The effectiveness of the functional movement screen in determining injury risk in tactical occupations

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Abstract: Injures are common in workers engaged in tactical occupations. Research suggests that the functional movement screen (FMS) may provide practitioners the ability to identify tactical athletes most at risk for injury. However, there exists controversy as to the effectiveness of the FMS as a tool for classifying injury risk. The purpose of the meta-analysis was to determine the predictive value of the FMS in determining injury risk in workers engaged in tactical occupations. We searched MEDLINE, Military & Government Collection (EBSCO), PubMed and National Institute for Occupational Safety and Health Technical Information Center databases for articles published between January 2007 and October 2017. Ten studies met the inclusion criteria. Multiple random-effects model meta-analyses were conducted, with an odds ratio as the effects metric. FMS cut-off score, occupation, injury type and sex were used as moderators for the analyses. The odds of injury were greatest for tactical athletes with FMS scores ≤14. Personnel scoring ≤14 had almost 2 times the odds of injury as compared to those scoring >14. However, the magnitude of the effects were small; thus the relationship between FMS cut scores and injury prediction does not support its use as a sole predictor of injury.

Key words: Military personnel, Firefighters, Preventive medicine, Military medicine, Occupational medicine

Introduction

Musculoskeletal injures (MSI) are common in tactical occupations such as military, law enforcement and fire and rescue[1, 2]. In military personnel, MSI such as low back pain and knee injuries accounted for 33% and 26% of 1st time injury visits for deployed personnel[3], with females being almost 2 times as likely to sustain an injury during deployment than their male counterparts[4]. The rate of MSI in firefighters and law enforcement personnel has also drawn considerable attention, with injury rates of 448.4 per 10,000 and 485.8 per 10,000 full-time workers, respectively[1]. MSI results in not only a reduction in physical performance, but also increases overall health care costs to tax payers[5], number of work days lost per injury[4], and poses immediate and future health consequences (e.g., traumatic osteoarthritis)[6, 7] to the employee and negatively influences their future quality of life.

Practitioners have suggested that screening tools such as the functional movement screen (FMS) may provide practitioners with the ability to identify sport (soccer, football, etc.)[8–10] and tactical (military, fire and law enforcement)[11–13] athletes most at risk for injury. The FMS has been described in the literature[13, 14] and uses a scoring system from 0–21, with 21 being the best possible score. The FMS consists of seven tests each graded on a 0 to 3

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scale. An individual scoring a 3 on each of the seven tests would have a final score of 21[14].

There is conflicting literature regarding whether the FMS is an effective tool for determining injury risk. Previous investigators have reported that the FMS is a predictor of injury[10, 13]. Several investigators have found that athletes scoring ≤14 have greater than 2 times odds of suffering injury compared to those scoring >14[13, 15]. In contrast investigators[16–18] have found the test is not associated with an increased risk of injury. In addition, the literature suggest the odds of injury change as a result of injury type[13, 19] and it also lacks sensitivity as a diagnostic tool[12, 13, 15, 20]. Adding to the controversy, research by Knapik et al.[12] suggests that the optimal cutoff score females (≤14) differs from males (≤11). Early attempts to synthesize or aggregate the available literature has not addressed all of these issues. In a recent meta-analysis, Moran et al.[21] reported finding that military personnel scoring ≤14 were at higher odds of injury as compared to those scoring >14. Moran et al.[21] reported observing strong evidence of a small association. However, their[21] analysis included only three studies that consisted of all male cohorts. The authors[21] also only explored the risk of injury based on a cutoff score of 14. Additionally, their analysis of all injuries were pooled; thus there remains a need to determine the odds or risk of sustaining a specific type of injuries (e.g. overuse and traumatic) based on FMS score.

In a meta-analysis performed Dorrel et al.[22], which included six studies, the FMS had low sensitivity of 25% with a high specificity of 85%. However, Dorrel et al.[22] did not provide separate moderated analyses for females. The Dorrel et al.[22] analysis combined males and females from across various sports and occupations similar to a meta-analysis conducted by Bonazza et al[23]. Additionally, the Dorrel et al.[22] meta-analysis did not appear to account for the various cutoff scores used in each included study. This combined with not providing separate analyses for males and females arguably convolutes the analyses. Given the state of the available literature, there remains a need to investigate the predictive value of the FMS in females, across various cutoff scores, and occupations specific to tactical athletes.

Although the fitness requirements for tactical athletes (e.g., adequate strength, cardiorespiratory fitness, speed and agility) often resemble those of traditional athletes, it is important to distinguish personnel in tactical occupations from traditional athletes because of their unique job environment. Tactical athletes (such as firefighters and military personnel) are often required to perform their job related duties wearing cumbersome equipment and gear in environments in which there is a high chance of fatality[24, 25]. For a firefighter, sustaining a MSI at a fire scene can pose a serious hazard not only to the firefighter, but also to those he or she is attempting to rescue. Thus, methods that help reduce the risk of fatal and nonfatal casualties may not only help to benefit the tactical athlete but also those they serve and protect.

As those charged with the safety and wellness of tactical athletes are working to develop effective screening methods that will predict MSI, a better understanding of the optimal FMS cutoff score for classification of injury risk as it pertains to this unique group of individuals is necessary. Development of risk classification tools will help those tasked with the health and wellness of tactical athletes to better utilize resources. Given the state of the literature, it is necessary to synthesize the available literature systematically and pool the individual studies quantitatively to reanalyze. The purpose of the meta-analysis was to determine the predictive value of the FMS in determining injury risk in workers engaged in tactical occupations. This study is the first to parse out the confounding information related to the predictive value of the FMS and injury risk in athletes such as appropriate cutoff score, injury type and sex. The study also aims to provide clear guidelines for practitioners working within fire, military and law enforcement.

