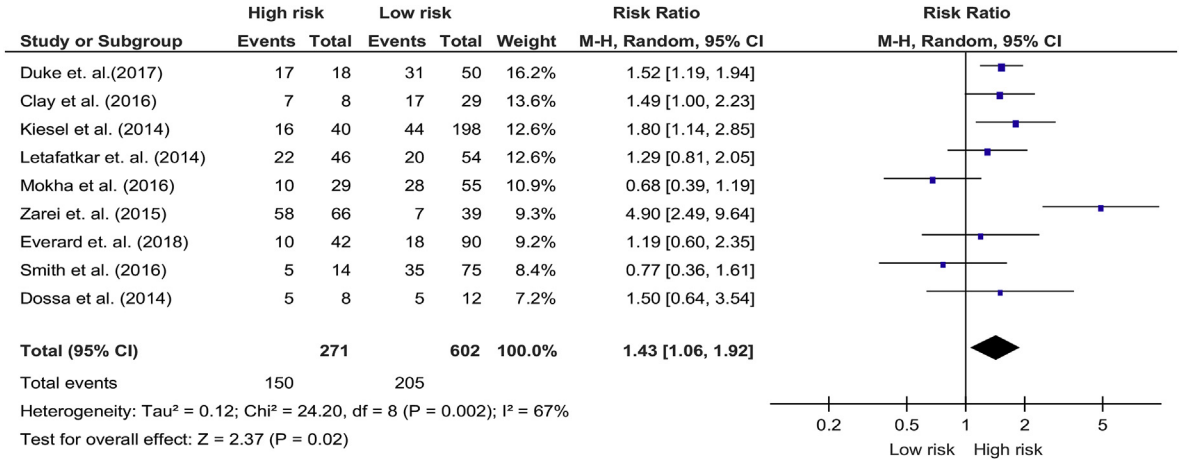

Fig. 5. Forest plot of the results from a random-effects meta-analysis shown as the relative risk (RR) with 95% CIs to analyze the studies that used FMS™ for injury prediction that considered the two criteria for injury definition: I) the injury was associated with athletic participation or military exercises; and III) there was time lost with restricted participation for at least 24 h. For each study, the squares represent the risk ratio of the "high risk" group in FMS, intersecting it as the lower and upper limits of the 95% CI. The size of each square is indicative of the relative weight that the study carried in the meta-analysis.

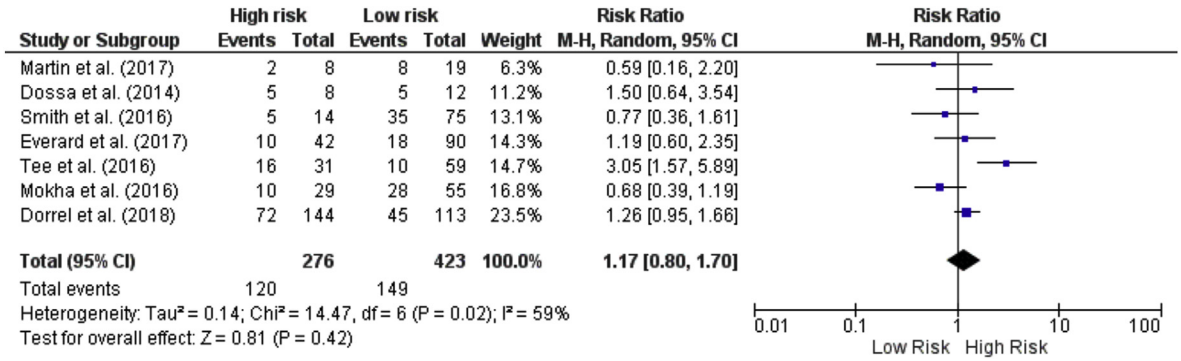

Fig. 6. Forest plot of the results from a random-effects meta-analysis shown as the relative risk (RR) with 95% CIs to analyze the studies that used FMS™ for injury prediction that considered the three criteria for injury definition: I) the injury was associated with athletic participation or military exercises; II) there was a need for health care; and III) there was time lost with restricted participation for at least 24 h. For each study, the squares represent the risk ratio of the "high risk" group in FMS, intersecting it as the lower and upper limits of the 95% CI. The size of each square is indicative of the relative weight that the study carried in the meta-analysis.

point cut-off to categorize subjects at high risk and that adopted the three criteria for injury definition there was the smallest heterogeneity ($I^2 = 0\%$) (Fig. 10). However, this association was by chance (RR = 0.89 and 95% CI = 0.64–1.24).

