Do Normative Composite Scores on the Functional Movement Screen Differ Across High School, Collegiate, and Professional Athletes? A Critical Review

Travis R. Pollen, MS,* Frazier Keitt, DO,† and Thomas H. Trojian, MD†

Abstract

Objective: The Functional Movement Screen (FMS) is a battery of 7 unloaded tests designed to rate human movement competency. Injury rates vary across the different level of a sport. The purpose of this critical review was to determine whether normative FMS composite scores differ across high school, collegiate, and professional athletic populations and to determine whether normative composite scores correlate with rates of severe injury across different collegiate sports. **Data Sources:** PubMed, Web of Science, and EBSCO databases from inception to September 2017 with the following syntax: "functional movement screen*" OR "movement screen*". Additional records were identified by citation tracking and hand search of articles. **Study Selection:** A total of 708 records identified, of which 36 were included. Studies were included if they reported a FMS composite score for one of the groups. **Data Extraction:** Two reviewers (T.R.P. and F.K.) screened records for the author and year; sample size; study design; sport(s); number, age, and sex of participants; testing conditions; methodological quality; and mean or median composite score(s). **Data Synthesis:** Normative FMS composite scores were invariant to level of play, with 61% of reported scores falling between 14 and 16, despite injury rates increasing by level of play. Scores for high school, college, and professional athletes were 14.1, 14.8, and 15.7, respectively. There was a significant positive relationship between composite scores and rate of severe injury in college sports ($r(11) = 0.66$, $P = 0.014$). **Conclusions:** Our findings potentially undermine the FMS's predictive validity. Although the FMS may have other applications, this critical review provides further evidence against the composite score for injury prediction in competitive athletes.

Key Words: Functional Movement Screen, preparticipation physical examination, injury prediction, injury rate, injury risk

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INTRODUCTION

The Functional Movement Screen (FMS) is a battery of 7 unloaded, field-expedient tests, which was designed to rate movement competency and predict injury.[1–4] The battery includes tests for mobility (active straight-leg raise and shoulder mobility), motor control (rotary stability and trunk stability push-up), and functional patterning (inline lunge, hurdle step, and deep squat).[5] There are also 3 accompanying clearing tests for pain provocation (shoulder impingement, spinal extension, and spinal flexion). Performance on each test is quantified using a 0 to 3 scale: 3 denotes noncompensatory performance, 2 denotes performance with compensation, and 1 denotes an inability to perform the test. A score of 0 is given for a test if the individual reports pain anywhere in the body during the movement, regardless of performance. A composite score is calculated by summing the individual test scores, with a maximum possible score of 21.

Over the past decade, many studies have investigated the reliability and validity of the FMS. Based on multiple reviews and meta-analyses, the FMS has been shown to exhibit acceptable intrarater, interrater, and test–retest reliability.[6–10] These findings are largely independent of rater experience,[7,9,10] although some authors' contend experience improves reliability.[6,8] However, the FMS's validity for injury prediction remains controversial. When the FMS was initially described in the literature, it was proposed that it could be used to identify individuals who were more at risk of injury.[1,2] The first and oft-cited evidence of the FMS's predictive validity comes from a 2007 study of American professional football players.[11] Using a cutoff composite score of ≤14 points, this study found a relative risk (RR) of 4.20, which corresponds to over a 4-fold increase in injury risk for athletes who scored ≤14 points.

Since the initial study by Kiesel et al,[11] many researchers have endeavored to replicate the relationship between the composite score and injury across numerous populations. However, no follow-up study has reproduced the magnitude of the effect from the 2007 study, even when different cutoff scores were used.[9,10,12,13] Meta-analyses provide a summary odds ratio and RR of 2.74 and 1.5, respectively.[10,12]

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From the *Physical Therapy & Rehabilitation Sciences Department, College of Nursing & Health Professions, Drexel University, Philadelphia, Pennsylvania; and †Division of Sports Medicine, Drexel University College of Medicine, Philadelphia, Pennsylvania.

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Corresponding Author: Thomas H. Trojian, MD, Division of Sports Medicine, Drexel University College of Medicine, 10 Shurs Lane, Philadelphia, PA 19127 (Tht34@drexel.edu).