Methods

Data source

The sections of this article have been written in accordance with The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[26]. We searched MEDLINE, Military & Government Collection (EBSCO), National Institute for Occupational Safety and Health Technical Information Center and PubMed databases for articles published between January 2000 and October 2017. The following terms were searched alone or in combination using the population, intervention and outcome (PIO) format using Boolean operators (OR & AND): *P) athlete OR military personnel OR military warfighter OR firefighter OR Soldier OR Marine AND I) FMS OR functional movement screen OR movement screen OR screening tools OR movement assessment AND O) injury OR musculoskeletal injury OR ankle injury OR knee injury OR hip injury OR shoulder injury OR back injury OR spine injury OR low back injury OR cervical spine injury*

OR lumbar spine injury OR thoracic spine injury OR elbow injury OR neck injury OR joint injury OR overuse injury OR traumatic injury. In addition, we searched the reference lists of the acquired articles to find additional pertinent articles. Attempts were made to contact researchers for unpublished data.

Study selection

Inclusion criteria were determined before the start of the literature review. For inclusion, all studies were required to have used the FMS to predict injury, sample population of tactical athletes (e.g., warfighter, firefighter, law enforcement officer, etc.), and identified a FMS cut-off criterion. In addition, they needed to have identified the total number of participants above and below the FMS cut-off criterion (or odds ratio). After screening the titles and abstracts, two reviewers (R.K., M.L.) evaluated the relevant full-text articles for final inclusion. The reviewers resolved disagreements concerning article eligibility by coming to consensus or by arbitration of a third reviewer (G.G.) if disagreement persisted.

Data extraction

The reviewers extracted all relevant information from each eligible article: number of participants, sex, FMS cut-off criterion, number of total participants below and above the FMS cut-off criterion (or odds ratio), occupation (e.g. solider or firefighter), and injury type. All extracted data were entered in Comprehensive Meta-Analysis (version 3; Biostat Inc., Englewood, NJ, USA).

Data synthesis

Multiple weighted random effects meta-analyses were conducted using an odds ratio, centered on 1.00 as the effects metric. The magnitude of the effects for each meta-analysis was interpreted based on the following scale in which the magnitude was determined by the lower limit of the effects: trivial (<1.5), small (≥1.5<3.5), moderate (≥3.5<9) and large (≥9)[21, 27]. Separate meta-analyses were performed for each of the following moderators: FMS cut-off criterion (e.g., ≤14/>14), occupation (e.g., military and fire), sex, and injury type (e.g. overuse). A funnel plot was checked for symmetry to determine if a publication bias was present. In addition, multiple failsafe N (s) were calculated for each meta-analysis to determine the number of negative data points needed to increase the *p*-value to statistical insignificance (*p*≥0.05).
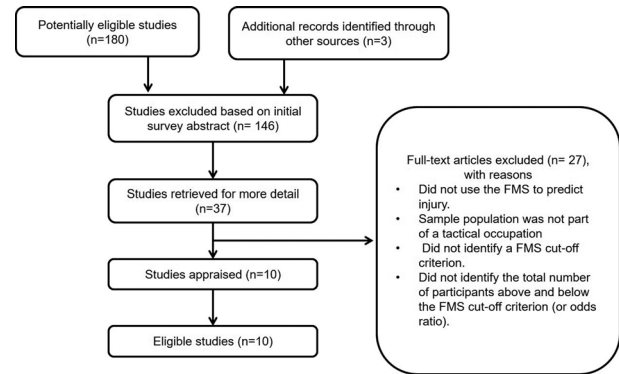

Fig. 1.　Outline of literature search and selection.

Results

The search revealed 183 potentially relevant studies. Ten studies[11–13, 15–20, 28] met the inclusion criteria (Fig. 1) accounting for 38 observed data points. The characteristics of each study are described in Table 1. Due to the limited number of studies meeting the inclusion criteria no studies were excluded from an analyses based on quality of evidence. The Scottish Intercollegiate Guidelines Network (SIGN) algorithm for classifying study design was used to classify the study design and identify the correct appraisal checklist required to appraise the quality of evidence and risk of bias inherent in each article (Table 1)[29, 30]. The SIGN uses the following criteria for assigning the level of evidence a particular article: 1, 2, 3, and 4.

The SIGN grading system rates the risk of bias using ++ (high quality, with little or no risk of bias), + (acceptable some flaws in the study with associated risk of bias) and − (low quality with significant flaws relating to key aspects of study design)[29]. The SIGN criteria of 1 ++ represents the highest level of evidence and would be considered a "high quality meta-analyses, systematic reviews of RCTs, or RCTs with a very low risk of bias"[29]. The final recommendation was based on the SIGN criteria, forms of recommendation (strong for, strong against, conditional against and conditional for)[29]. The SIGN is a commonly used instrument used to appraise manuscripts[31, 32] and determine level of selection, performance, attrition, and detection bias[33, 34]. Two reviewers (R.K., D.H.) appraised each of the included articles. The reviewers resolved disagreements concerning article quality and level of bias by coming to consensus or by arbitration of a third reviewer (G.G.) if disagreement persisted. A funnel plot was conducted for the analyses using a ≤14/>14 cutoff score because it represented our largest pool of studies. The fun-