Publication bias was not suspected in the meta-analysis (Fig. 11), since the variation of the estimation of the results of the selected

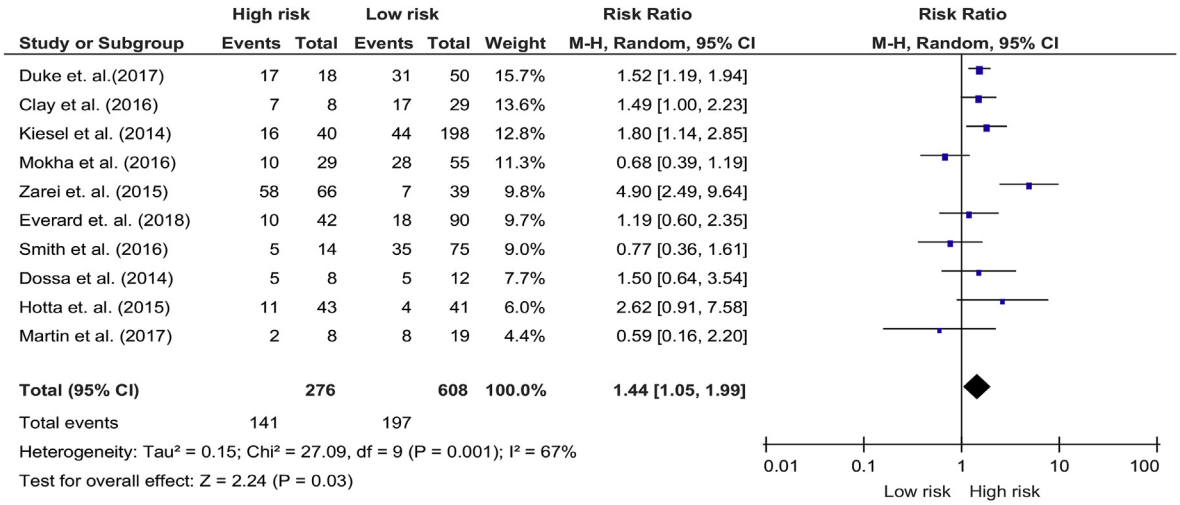

Fig. 7. Forest plot of the results from a random-effects meta-analysis shown as the relative risk (RR) with 95% CIs to analyze the studies that used FMS™ for injury prediction that considered at least the criteria III: "there was time lost with restricted participation for at least 24 h". For each study, the squares represent the risk ratio of the "high risk" group in FMS, intersecting it as the lower and upper limits of the 95% CI. The size of each square is indicative of the relative weight that the study carried in the meta-analysis.