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Relatedly, nearly all the prospective studies that have used a cutoff composite score report low sensitivity (ie, a high false-negative rate).[12,14,15] Potentially further weakening the case for validity of the composite score, factor analyses on athletes have yielded mixed results regarding the number of underlying constructs measured by the 7 tests.[16,17] If the tests do measure more than one construct, it would be mathematically inappropriate to add the individual test scores together to form a composite score.[14,18] Frost et al[19] demonstrated one final threat to validity. They showed that knowing the scoring criteria can immediately improve composite scores by 2.6 points. Although this study was conducted on firefighters, it brings into question whether the FMS truly measures movement competency and, by extension, injury risk.

In recent years, the FMS team has updated its stance on the composite score's utility for injury prediction. In 2014, Cook et al[4] explicitly discouraged the use of the composite score. The authors further acknowledged that even if an athlete scores high on the FMS, they may still have other intrinsic risk factors that could predispose them to injury. They advocated for additional sports-specific testing beyond the FMS to determine injury risk. Also, in 2014, Kiesel et al[20] conducted another study on American professional football players. This time they showed that movement asymmetry (ie, a difference in performance between sides) was associated with injury (RR = 1.80). The authors also encouraged practitioners to remediate athletes with individual tests scores of 0 or 1, independent of composite score. Taken together, this emphasis on asymmetries and low test scores is more in line with Cook et al's[4] recommendations. Mokha et al[21] confirmed the importance of asymmetry when they found it was associated with injury (RR = 2.73), but composite score $\leq$14 was not (RR = 0.68).

Clearly, at this point, the use of the FMS composite score as an injury prediction tool should be questioned. Yet, despite all the previously described evidence—as well as the FMS's creators' updated 2014 recommendations—researchers continue studying the predictive validity of a cutoff composite score.[22–24] To aid in the understanding of the relationship between the FMS composite score and injury, in this critical review, we propose a novel perspective. Instead of asking whether the composite score predicts injury prospectively, we pose a slightly different question: Do athletic populations known to be at higher risk of injury perform worse (ie, have lower composite scores) on the FMS? Data from epidemiology studies show that injury rates for high school,[25] college,[26] and professional[27–30] male athletes tend to increase with level of play in basketball, baseball, football, and soccer (see **Table 1, Supplemental Digital Content 1**, http://links.lww.com/JSM/A191). If the FMS composite score could indeed be used in isolation for injury prediction, it would be reflected by lower normative composite scores for athletes with higher injury rates. After all, if performing poorly on the FMS means an athlete is at greater risk of injury, then being at greater risk of injury should also imply an athlete or group of athletes will perform poorly on the FMS.

The purpose of this critical review was to determine whether normative FMS composite scores differ across high school, collegiate, and professional athletic populations with differing injury rates. A secondary aim was to determine whether normative composite scores correlate with injury rates within a single level of play (college sports). Based on previous observations, wherein most normative composite scores fall between 14 and 16, we hypothesized that FMS scores would be invariant across athletic populations and therefore not correlate with injury rates.

METHODS

Search Strategy

A systematic literature search was conducted on September 21, 2017, to identify all relevant studies. The PubMed, Web of Science, and EBSCO databases were searched since inception with the following syntax: "functional movement screen*" OR "movement screen*." Additional records were identified by citation tracking and hand search of articles in press. All records were saved using the Mendeley Desktop reference manager (Mendeley, Ltd, London, United Kingdom). Duplicate records were removed.

Selection Criteria

Two reviewers (T.R.P. and F.K.) screened records for eligibility. Studies were included in the critical review if they reported a FMS composite score for one or more groups of high school, college, or professional sports. Studies were excluded for any of the following reasons: (1) not English or Spanish language; (2) unrelated to the FMS; (3) review papers, conference abstracts, or theses; (4) not conducted on athletes; or (5) did not report a separate composite score for athletes by sport, sex, and level. The author and year; sample size; study design; sport(s); number, age, and sex of participants; testing conditions; methodological quality of FMS administration; and mean or median composite score(s) were then extracted from each included study by 2 reviewers (T.R.P. and F.K.). Composite scores based on fewer than 5 participants were not included. For studies in which the FMS was tested at multiple time points (as in an intervention study), only the first observation was extracted.