Table 1. Study demographics and level of evidence

Study	Sex	Occupation	Age (yr)	Height (cm)	Mass (kg)	FMS score	FMS cutoff criterion	Type of injury	Level of evidence
Knapik et al.[12]	770 M 275 F	U.S. Coast Guard Cadets	18.1 ± 0.7 17.9 ± 0.7	179 ± 7 166 ± 7	7 ± 12 6 ± 8	14.5 ± 1.9 15.1 ± 1.9	≤9/>9 through ≤18/>18	Training-related	2 (+)
McGill et al.[20]	53 M	Elite Task Force Police	37.9 ± 5.0	180 ± 10	88.7 ± 12.1	15.1 ± 2.4	≤13/>13	Back Injury	2 (+)
Kodesh et al.[18]	158 F	Israeli Soldiers	19 (med)	164 (med)	56 (med)	16 (med)	≤14/>14	Serious§	2 (−)
Everard et al.[16]	132 M	Irish Defense Force	22.4 ± 4.2	177 ± 35	74.5 ± 5.8	15 (med)	≤14/>14	Time-loss MSI	2 (+)
Bushman et al.[15]	2,476 M	U.S. Soldiers	18 to 57	NP	NP	NP	≤14/>14 through ≤16/>16	Any injury Overuse Traumatic	2 (+)
Lisman et al.[19]	874 M	U.S. Marine Corp Officer Candidates	22.4 ± 2.7	NP	NP	16.6 ± 1.7	≤14/>14	Any injury Overuse Traumatic	2 (+)
O'Connor et al.[13]	874 M	U.S. Marine Corp Officer Candidates	LC:23 ± 2.6 SC:21.7 ± 2.6	NP	NP	16.6 ± 1.7	≤14/>14 ≤17/>17	Any injury Overuse Traumatic⌡ Serious*	2 (+)
Butler et al.[28]	108 B	Firefighter Cadets	NP	NP	NP	NP	≤14/>14	Injury requiring 3 consecutive missed training days†	2 (−)
Peate et al.[17]	433 B	Firefighters	M: 41.8 F: 37.4	NP NP	NP NP	NP NP	≤16/>16	All injuries‡	2 (+)
Cosio-Lima et al.[11]	31 M	U.S. Coast Guard MSRT Candidates	28 ± 4	179.6 ± 6.1	84.4 ± 12.5	15 ± 2.0	≤14/>14 & ≤16/>16	Training-related	2 (−)

M: male; F: female; B: both males and female included, but number of each not specified; med: median; NP: not provided; MSRT: Maritime Security Response Team; MSI: musculoskeletal injury; §serious: any injury resulting in 2 or more days of missed training; ⌡did not report values; ‡did not include burns, abrasions and lacerations; LC: long-cycle; SC: short-cycle. *serious: individual attired from training; †did not including burns; ‡did not include burns, abrasions and lacerations; LC: long-cycle; SC: short-cycle.
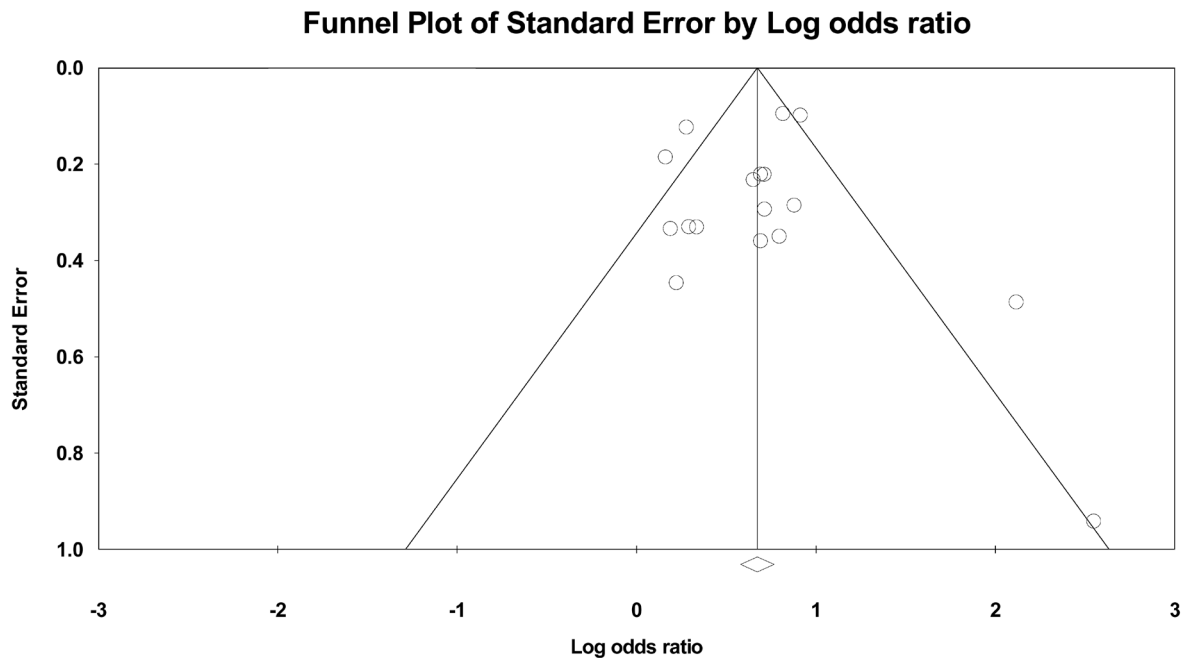
Funnel Plot of Standard Error by Log odds ratio

Fig. 2. Funnel plot of included studies for ≤14/>14 cutoff score.

nel plot of the effect-size data were symmetric, indicating no publication bias (Fig. 2).