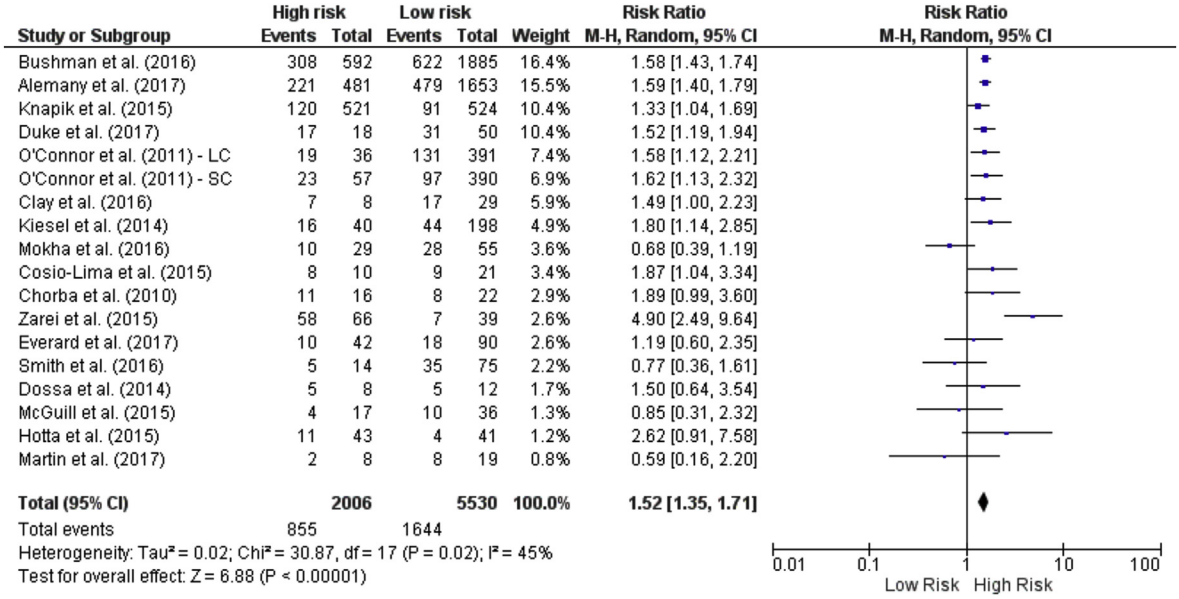

Fig. 8. Forest plot of the results from a random-effects meta-analysis shown as the relative risk (RR) with 95% CIs to analyze the studies that used FMS™ for injury prediction that used the 14-point cut-off to categorize individuals at high risk (≤14) or low risk (>14 points). For each study, the squares represent the risk ratio of the "high risk" group in FMS, intersecting it as the lower and upper limits of the 95% CI. The size of each square is indicative of the relative weight that the study carried in the meta-analysis.

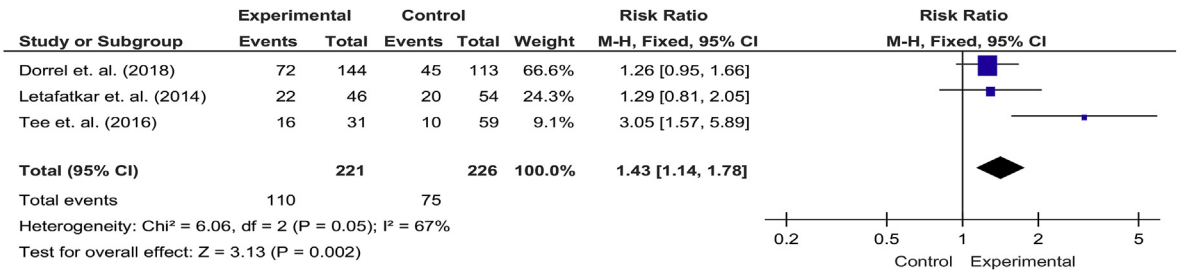

Fig. 9. Forest plot of the results from a random-effects meta-analysis shown as the relative risk (RR) with 95% CIs to analyze the studies that used FMS™ for injury prediction that used others cut-off points (except 14 points) to categorize individuals at high risk or low risk. For each study, the squares represent the risk ratio of the "high risk" group in FMS, intersecting it as the lower and upper limits of the 95% CI. The size of each square is indicative of the relative weight that the study carried in the meta-analysis.