Data Analysis and Synthesis

A dot-density plot was generated using MATLAB (MathWorks, Natick, MA) to visualize the spread of mean and median FMS composite scores across levels of play. Weighted average scores per level of play were also computed using Excel 2015 (Microsoft, Redmond, WA). Weights were based on the number of corresponding participants, and only mean scores were included (ie, median scores were excluded). Weighted averages were also computed in the same way for each college sport that was reported on by multiple studies. Using the sports-specific weighted averages, 2-tailed Pearson correlations were run between composite scores and available national average injury rates for NCAA sports[31,32] using SPSS 24.0 (IBM, Corp, Armonk, NY). These correlations were conducted in 2 ways: with the rate of all injuries requiring medical attention from 2009 to 2014[31] and with the rate of only severe injuries from 2009 to 2015 (ie, time loss injuries of 3 weeks or more).[32] To control familywise error rate for the 2 correlations, a Bonferroni correction was used to set significance to $\alpha = 0.025$.

RESULTS

The literature search identified 708 total records, of which 36 were included in the critical review, as shown in the flow diagram (Figure 1). These 36 studies provided 62 unique

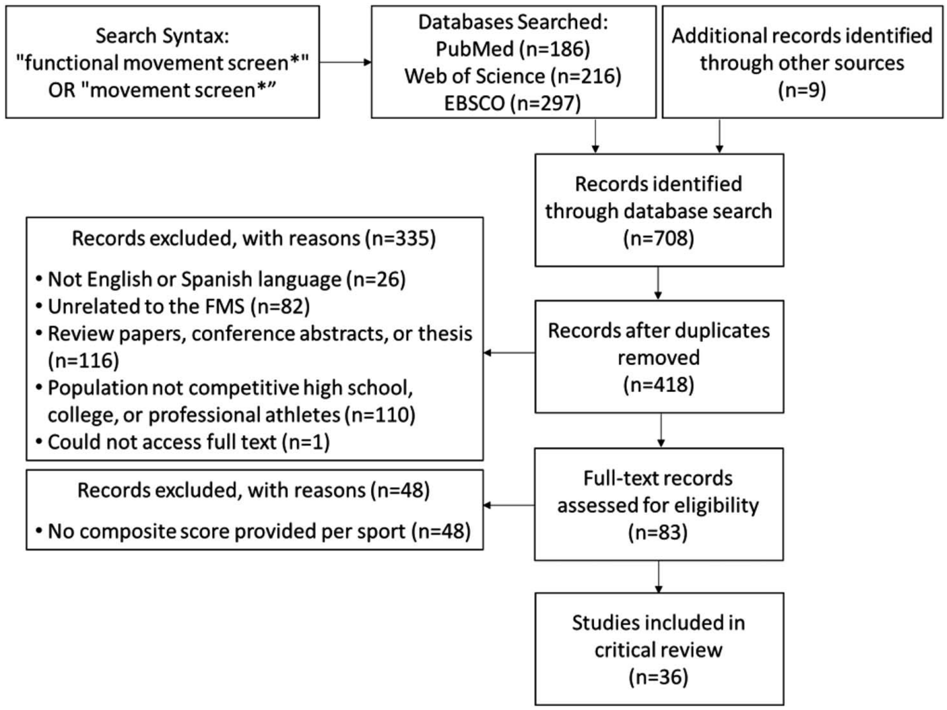

Figure 1. Flow diagram of search strategy and study inclusion/exclusion.

composite scores (13 high school, 26 college, and 23 professional) representing a total of 3215 athletes (2638 males and 577 females). The included studies are described in Table 1. Mean and median FMS composite scores per sport ranged from 12 (men's college basketball)[33] to 17.5 (men's professional soccer)[34] (Figure 2). Of the 62 total composite scores, 38 of them (61%) fell between 14 and 16. The weighted average composite scores by level of play were 14.1, 14.8, and 15.7 for high school, college, and professional athletes, respectively. At $\alpha = 0.025$, there was no significant relationship between collegiate FMS composite scores and all injury rate ($r(11) = 0.57$, $P = 0.041$) (Figure 3). However, there was a significant positive relationship between collegiate FMS composite scores and severe injury rate ($r(11) = 0.66$, $P = 0.014$) (Figure 4).