FMS cutoff criterion

As depicted in Table 2, the odds of tactical athletes sustaining an injury with a FMS cutoff score of ≤14 ($p<0.001$) were 1.90 times higher as compared to athletes with scores >14. Failsafe N indicated that for this analysis, 627 missing data points would be required to increase the meta-analysis p-value to more than 0.05. The odds of injury were also found to be significantly ($p<0.05$) greater when using the cutoff scores of ≤15/>15, ≤16/>16, and ≤17/>17. The Failsafe N (s) for ≤15/>15, ≤16/>16, and ≤17/>17 indicated that 99, 7, and 0 missing data would be required to increase the meta-analysis p-value to more than 0.05. Individual scoring ≤12 were not at significantly ($p=0.193$) greater odds of sustaining an injury as compared to those scoring above >12. Those scoring ≤13 was also not at significantly ($p=0.371$) greater odds of injury.

Occupation

Table 3 summarizes the results of the moderated analyses for occupation. The analyses of tactical athletes employed by the U.S. armed forces revealed that athletes scoring ≤14 ($p<0.001$) had a 1.83 times greater odds of sustaining an injury as compared to those scoring >14.

Failsafe N indicated that for this analysis, 520 missing data points would be required to increase the meta-analysis p-value to more than 0.05. The odds of sustaining an injury if U.S. armed forces personnel scored ≤15 ($p<0.001$), ≤16 ($p=0.037$) and ≤17 ($p=0.038$) were also significantly greater. Failsafe N (s) indicated that for the cutoff scores of ≤15/>15, ≤16/>16, and ≤17/>17, 99, 3 and 0 missing data points, respectively, were required to increase the meta-analysis p-value to more than 0.05.

Moderating the analyses for specific branch, we observed the U.S. Coast Guard personnel (specifically, Candidates in Summer Warfare Annual Basic: SWAB and Maritime Security Response Team: MSRT) scoring ≤14 ($p=0.066$) or ≤16 ($p=0.102$) were not at significantly greater odds for sustaining injury in comparison to those that scored above either 14 or 16. However, a moderated analysis revealed that soldiers scoring ≤14 had significantly ($p<0.001$) greater odds of sustaining an injury as compared to soldiers scoring above. Failsafe N indicated that for this analysis, 106 missing data points would be required to increase the meta-analysis p-value to more than 0.05. Using U.S. Marine Corp Officer Candidates as a moderator, we found that candidates scoring ≤14 had significantly ($p<0.001$) greater odds of sustaining an injury as compared to U.S. Marine Corp Officer Candidates scoring above 14. Failsafe N indicated that for this analysis,

Table 2. Analyses moderated by FMS cutoff score

Cutoff score	Effect size and 95% CI			z-value	p-value	Heterogeneity					Included studies	Relative weight	Number of data points used	Study quality
	LL	OR	UL			Q statistic	df	p-value	I^2	t^2				
12	0.86	1.34	2.08	1.30	0.193	8.39	2	0.015	76.16	0.11	Knapik et al.[12]	55.75	2	+
											Kodesh et al.[18]	44.25	1	−
13	0.71	1.34	2.54	0.90	0.371	5.76	2	0.056	65.25	0.19	Knapik et al.[12]	83.87	2	+
											McGill et al.[20]	16.13	1	+
14*	1.58	1.90	2.29	6.84	<0.001	44.68	16	<0.001	64.19	0.08	Bushman et al.[15]	30.22	3	+
											Butler et al.[28]	2.82	1	−
											Cosio-Lima et al.[11]	0.92	1	−
											Everard et al.[16]	3.21	1	+
											Knapik et al.[12]	13.56	2	+
											Kodesh et al.[18]	4.70	1	-
											Lisman et al.[19]	18.58	3	+
											O'Conner et al.[13]	25.99	5	+
15*	1.52	1.90	2.37	5.63	<0.001	7.75	3	0.051	61.29	0.03	Bushman et al.[15]	72.35	2	+
											Knapik et al.[12]	27.65	2	+
16*	1.06	1.26	1.52	2.54	0.011	2.86	4	0.582	0	0	Bushman et al.[15]	68.82	1	+
											Cosio-Lima et al.[11]	0.64	1	−
											Knapik et al.[12]	14.18	2	+
											Peate et al.[17]	16.37	1	+
17*	0.55	0.74	0.98	−2.08	0.038	1.87	3	0.599	0	0	Knapik et al.[12]	14.27	2	+
											O'Conner et al.[13]	85.73	2	+

*$p \leq 0.05$.

74 missing data points would be required to increase the meta-analysis p-value to more than 0.05.

Sex

Table 4 details our findings for sex as a moderator. The odds of male tactical athletes with a FMS cutoff score of ≤14 of sustaining an injury were 1.83 times higher as compared to athletes with scores >14 (p<0.001). Failsafe N indicated that for this analysis, 440 missing data points would be required to increase the meta-analysis p-value to more than 0.05. In male tactical athletes, those with a FMS cutoff score of ≤15 had a 1.83 times higher odds of sustain an injury as compared to athletes with scores >15 (p<0.001). Failsafe N indicated that for this analysis, 73 missing data points would be required to increase the meta-analysis p-value to more than 0.05. Finally, in males alone the odds of injury were not significantly higher in tactical athletes scoring ≤16 (p=0.122) as compared to those scoring >16. Females scoring ≤12 were not at significantly (p=0.440) greater odds of sustaining injury than those females scoring >12.