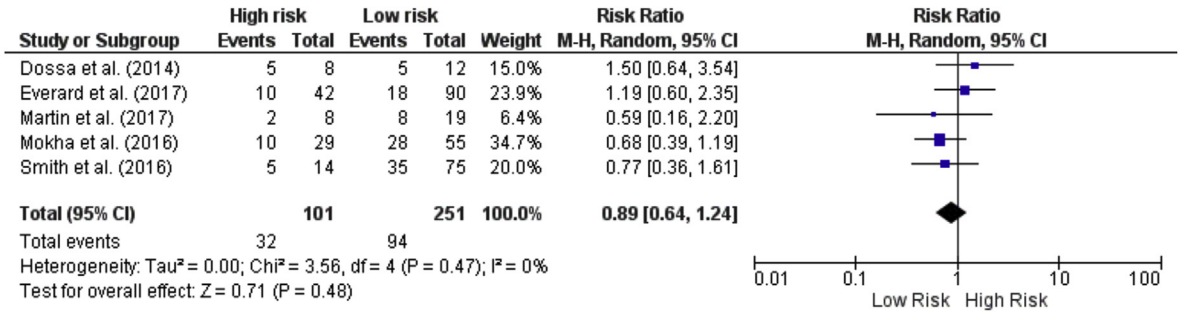

Fig. 10. Forest plot of the results from a random-effects meta-analysis shown as the relative risk (RR) with 95% CIs to analyze the studies that used the FMS™ 14-point cut-off to categorize individuals at high risk (≤14) or low risk (>14 points). The studies have considered the three criteria for injury definition: I) the injury was associated with athletic participation or military exercises; II) there was a need for health care; and III) there was time lost with restricted participation for at least 24 h. For each study, the squares represent the risk ratio of the "high risk" group in FMS, intersecting it as the lower and upper limits of the 95% CI. The size of each square is indicative of the relative weight that the study carried in the meta-analysis.

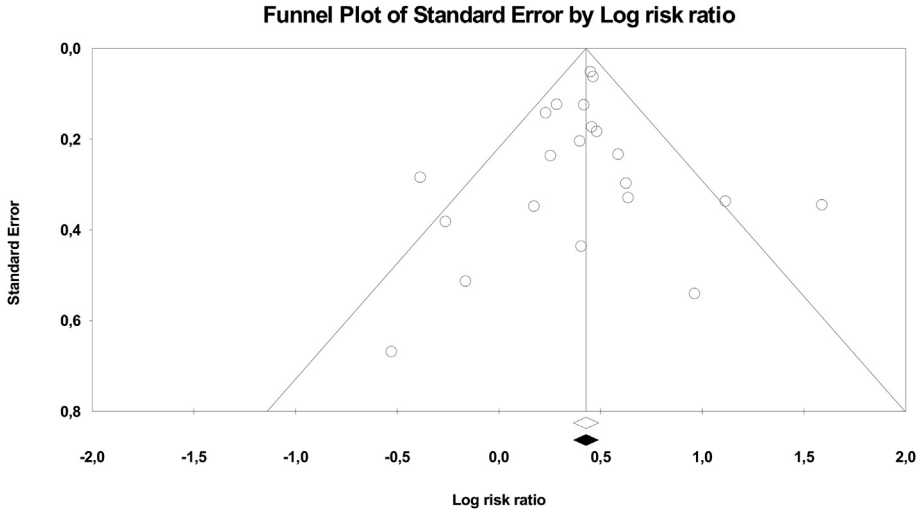

Fig. 11. Funnel plot of the 20 studies included in the meta-analysis with Begg and Mazumbar rank correlation. Kendall's statistic with tau continuity correction was performed, with Tau = −0.14; z-value for tau = 0.09 and P-value (2-tailed) = 0.92.

studies that was divided by its standard error was by chance in the Begg Test (P = 0.92).

3.3. Risk of bias and level of evidence

The main sources of biases were the representativeness of the exposed cohort, lack of comparability with potential confounders, lack of a blind assessment of the outcome and absence of an attrition rate (Fig. 9). Nine studies had a low risk of bias (Bushman et al., 2016; Chorba et al., 2010; Dorrel et al., 2018; Duke et al., 2017; Hotta et al., 2015; Letafatkar et al., 2014; McGill et al., 2015; Smith & Hanlon, 2016; Zarei et al., 2015), ten had an unclear risk (Alemany et al., 2017; Clay et al., 2016; Cosio-Lima et al., 2016; Dossa et al., 2014; Everard et al., 2018; Kiesel et al., 2014; Knapik et al., 2015; Martin et al., 2017; Mokha et al., 2016; Tee et al., 2016) of bias, and one had a high risk of bias (O'Connor et al., 2011) (Table 2). Using the GRADE instrument, the overall quality of evidence was very low (Table 3).