DISCUSSION

The purpose of this critical review was to determine whether normative FMS composite scores differ across high school, collegiate, and professional athletic populations with differing injury rates. As hypothesized, FMS scores were relatively invariant to level of play, with 61% of the reported scores falling between 14 and 16. The weighted average composite scores for high school, college, and professional athletes were 14.1, 14.8, and 15.7, respectively. Previous research has shown that the minimum detectable difference (95% confidence interval) in the composite score is between 2.1 and 2.7.[35,36] Therefore, it is unlikely that the observed differences in composite scores between levels of play exceed the measurement error of the FMS. This invariance in composite score across levels of play contrasts with substantial increases in injury rates from high school to college to professional sports. In high school sports during the 2015 to 2016 academic year, 1.39 and 4.74 injuries occurred per 1000 athlete-exposures in practice and competition, respectively.[25] These figures swell to 3.7 and 11.4, respectively, in college sports for the 2003 to 2004 year.[26] In these high school and college epidemiology studies, injury was defined identically as one or more days of time loss. Injury rates are even higher in professional sports (basketball, baseball, and football, for example).[27–29] It is evident that FMS composite scores do not reflect these differences in injury rates across levels of play.

The secondary aim of this critical review was to determine whether normative FMS composite scores correlate with injury rates within a single level of play (college sports). If performing poorly on the FMS was indicative of an athlete being at greater risk of injury, then being at greater risk of injury would similarly indicate poor performance on the FMS. Contrary to this logic and to our hypothesis of no relationship, a positive relationship was found between FMS score and severe injury rate in college sports. That is, as severe injury rate increases, FMS composite score also increases. Given existing multifactorial models of athletic injury etiology, this finding is not surprising. It is well known that there are myriad intrinsic risk factors (eg, age, injury history, and strength) and extrinsic risk factors (eg, equipment and playing conditions) for injury.[37–40] Based on these findings, other risk factors must be contributing more to injury rates in college sports than movement competency, at least as measured by the FMS. It may be that different sports require different cutoff scores for injury risk, which would complicate the comparison across sports, although this hypothesis has yet to be explored.

Based on the findings of this critical review and the mounting body of evidence, the FMS composite score should not be used in isolation to predict injury. However, there is