Injury type

For overuse injuries males with a FMS cutoff score of ≤14 were 1.82 times higher as compared to athletes with scores >14 (p=0.012). Failsafe N indicated that for this analysis, 30 missing data points would be required to increase the meta-analysis p-value to more than 0.05. The odds of traumatic injury were significantly higher in male tactical athletes with a FMS cutoff score of ≤14 compared to athletes with scores >14 (p=0.021). We were unable to run a Failsafe N for this analysis because there were less than 3 data points available for the analysis.

Discussion

Our main findings suggest the odds of injury were greatest for tactical personnel using FMS cutoff scores ≤14 and ≤15. In addition, to our knowledge it is the first to provide data on female tactical athletes. We found that using a cut score of ≤12 or ≤14, females in the armed forces were not at significantly greater odds of injury as compared to those females scoring above the cutoff scores. The present study was also the first to investigate the predictive value of the FMS in subgroups of the armed forces (e.g. Marine Corp, Army, and Coast Guard). We observed that soldiers and Marine Corp candidates scoring ≤14 had a significantly greater odds of injury than personnel scoring >14.

Of the available data, the cutoff criterion of ≤14/>14 yielded the highest odds ratio with those scoring ≤14 being almost two times more likely to suffer an injury. Bushman *et al.*[15] had the largest sample population (N=2,476, male U.S. soldiers) and used cut-off criterions ranging from ≤14/>14 through ≤16/>16. That group[15] reported the odds to be two times as great for those scoring ≤14 as compared to those scoring >14, similar to our overall analyses using the ≤14/>14 cutoff criteria. Bushman *et al.*[15] also reported that the test lacked sensitivity (33%) at the ≤14/>14 cutoff criteria. The authors[15] observed that increasing the cutoff criteria, lead to gains in sensitive and decreases in specificity, resulting in a lower number of true negatives and higher numbers of false positives. Knapik *et al.*[12] reported similar findings in men and women U.S. Coast Guard Cadets.

The search yielded two studies[17, 28] with a sample population of firefighters and one study[20] with a sample of law enforcement officers. This indicates area for future study. From the available data a moderated analysis for fire personnel alone was not possible because the two study meeting inclusion reported data different cutoff scores. Butler *et al.*[28] used a ≤14/>14, while Peate *et al.*[17] used a ≤16/>16. Peate *et al.*[17] used the largest sample of firefighters (N=433) and observed the odds of injury was not significantly higher for career firefighters scoring ≤16 as compared to those scoring >16. However, Butler *et al.*[28] found the odds of injury increased more than eight times for fire cadets scoring ≤14 as compared to cadets scoring >14. Butler *et al.*[28] also reported that the ≤14/>14 cutoff criteria only correctly classified 77.8% of the cadets.

Due to the lack of studies including law enforcement officers, a moderated analysis using this occupation was not possible. However, this study did report valuable insight into the effectiveness of the FMS in this population. McGill *et al.*[20] reported finding that using a FMS with a cutoff score of ≤14, the tool had a sensitivity of 26% and a specificity 76% for predicting back injuries. The sensitivity and specificity was 42% and 47%, respectively for the FMS's ability to predict any type of injury using the ≤14 cutoff score. Based on the reported sensitivity values, it appears that the FMS, when using the ≤14 cutoff score, is ineffective when attempting to correctly identify male law enforcement officers that may sustain an injury (true positive rate).

The majority of the studies[11–13, 15, 16, 18, 19] reported data on samples consisting of armed forces personnel (coast guard, soldiers and marines). Using occupation as a moderator revealed that personnel in U.S. Coast Guard

Basic Training or MSRT scoring ≤14 or ≤16 were not at statistically significant greater odds of sustaining an injury as compared to those scoring above the 14 or 16 cutoff criteria. Two[11, 12] of the 10 included studies were used in this moderated analysis for a total of 3 data points. The included studies[11, 12] provided level two evidence. Using the SIGN, we rated Knapik *et al.*[12] at a higher level with a 2+ as compared to 2− assigned to Cosio-lima *et al*[11]. Cosio-lima *et al.*[11] was the smaller of the two included studies with a sample of 31 male Maritime Security Response Team candidates. The authors[11] observed the risk (RR=5.6, 95% CI=0.89–35.29, *p*<0.01) of injury was more than 5 times greater for males scoring ≤14 as compared to males scoring >14. However, the dispersion of the 95% CI is very high, thus their conclusion may be less certain[35]. The other included study, Knapik *et al.*[12], observed in a much larger sample (n=770) that the risk in male Coast Guard cadets in the Summer Warfare Annual Basic scoring ≤14 were not at greater risk (RR=1.14, 95% CI=0.85–1.54, *p*=0.38) of sustaining an injury compared to those scoring >14.

Five[13, 15, 16, 18, 19] of the 10 studies used a sample population consisting of soldiers or marines. The most common cutoff score was ≤14/>14. The largest of these studies was Bushman *et al.*[15] with a sample of 2,476 male U.S. Army soldiers. In that group of soldiers, the authors[15] observed that the mean FMS score for those not injured was 16.3 ± 2.3 (range, 5–21). The groups investigated injury risk using ≤14/>14, ≤15/>15 and ≤16/>16. In the prior study[15] the odds of injury were highest at the ≤14/>14 cutoff value. Bushman *et al.*[15] observed that soldiers scoring ≤14 had a two times greater odds of sustaining any type of injury than those scoring >14. In a group of 874 male U.S. Marine Corp Officer Candidates, Lisman *et al.*[19] reported similar findings as it relates to the ≤14/>14 cutoff score. Although the odds of sustaining an injury appears to be 2 times as great in those scoring ≤14, several studies show the tool lacks sensitivity when using the ≤14/>14 cutoff score[12, 13, 15]. It has also been observed that while higher cutoff scores allow for increased sensitivity of the FMS, it resulted in decrease specificity (true negatives)[12, 15].