4. Discussion

Systematic reviews with or without meta-analyses based on an analysis of diagnostic accuracy indicators or the OR calculation concluded that there was no evidence to support the use of FMS™ as a predictor of injury (Dorrel et al., 2015; McCunn et al., 2015; Moran, Schneiders, Major, & Sullivan, 2015). The meta-analysis of the 20 included cohort studies showed that among the 2227 participants classified as high risk according to FMS™, 964 suffered injuries, while among the 5756 participants classified as low risk according to FMS ™, 1719 suffered injuries during physical exercises. These results suggest that individuals classified as high risk according to FMS™ have a 1.51-fold higher risk of developing injuries (95% CI = 1.35–1.69) (Fig. 2).

The strength of an association depends on the magnitude of the RR. According to some epidemiologists, an increased risk of less than 50% (RR = 1.0–1.5) is considered to be a weak association or no association (Craun, 1979). Strong evidence of association is considered in studies with a RR > 2 (Summerfield, 2004). Consequently, the results of the present meta-analysis suggest that there is an association between "weak" and "strong" of the FMS™ risk score and risk of musculoskeletal injuries in exercise practitioners.

FMS™ is an evaluation tool that attempts to evaluate movement compensations in the kinetic chain. After identifying certain types of movement patterns, FMS is used to prescribe exercises to address these perceived compensations (Cook et al., 2006). Due to its ease of use and objectivity, use of FMS™ has expanded to several sports modalities (McCunn et al., 2015) as well as to the military environment (Bushman et al., 2016; Lisman et al., 2013). Application of

Table 2
FMS™ bias Risk Analysis (NOS).

Domain/study	Selection				Comparison		Result				
	1	2	3	4	5	6	7	8	9	Score	Risk
Duke et al. (2017)	*	*	*	*	*		*	*	*	8	Low
Dorrel et al. (2018)	*	*	*	*	*	*	*			7	Low
Smith & Hanlon (2016)	*	*	*	*		*	*	*		7	Low
Chorba et al. (2010)		*	*	*		*	*	*		6	Low
Bushman et al. (2016)	*	*	*		*	*		*		6	Low
McGuill et al. (2015)	*	*		*	*			*	*	6	Low
Hotta et al. (2015)		*		*	*	*		*	*	6	Low
Zarei et al. (2015)		*		*	*		*	*		5	Low
Letafatkar et al. (2014)		*		*	*	*		*		5	Low
Alemany et al. (2017)	*	*	*	*			*	*		6	Uncertain
Mokha et al. (2016)	*	*	*	*			*	*		6	Uncertain
Everard et al. (2018)		*	*	*			*	*		5	Uncertain
Knapik et al. (2015)	*	*	*				*	*		5	Uncertain
Cosio-Lima et al. (2016)		*	*				*	*	*	5	Uncertain
Dossa et al. (2014)		*	*				*	*	*	5	Uncertain
Kiesel et al. (2014)	*	*	*				*		*	5	Uncertain
Martin et al. (2017)		*		*			*	*	*	5	Uncertain
Clay et al. (2016).		*	*	*			*	*		5	Uncertain
Tee et al. (2016)	*	*	*	*				*		5	Uncertain
O'Connor et al. (2011)	*	*	*				*			4	High

Note: Domains of the Newcastle-Ottawa Scale (NOS): Selection (1 - representativeness of the exposed cohort; 2- selection of the non-exposed cohort; 3 - ascertainment of exposure; 4 - demonstration that the outcome of interest was not present at the start of study); Comparability (5- principal factor and 6- any additional factor); and Outcome (7 - assessment of outcome; 8 - if the follow-up was long enough for outcomes to occur; and 9-adequacy of follow-up cohorts).