TABLE 1. Characteristics of Included Studies

Reference	Study Design	Population	Number, Sex, and Type of Relevant Participants	Age (Mean ± SD, yrs)	Testing Conditions Specified (eg, Preseason)	Composite Score (Mean ± SD, Unless Otherwise Indicated)	Methodological Quality of FMS Administration	Additional Comments
Adamczyk et al,[55] 2015	Cross-sectional	Polish male track and field runners	60 M	19.6 ± 2.4	Testing occurred during a regular high-intensity training period	16.7 ± 1.4	Rater(s) not described; reliability not reported Clearing tests not described as part of FMS administration	
Azzam et al,[56] 2015	Prospective cohort	NBA players	34 M	Not provided	Preseason over the course of 4 seasons	13.2 ± 2.6	Two FMS-certified raters (both certified athletic trainers); reliability not reported	
Bullock et al,[57] 2017	Cross-sectional	High school and college swimmers	140: 43 M (high school), 27 F (high school), 34 M (college), and 36 F (college)	17.0 ± 1.1 (high school M), 16.7 ± 0.7 (high school F), 20.8 ± 1.2 (college M), and 20.5 ± 1.2 (college F)	Not provided	Means: 12.4 (high school M), 12.8 (high school F), 13.9 (college M), and 14.0 (college F)	Raters were trained in the FMS; reliability not reported	Upper Quarter Y-Balance Test also conducted
Chalmers et al,[49] 2017	Prospective cohort	Elite junior Australian football (soccer) players from 8 South Australian National Football League U18 clubs	237 M	16.6 ± 0.8	Late preseason	13.5 ± 2.3	Seven FMS-certified raters (6 physiotherapists and 1 strength and conditioning coach), all with at least 3 years of experience in practicing; reliability not reported Contrary to the FMS protocol,[5] warm-up and test demonstrations were provided	Sex not explicitly stated, but assumed male FMS conducted as part of a fitness testing combine
Chapman et al,[58] 2014	Prospective cohort	US track and field	121 (55 M and 66 F)	Not provided	Preseason	15.2 ± 1.9 (M) and 15.6 ± 1.9 (F)	Two FMS-certified raters (both sports medicine physicians) who had each conducted over 1000 screens; reliability not reported Clearing tests not described as part of FMS administration	
Chimera et al,[50] 2015	Cross-sectional	Division I athletes across multiple sports	157: 17 (W cross country), 29 (W soccer), 15 (W swimming and diving), 7 (W volleyball), 7 (M basketball), 11 (M cross country), 61 (M football), 5 (M tennis), and 5 (M track and field)	20.0 ± 1.5 (M) and 20.0 ± 1.4 (W)	During preseason preparticipation examination	15 ± 2 (W cross country), 15 ± 2 (W soccer), 14 ± 2 (W swimming and diving), 13 ± 2 (W volleyball), 14 ± 2 (M basketball), 14 ± 3 (M cross country), 14 ± 3 (M football), 15 ± 2 (M tennis), and 15 ± 2 (M track and field)	Two raters (one a certified athletic trainer and one physical therapist); interrater and intrarater reliability reported in a previous study[59] (ICC = 0.87-0.89 and ICC = 0.81-0.91, respectively)	Y-Balance Test also conducted as part of this study
Chorba et al,[51] 2010	Prospective cohort	NCAA Division II female athletes	38 F: 15 (soccer), 11 (volleyball), and 12 (basketball)	18.93 ± 1.10 (soccer), 18.91 ± 1.04 (volleyball), and 19.92 ± 1.24 (basketball)	Within 2 weeks of the beginning of the athletes' respective seasons	13.4 (soccer), 15.3 (volleyball), and 14.6 (basketball)	Two raters (both licensed physical therapists) with experience with the FMS; interrater reliability (through video) reported (ICC = 0.976) Clearing tests not described as part of FMS administration	7 of the 38 athletes had previous ACL injury and reconstruction. Mean FMS score for those 7 athletes was higher than that for the other 31.

TABLE 1. Characteristics of Included Studies *(Continued)*

Reference	Study Design	Population	Number, Sex, and Type of Relevant Participants	Age (Mean ± SD, yrs)	Testing Conditions Specified (eg, Preseason)	Composite Score (Mean ± SD, Unless Otherwise Indicated)	Methodological Quality of FMS Administration	Additional Comments
Clifton et al,[33] 2015	Cross-sectional	NCAA Division I athletes (men's basketball, women's basketball, and women's soccer)	103: 18 M (basketball), 23 W (basketball), and 62 W (soccer)	Not provided	Off-season	Medians: 12 (M basketball), 15 (W basketball), and 16 (W soccer)	One FMS-trained rater (a certified athletic trainer); reliability not reported Clearing tests not described as part of FMS administration	
Dossa et al,[60] 2014	Prospective cohort	Major junior hockey team athletes	20 M	18 ± 1	Preseason	14.7 ± 2.58	One FMS-certified rater (a chiropractor); reliability not reported	
Fox et al,[61] 2014	Cross-sectional	Elite male Gaelic field sports athletes	30 M: 18 (hurling) and 12 (Gaelic football)	23.50 ± 3.24 (hurling) and 20.67 ± 0.89 (Gaelic football)	Galway Hurling Training Gym and Biomechanics Laboratory	15.61 ± 1.79 (hurling) and 16.08 ± 1.24 (Gaelic football)	One rater, trained in the FMS as per a previous study[59]; reliability not reported Contrary to the FMS protocol,[5] participants were barefoot and scoring was completed by video	Players deemed elite if they were chosen to play for their county (top 28-30 in each county)
Fuller et al,[46] 2017	Cross-sectional	Elite junior male Australian football players	301 M	17 ± 1	Preseason	Median: 14, IQR: 12-15	Seven FMS-certified raters (6 physiotherapists and 1 strength and conditioning coach) Contrary to the FMS protocol,[5] warm-up was provided	FMS conducted as part of a fitness testing combine
Gábriš et al,[62] 2015	Prospective cohort	Slovak women's national football (soccer) teams	58 W: 19 (A-team), 20 (U19), and 19 (U17)	20.84 ± 2.8 (A-team), 16.35 ± 0.49 (U19), and 14.42 ± 0.5 (U17)	National Training Center at the end of November	14.84 ± 2.61 (A-team), 14.35 ± 2.08 (U19), and 15.58 ± 1.54 (U17)	One FMS-certified rater (the team fitness coach); reliability not reported	Changes in the FMS measured in consecutive years. Extracted data are for the first year.
Gadziński et al,[34] 2017	Prospective cohort	Soccer players of Beskids Sports Association club, Rekord Bielsko-Biala ages	30 M (15 from senior futsal and 15 from senior 3rd league)	26.34 ± 4.83 (senior futsal) and 24.34 ± 4.17 (senior 3rd league)	Winter break between seasons (February 1, 2015-March 20, 2015)	16.80 ± 1.37 (senior futsal) and 17.53 ± 1.81 (senior 3rd league)	Rater(s) not described; reliability not reported	
Grygorowicz et al,[63] 2013	Cross-sectional	Polish female soccer players	43 F (21 Polish Premier League and 22 1st Division)	23.0 ± 0.8 (Polish Premier League); 19.0 ± 0.4 (1st Division)	Not provided	16.0 ± 0.5 (Polish Premier League) and 15.5 ± 0.6 (1st Division)	Rater(s) not described; reliability not reported	1st Division players less experienced than Premier League players FMS conducted as part of a physiotherapeutic examination
Hotta et al,[52] 2015	Prospective cohort	Competitive college track and field athletes	84 M	20.0 + 1.1	Preseason	14.1 ± 2.3	Two raters (physical therapists) trained by an FMS specialist; interrater reliability reported (ICC = 0.98) Clearing tests not described as part of FMS administration Contrary to the FMS protocol,[5] test demonstrations were provided	