Six[11, 13, 15, 16, 19, 20] out of 10 studies provided data exclusively on males, one[18] out of 10 studies provided data exclusively on females, one[12] study provided data separately on males and females, while two[17, 28] others grouped male and female data into one sample. Our finding of a heightened odds of injury in male armed forces personnel scoring ≤14 are inline line with a previous meta-analysis conducted by Moran *et al.*[21] in which their report indicated male armed forces personnel scoring ≤14

Table 3. Analyses moderated by FMS cutoff score and profession

Cutoff score	Occupation	Effect size and 95% CI			z-value	p-value	Heterogeneity					Included studies	Relative weight	Number of data points used	Study quality
		LL	OR	UL			Q statistic	df	p-value	I²	t²				
12	Armed forces	0.86	1.34	2.08	1.30	0.193	8.39	2	0.015	76.16	0.11	Knapik et al.[12]	55.75	2	+
												Kodesh et al.[18]	44.25	1	−
14*	Armed forces	1.54	1.83	2.17	6.91	<0.001	35.80	15	0.002	58.11	0.06	Bushman et al.[15]	33.72	3	+
												Cosio-Lima et al.[11]	0.81	1	−
												Everard et al.[16]	2.97	1	+
												Knapik et al.[12]	13.87	2	+
												Kodesh et al.[18]	4.52	1	−
												Lisman et al.[19]	18.66	3	+
												O'Conner et al.[13]	25.45	5	+
15*	Armed forces	1.52	1.90	2.37	5.63	<0.001	7.75	3	0.051	61.29	0.03	Bushman et al.[15]	72.35	2	+
												Knapik et al.[12]	27.65	2	+
16*	Armed forces	1.01	1.23	1.50	2.08	0.037	2.50	3	0.475	0.00	0.00	Bushman et al.[15]	82.28	1	+
												Cosio-Lima et al.[11]	0.77	1	−
												Knapik et al.[12]	16.95	2	+
17*	Aarmed forces	0.55	0.74	0.98	−2.08	0.038	1.87	3	0.599	0.00	0.00	Knapik et al.[12]	14.27	2	+
												O'Conner et al.[13]	85.73	2	+
14	U.S. Coast Guard	0.95	2.25	5.35	1.84	0.066	9.60	2	0.008	79.16	0.40	Cosio-Lima et al.[11]	15.10	1	−
												Knapik et al.[12]	84.90	2	+
16	U.S. Coast Guard	0.93	1.48	2.37	1.64	0.102	1.80	2	0.407	0.00	0.00	Cosio-Lima et al.[11]	4.32	1	−
												Knapik et al.[12]	95.68	2	+
14*	Soldiers	1.32	1.84	2.56	3.59	<0.001	19.96	3	<0.001	84.97	0.09	Bushman et al.[15]	85.75	3	+
												Kodesh et al.[18]	14.25	1	−
14*	Marine Corp Officer Candidates	1.56	1.89	2.28	6.49	<0.001	2.39	7	0.935	0.00	0.00	Lisman et al.[19]	45.68	3	+
												O'Conner et al.[13]	54.32	5	+

*$p \leq 0.05$. Armed forces: combines 2 or more studies with samples from different branches of military service (e.g. U.S. Coast Guard and U.S. Marine Corp.).

Table 4. Analyses moderated by FMS cutoff score, sex and injury type

Cutoff score	Sex	Injury type	Effect size and 95% CI			z-value	p-value	Heterogeneity					Included studies	Relative weight	Number of data points used	Study quality
			LL	OR	UL			Q statistic	df	p-value	I²	t²				
12	F	All injuries	0.65	1.32	2.69	0.77	0.440	4.99	1	0.025	79.96	0.22	Knapik et al.[12]	40.64	1	+
													Kodesh et al.[18]	59.36	1	−
13	M	All injuries	0.69	1.01	1.46	0.03	0.975	0.12	1	0.727	0.00	0.00	Knapik et al.[12]	92.35	1	+
													McGill et al.[20]	7.65	1	+
14	F	All injuries	0.89	1.75	3.43	1.62	0.105	2.45	1	0.117	59.24	0.14	Knapik et al.[12]	53.18	1	+
													Kodesh et al.[18]	46.82	1	−
14*	M	All injuries	1.53	1.83	2.20	6.52	<0.001	33.24	13	0.002	60.89	0.06	Bushman et al.[15]	37.11	3	+
													Cosio-Lima et al.[11]	0.91	1	−
													Everard et al.[16]	3.35	1	+
													Knapik et al.[12]	9.28	1	+
													Lisman et al.[19]	12.43	3	+
													O'Conner et al.[13]	28.51	5	+
14*	M	Overuse injuries	1.14	1.82	2.92	2.51	0.012	5.57	2	0.062	64.12	0.11	Bushman et al.[15]	47.76	1	+
													Lisman et al.[19]	26.13	1	+
													O'Conner et al.[13]	26.11	1	+
14*	M	Traumatic injuries	1.06	1.51	2.15	2.31	0.021	1.99	1	0.158	49.86	0.03	Bushman et al.[15]	64.02	1	+
													Lisman et al.[19]	35.98	1	+
15*	M	All injuries	1.42	1.83	2.36	4.68	<0.001	7.38	2	0.025	72.89	0.03	Bushman et al.[15]	79.32	2	+
													Knapik et al.[12]	20.68	1	+
16	M	All injuries	0.93	1.31	1.83	1.55	0.122	2.49	2	0.287	19.83	0.03	Bushman et al.[15]	75.39	1	+
													Cosio-Lima et al.[11]	2.19	1	−
													Knapik et al.[12]	22.42	1	+