FMS™ is attractive, especially in large groups and in the absence of other evaluation methods. The main objective of FMS™ is to detect changes in the pattern of movement to direct the individual to an individualized prevention strategy (Cook et al., 2006). However, the subjectivity of the evaluations is one of the negative points of FMS™, and there is no consensus about the concept of normal movement patterns (McCall et al., 2015; McCunn et al., 2015).

The studies included in this meta-analysis included samples with distinct characteristics: members of the military, athletes from different ages and sports modalities and subjects from both sexes (Table 1). The three studies that were found to have the greatest weight in the meta-analysis (Alemany et al., 2017; Bushman et al., 2016; Knapik et al., 2015), were composed by military samples, which contributed 35% of the results. On the other hand, among the three studies that were found to have the lowest weight (Hotta et al., 2015; Martin et al., 2017; McGill et al., 2015), two consisted of samples that included adolescent cricket pace bowlers (Martin et al., 2017), runners (Hotta et al., 2015) and one with members of the police department (McGill et al., 2015), which contributed 3.0% of the results (Fig. 2).

Military personnel have an environment with similar activities and routines, in addition to the group being generally more homogeneous in terms of age, anthropometric characteristics and physical conditioning, which can influence the risk of musculoskeletal injuries (Grier et al., 2017; Sefton, Lohse, & Mcadam, 2016; Taanila et al., 2009, 2015). These factors minimize comparison biases (Wells et al., 2000). The study that had the greatest weight in the meta-analysis have showed a low risk of bias (Table 2). However, other studies with military personnel presented an uncertain (Alemany et al., 2017; Cosio-Lima et al., 2016; Knapik et al., 2015) or high risk of bias (O'Connor et al., 2011). In the present meta-analysis, the samples of athletes were more heterogeneous in terms of sex, age and modalities (Table 1). The different demands and risk factors could cause a high heterogeneity. When analyzing the results of the studies with athletes (Fig. 3), the only studies with significant results were those exposed to sports such as rugby (Duke et al., 2017; Tee et al., 2016) and football (Kiesel et al., 2014). In all cases, there is a high frequency of corporeal contact, and movements with greater strength and speed. All other studies presented non-significant RRs, whose sports practiced were running, cricket, rowing, etc. The only study that escaped this rule was Dossa et al. (2014), with a sample of hockey athletes. In the exposure to military activities, 7 of the 9 studies (78%) were significant, while among the studies with athletes, 3/12 studies (25%) were significant. The difference between these two proportions (53%) was significant ($P = 0.03$). The existence of heterogeneous samples did not result in differences in precision or association. Between military and athletes, the I^2 was 48 and 47%, respectively. Although the military routine imposes similar working hours, physical activities, food intake and hours of rest for the group, these similarities did not lead to a greater control over confounding variables. One possible explanation can the different injury definitions among the studies.

According to Hagglüng et al. (2005), in injury prediction studies, samples should be monitored during the sports season and musculoskeletal injuries are considered when three criteria are met: 1) the injury was verified by a health professional; 2) the injury took place in the sports participation; 3) the injury promoted the absence of the individual's functions for at least 24 h. In this meta-analysis, seven studies met these criteria (Dorrel et al., 2018; Dossa et al., 2014; Everard et al., 2018; Martin et al., 2017; Mokha et al., 2016; O'Connor et al., 2011; Smith & Hanlon, 2016; Tee et al., 2016), but only one presented significant results (Tee et al., 2016). The study with the greatest impact on the outcome of the meta-analysis did not use the criterion of including injuries that promoted an absence longer than 24 h (Bushman et al., 2016). Thus, complaints of musculoskeletal pain without the occurrence of injuries may have been included in the analysis (Hägglund et al., 2005) (Table 1).