TABLE 1. Characteristics of Included Studies *(Continued)*

Reference	Study Design	Population	Number, Sex, and Type of Relevant Participants	Age (Mean ± SD, yrs)	Testing Conditions Specified (eg, Preseason)	Composite Score (Mean ± SD, Unless Otherwise Indicated)	Methodological Quality of FMS Administration	Additional Comments
Kiesel et al,[11] 2007	Prospective cohort	Professional football players	46 M	Not provided	Preseason	16.9 ± 3.0	One rater (the team strength and conditioning coach) with 11 years of experience; reliability not reported	FMS conducted as part of preseason physical performance testing
Kiesel et al,[64] 2011	Intervention	Professional American football players	62 M (32 linemen and 30 nonlinemen)	Not provided	Start of the offseason	Combined: 12.5 ± 2.0; by position: 11.8 ± 1.8 (linemen) and 13.3 ± 1.9 (nonlinemen)	Rater(s) not described; reliability not reported Clearing tests not described as part of FMS administration	Study also provides FMS scores after intervention. Extracted data are only from preintervention.
Kiesel et al,[20] 2014	Prospective cohort	Professional football players	238 M	Not provided	Before the start of training camp	16.9 ± 1.7	Two raters (the strength and conditioning coaches of the 2 included teams), with 5 and 8 years of experience using the FMS; reliability not reported Clearing tests not described as part of FMS administration	Nonindependence of observations: one of the teams included in the study participated over 2 consecutive seasons, which resulted in some athletes being counted twice
Linek et al,[47] 2016	Intervention	Young male volleyball players	17 M	14	Before stabilization training	16.3 ± 2.4	One rater, described as “qualified and experienced”; reliability not reported Clearing tests not described as part of FMS administration Contrary to the FMS protocol,[5] warm-up was provided, only 2 trials were provided per test (instead of the normal 3), and test order may have been altered	Study also provides FMS scores after intervention. Extracted data are only from preintervention.
Lloyd et al,[48] 2015	Cross-sectional	Male youth soccer players from a professional soccer club in the United Kingdom	11 M (U16)	15.6 ± 0.7	Not provided	16.0 ± 2.0	One rater with 2 years of FMS experience; reliability not reported Contrary to the FMS protocol,[5] warm-up and test demonstrations were provided, and test order may have been altered	Squat and maximal rebounding test and reactive agility test conducted after the FMS
Martin et al,[65] 2017	Prospective cohort	Male adolescent cricket pace bowlers	27 M	16.82 ± 1.70 (injured, n = 10) and 16.44 ± 0.78 (uninjured, n = 17)	Preseason	16.44 ± 2.41	Rater(s) not described; reliability not reported	Screening of one athlete was discontinued due to knee pain during the deep squat, and that athlete was excluded from the study