*$p \geq 0.05$.

had a 1.47 risk of sustaining injury. The findings of the current meta-analysis extend those of previous systematic reviews[21–23] in several ways. First, using sex as a moderator we found females scoring ≤14 and even as low as ≤12 were not at significant odds of injury as compared to those scoring above those cutoff scores. Our results are based on two studies; in the first, Knapik et al.[12] favored the outcome of greater odds of sustaining injury in females at both cutoff scores, while in the second Kodesh et al.[18] did not. We were not able to explore other cutoff values in females because we did not have a minimum of two studies using the same cutoff score. Removing females only dropped the odds of sustaining injury by 0.07 times using a cutoff criterion of ≤14/>14. We also observed a similar drop using the cutoff criterion of ≤15/>15. The data clearly supports that male tactical athletes with FMS scores ≤14 and ≤15 do have a higher odds of injury as compared to males scoring >14 and >15. Further literature is required for the same assertion can be made regarding female tactical athletes. A greater understanding of how FMS scores affect the odds of injury in female tactical athletes would help in the development more specific training programs to help better address deficiencies in movement quality in female tactical athletes, similar to injury prevention approaches used to address poor landing mechanics in females engaged in traditional athletics[36, 37].

Second, with a moderated analysis for injury type, the present study confirmed that odds of overuse and traumatic injuries for personnel scoring ≤14 were similar to the results of analyses in which injury type was pooled. Earlier research has suggested that injury definitions largely impact injury incidence[38]. To our knowledge, this is the first meta-analysis to moderate for injury type. Moran et al.[21] discussed pooling based on injury definition in their methodology, but it is unclear how this was done given that the one[12] of the studies included in their analysis used a different injury definition. In the present meta-analysis, eight[11–13, 15, 16, 18, 19, 28] of the 10 studies used the cutoff score of ≤14/>14. In the available literature meeting the inclusion criteria, only 3 studies[13, 15, 19] provided data specifically on overuse injury in males, while two studies[15, 19] provided data on traumatic injuries in males. Only McGill et al.[20] grouped by body region. Using a ≤13/>13 cutoff score, the group[20] found the FMS lacked sensitivity and reported that a coin flip would have predicted injury better.

Taken together the odds of sustaining injury appear to be the highest for personnel scoring ≤14 of the FMS. The odds of injury for those scoring ≤14 are approximately two times greater than those scoring >14. However, cau-

tion is warranted as early reports indicate the sensitivity of the FMS tool (using a cutoff score of ≤14/>14) can range widely between 11.8% to 60.3% depending on sex and injury type[12, 13, 15]. Furthermore using higher cutoff scores negatively impacts the specificity of the tool[12]. Thus, while individual may be at increased odds for sustaining injury, given a cutoff score of ≤14/>14, the tool lacks the sensitivity and specificity to correctly classify personnel as having a high or low risk of injury.

Overall, the magnitude of the effects for each meta-analysis conducted in the present study ranged from trivial to small. Based on our review, the level of evidence provided by the included studies and the analyses of the provided data, we propose a conditional recommendation for the use of the FMS with the following caveat. Practitioners should not adopt the FMS as the sole indicator in classifying personnel as having a high or low risk of injury. Viewing the FMS in combination with other variables such as body composition, previous injury history or level of fitness may help to provide a better indicator of injury risk. Our recommendation as per the SIGN guidelines reflects the judgement that the desirable consequences likely outweigh undesirable consequences[29]. As a screening tool, the FMS can help direct practitioners to limitations in stability and mobility and help give practitioners baseline information of an individual's ability to move.

The following limitations are acknowledged. First, there is a possibility that not all available data (published or unpublished) were included in the analyses. However, a failsafe was provided that informs the reader of the negative data points required to negate the significant findings and increase the p-value above 0.05. In addition, interpretation of the findings solely on p-value may be misleading. There is a possibility that although the findings of a particular analysis were not statistically significant, they perhaps are clinically relevant. For example, we observed that U.S. Coast Guard personal scoring ≤14 were not at significant (p=0.066) odds of sustaining injury as compared to those scoring >14; however, the non-significant odds was 2.25. Arguably, a 2.25 greater odds of sustaining injury represent a clinically relevant finding, which would prompt a practitioner to explore means of reducing a tactical athlete's injury risk[35]. In the present analysis, an effect range estimate including one was considered a non-significant find. Effect range estimates, however, are impacted by the sample size and 95% CIs of the included studies[35]. In the analysis using U.S. Coast Guard as a moderator only two studies[11, 12] were included. One[11] of the included studies had a small sample (n=310) and very wide 95%