Analyzing studies that adopted at least two criteria for injury definition (criteria 1 and 3), the I^2 was 67% and $RR = 1.43$ (95% $CI = 1.06–1.92$). However, among studies that adopted the three criteria, the I^2 has reduced, showing the impact of the injury definition in the injury risk (Fig. 6). Lower values of I^2 also occurred when analyzing only studies with a cut-off point equal to 14 (Fig. 8). Moreover, among studies that adopted the three criteria and used the FMS 14-point cut-off to categorize individuals at high risk or low risk, the I^2 abruptly reduced, showing the impact of the injury

Table 3
Grading of Recommendations Assessment, Development and Evaluation of the Meta-analysis (studies on athletes and the military).

Certainty assessment							№ of patients		Effect		Certainty	Importance
№ of studies	Study design	Risk of bias	Inconsistency	Indirectness	Imprecision	Other considerations	High Risk in the FMS score	Low Risk in the FMS score	Relative (95% CI)	Absolute (95% CI)		
New outcome												
20	observational studies	serious[a]	serious[b]	not serious	not serious	publication bias is not suspected[c]	964/2227 (43.3%)	1719/5756 (29.9%)	**RR 1.51** (1.35–1.69)	**155 more per 1000** (from 93 more to 221 more)	⊕○○○ VERY LOW	IMPORTANT

CI: Confidence interval; **RR:** Risk ratio.
Note.
[a] Most of the studies presented an high or uncertain risk of bias according to the Newcastle-Ottawa Scale tool.
[b] $I^2 = 47\%$, heterogeneity $P < 0.01$, and non-overlapping confidence intervals.
[c] Publication bias is not suspected (Begg Test and Mazumbar rank correlation with $P = 0.92$).

definition and of the cut-off point in the injury risk (Fig. 10).

Subgroup analysis showed that RR = 1.45 (95% CI = 1.28–1.65) increased significantly to 1.59 (5%), when only military participants were analyzed and decreased significantly to 1.41 (−6%), when only athletes were analyzed. Regardless, when the studies that used at least the withdrawal of the activities for more than 24 h as a criterion for the occurrence of the injury were analyzed, the RR decreased significantly to 1.44 (−4%). Considering only the studies that used the diagnosis of injury given by a physician and the withdrawal of activities for more than 24 h as criteria for the occurrence of the injury, the RR decreased significantly to 1.43 (−5%). On the other hand, the studies that used the diagnosis of injury given by a physician, the injury occurred during the practice of physical exercise and the withdrawal of the activities for more than 24 h as criteria for the occurrence of the injury, RR decreased by chance to 1.17 (−22%). These results clearly show that the profile of the participants, indirectly the physical exercise performed by them, and the adoption of the criteria to characterize the occurrence of the injury are confounding variables that can generate heterogeneity (I^2), when the classification association is studied risk based on FMS™ motor dysfunction with the occurrence of injuries.

The different sports (rowing, cricket, soccer, rugby, run, volleyball, football and basketball) (Table 1) of the studies included in this meta-analysis have different biomechanical characteristics, which contributed to the inconsistency (I^2) of this meta-analysis. However, the use of random effects analysis model (in order to correct the heterogeneity found if $I^2 \geq 25\%$) (Figs. 2–8 and 10) aimed to correct the effects of this heterogeneity on the final result of this meta-analysis (Moola et al., 2015). Four studies presented and protective effect (Martin et al., 2017; McGill et al., 2015; Mokha et al., 2016; Smith & Hanlon, 2016), however, it was by chance. One possible explanation can be the sample size. Studies that had larger sample sizes (Alemany et al., 2017; Bushman et al., 2016; Knapik et al., 2015) have shown the significant risk effect of motor dysfunction for the occurrence of the injury (Fig. 2).

In this meta-analysis, all of the included studies provided a 2 × 2 table or the RR, making it unnecessary to calculate the odds ratios (OR). To avoid misinterpretation of the OR (Knol, Le Cessie, Algra, Vandenbroucke, & Groenwold, 2012), it is recommended the use of the RR analysis. Relative risk is the effect measure recommended to quantify the relationship between a risk factor and an outcome in cohort studies. The OR is applied in case-control studies. Use of the OR is recommended when the RR calculation is not possible (Zhang & Yu, 1998). However, the OR provides an overestimation of the RR, especially when the outcome is frequent (Knol, 2012). The OR can exaggerate the RR, even when using multivariable logistic regression. Thus, the Mantel-Haenszel method is suggested to adequately assess the magnitude of the association and estimate the RR (Cummings, 2009), especially in cases in which the incidence of the outcome is greater than 10%.