Table 5. Effects per datum point used in study

Subgroup within study	Statistics for each study				FMS cutoff score	Sex	Sample size	Occupation	Injury type
	Lower limit	Odds ratio	Upper limit	*p*-value					
Bushman *et al.*[15]	1.677	1.986	2.352	<0.001	15	M	2,476	U.S. Soldiers	All
	2.054	2.495	3.030	<0.001	14	M	2,476	U.S. Soldiers	Overuse
	1.811	2.167	2.593	<0.001	15	M	2,476	U.S. Soldiers	Overuse
	1.037	1.322	1.686	0.024	14	M	2,476	U.S. Soldiers	Traumatic
	0.954	1.186	1.476	0.125	16	M	2,476	U.S. Soldiers	Traumatic
	1.876	2.264	2.732	<0.001	14	M	2,476	U.S. Soldiers	All
Butler *et al.*[28]	3.199	8.310	21.590	<0.001	14	B	108	Firefighter	Time Loss Injury
Cosio-Lima *et al.*[11]	2.020	12.800	81.115	0.007	14	M	31	U.S. Coast Guard-MSRT	Training-related injury
	0.624	6.000	57.681	0.121	16	M	31	U.S. Coast Guard-MSRT	Training-related injury
Everard *et al.*[16]	0.520	1.250	3.002	0.618	14	M	132	Irish Defense Force	Time loss MSI
Knapik *et al.*[12]	0.698	1.025	1.507	0.899	13	M	770	U.S. Coast Guard	Training-related injury
	0.155	0.817	4.310	0.812	18	F	275	U.S. Coast Guard	Training-related injury
	0.749	1.145	1.750	0.532	15	M	770	U.S. Coast Guard	Training-related injury
	1.299	2.400	4.433	0.005	15	F	275	U.S. Coast Guard	Training-related injury
	0.994	1.513	2.305	0.054	12	M	770	U.S. Coast Guard	Training-related injury
	1.084	2.048	3.867	0.027	12	F	275	U.S. Coast Guard	Training-related injury
	1.295	2.294	4.062	0.004	13	F	275	U.S. Coast Guard	Training-related injury
	0.817	1.177	1.695	0.382	14	M	770	U.S. Coast Guard	Training-related injury
	1.376	2.411	4.223	0.002	14	F	275	U.S. Coast Guard	Training-related injury
	0.314	0.792	2.000	0.622	17	M	770	U.S. Coast Guard	Training-related injury
	0.296	1.111	4.165	0.876	17	F	275	U.S. Coast Guard	Training-related injury
	0.820	1.551	2.932	0.177	16	M	770	U.S. Coast Guard	Training-related injury
	0.578	1.203	2.505	0.622	16	F	275	U.S. Coast Guard	Training-related injury
	0.132	1.141	9.846	0.904	18	M	770	U.S. Coast Guard	Training-related injury
Kodesh *et al.*[18]	0.872	0.980	1.102	0.736	12	F	158	Isreali Soldiers	All
	0.628	1.210	2.331	0.570	14	F	158	Isreali Soldiers	All
Lisman *et al.*[19]	1.321	2.040	3.151	0.001	14	M	874	U.S. Marine Corp Officer Candidates	All
	0.701	1.340	2.563	0.376	14	M	874	U.S. Marine Corp Officer Candidates	Overuse
	1.215	1.920	3.033	0.005	14	M	874	U.S. Marine Corp Officer Candidates	Traumatic
McGill *et al.*[20]	0.210	0.800	3.046	0.744	13	M	53	Elite Task Force Police	Any Back Injury
O'Conner *et al.*[13]	1.116	2.218	4.410	0.023	14	M	427	U.S. Marine Corp Officer Candidate	All
	1.148	2.043	3.638	0.015	14	M	447	U.S. Marine Corp Officer Candidate	All
	0.376	0.588	0.919	0.020	17	M	427	U.S. Marine Corp Officer Candidate	All
	0.560	0.860	1.320	0.490	17	M	446	U.S. Marine Corp Officer Candidate	All
	1.295	2.000	3.088	0.002	14	M	874	U.S. Marine Corp Officer Candidate	All
	0.732	1.400	2.679	0.310	14	M	874	U.S. Marine Corp Officer Candidate	Overuse
	0.988	2.000	4.050	0.054	14	M	874	U.S. Marine Corp Officer Candidate	Serious
Peate *et al.*[17]	0.916	1.433	2.242	0.115	16	B	433	Firefighter	All

CI. Finally, a limited number of studies met our inclusion criteria; thus, we chose to include all available data into our analyses meeting the inclusion criteria, regardless of perceived quality. To determine the negative influence of pooling studies of varying quality, a sensitivity analysis was undertaken in which studies of low quality were removed. However, we did not perform a sensitivity analysis if the pooled analysis only included two studies and one was of low quality. Removal of the low quality studies in the remainder of the analyses did not change our earlier observed outcomes; thus, we believe inclusion of all studies regardless of quality is justified. The authors have provided the separate effects for each datum point included (Table 5). Providing the effects for each datum used in the meta-analysis will allow readers to reanalyze the data and exclude studies based on specific study characteristics (e.g. quality of study, sex, FMS cutoff score, and occupation). As more evidence becomes available researchers will be able to quickly add new data to this pre-existing data set and provide further insight into the FMS as a diagnostic tool.

The odds of sustaining injury were greatest for tactical athletes with FMS scores ≤ 14 as compared to tactical athletes scoring >14; however, the magnitude of the effects for each meta-analysis conducted in the present study ranged from trivial to small. Thus, while as a tool the FMS can help alert the practitioner to possible at risk patterns of movement, it should not be used as a singular method of determining if a tactical athletes should be classified as high or low risk for injury.

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