In the funnel plots, the estimated standard error was plotted on the vertical axis and the RR for each study was plotted on the x-axis. In the meta-analysis with no suspicion of publication bias, the scatter results were from sampling, and the effect estimates from smaller studies should scatter more widely at the bottom, with the spread narrowing among the most powerful studies. Therefore, according to the symmetrical funnel plots (Fig. 11) and the Begg Test and Mazumbar rank correlation (P = 0.92), there was no suspicion of publication bias.

Few studies met the criteria of the “comparison” domain (Fig. 12). Most studies failed by not assessing the influence of potential confounding factors. An additional confounding factor related to FMS™ was performers' knowledge. Participants adapt their movement patterns according to their understanding or

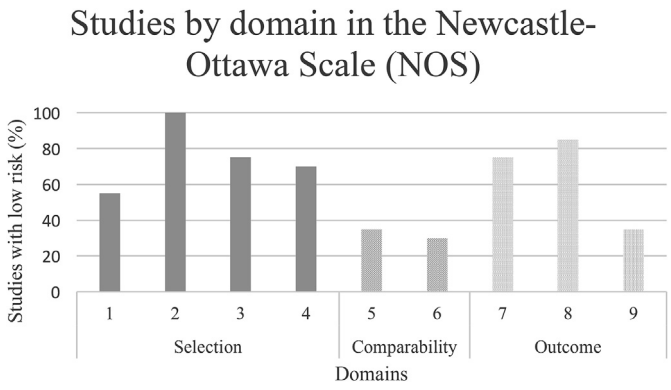

Fig. 12. Percentage of studies with a low risk of bias by domain of the Newcastle-Ottawa Scale. Domains: Selection (1 - representativeness of the exposed cohort; 2-selection of the non-exposed cohort; 3 - ascertainment of exposure; 4 - demonstration that the outcome of interest was not present at the start of study); Comparability (5-principal factor and 6- any additional factor); and Outcome (7 - assessment of outcome; 8 - if the follow-up was long enough for outcomes to occur; and 9-adequacy of follow-up cohorts).

interpretation of the instructions provided by the evaluators or their familiarity with the tasks Frost, Beach, Callaghan, & M, 2015). In the "results" domain, few studies have reported whether the assessors responsible for the injury follow-up were unaware of the participants' injury risk ratings according to the FMS™ score and did not report any sample losses. In studies on athletes, most of those with a better methodological quality did not have significant results (Chorba et al., 2010; Dorrel et al., 2018; Hotta et al., 2015; Letafatkar et al., 2014; Martin et al., 2017; Smith & Hanlon, 2016) (Table 1).

This meta-analysis is not free of limitations. First, considering the 20 studies, the level of evidence from the meta-analysis was very low. The most crucial factors were: the high risk of bias in most studies and high heterogeneity among the studies (Sterne et al., 2011). Moreover, the FMS™ performance improves with experience, focus of attention, motivation, awareness of the grading criteria and more detailed instructions regarding the scoring criteria (Frost et al., 2015). Consequently, the validity of the first testing session that occurs in these screening studies can be limited. Finally, some studies included in this meta-analysis did not use the criterion of injury proposed by Hagglünd et al. Therefore, the studies included both light or severe injuries, with a potential limitation of results.

5. Conclusions

Health professionals, in particular, physical educators, personal trainers and physiotherapists, should consider that the association of the FMS™ score and the injury risk is not by chance. According to the results of the present meta-analysis, individuals classified as "high risk" by FMS™ are 51% more likely to be affected by injury than those classified as having "low risk". Moreover, if the participant is guided or trained to perform the correct movement, it is inappropriate to consider that someone's movement patterns, analyzed separately, can predict the risk of injury.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ptsp.2018.11.011.

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