TABLE 1. Characteristics of Included Studies *(Continued)*

Reference	Study Design	Population	Number, Sex, and Type of Relevant Participants	Age (Mean ± SD, yrs)	Testing Conditions Specified (eg, Preseason)	Composite Score (Mean ± SD, Unless Otherwise Indicated)	Methodological Quality of FMS Administration	Additional Comments
Newton et al,[22] 2017	Prospective cohort	English Premier League youth academy football (soccer) players	84 M	13.0 ± 1.3	Preseason	15.5 ± 1.9	Multiple raters (strength and conditioning coaches and physiotherapists) each with multiple years of assessment experience; reliability not reported Clearing tests not described as part of FMS administration	
Nicolozakes et al,[66] 2018	Cross-sectional	NCAA Division I football players	38 M (24 normal BMI and 14 obese)	18.0 ± 0.7	Testing occurred during the summer before the onset of their first official collegiate fall practice season	Combined: 14.9 ± 2.4; by BMI: 15.8 ± 1.4 (normal BMI) and 13.4 ± 3.0 (obese)	One rater (a state-licensed athletic trainer) with 3 years of FMS experience; reliability not reported	
Portas et al,[67] 2016	Cross-sectional	Male English Football League soccer players	499 M	128 (U15), 121 (U16), and 250 (U18)	End of preseason at regular training venue	Medians: 13 (U15), 13 (U16), and 14 (U18)	One rater with 5 years of FMS experience; reliability not reported	
Rowan et al,[68] 2015	Cross-sectional	Elite junior hockey players from around the world who took part in the 2013 NHL Combine	111 M	17.8 ± 0.4	Precombine	15.20 ± 2.51	Four raters who underwent ~20 hours of FMS training; reliability not reported Contrary to the FMS protocol,[5] the tests were conducted in a random order, participants were shown pictures and demonstrations of each test, and raters attempted to identify the causes of movement compensations while scoring	FMS conducted as part of NHL Combine that assessed player medical, physical, and physiological health
Salatkaitė et al,[69] 2016	Cross-sectional	Lithuanian women basketball league players (guards and forwards)	100 F (38 guards and 62 forwards)	22.62 ± 5.21	Preseason training period in September of 2014	Combined: 16.04 ± 1.81; by position: 16.47 ± 1.94 (guards) and 15.79 ± 1.69 (forwards)	Rater(s) not described; reliability not reported Clearing tests not described as part of FMS administration	Lower Quarter Y-Balance Test also conducted
Silva et al,[70] 2017	Cross-sectional	Youth elite soccer players	48 M: 22 (U16) and 26 (U19)	15.78 ± 0.52 (U16) and 17.32 (U19)	Not provided	13.87 ± 2.93 (U16) and 14.96 ± 2.07 (U19)	One rater (an FMS specialist) with 3 years of experience; reliability not reported	Sex not explicitly stated, but assumed male Physical performance tests also conducted: jumping during the same testing session as the FMS, and repeated sprints and kick speed during a later session on the same day
Słodownik et al,[71] 2014	Cross-sectional	1st division Polish handball players	15 M	24.1 ± 3.4	Following the competitive season	15.5 ± 1.9	Rater(s) not described; reliability not reported Contrary to the FMS protocol,[5] test demonstrations were provided	Study also reported on 2nd division players (composite score mean ± SD = 15.4 ± 2.6)

TABLE 1. Characteristics of Included Studies *(Continued)*

Reference	Study Design	Population	Number, Sex, and Type of Relevant Participants	Age (Mean ± SD, yrs)	Testing Conditions Specified (eg, Preseason)	Composite Score (Mean ± SD, Unless Otherwise Indicated)	Methodological Quality of FMS Administration	Additional Comments
Smith and Hanlon,[72] 2017	Prospective cohort	Semi-professional male soccer athletes (League of Ireland)	89 M	23.2 ± 4.4	Preseason	16.3 ± 1.8	One level-2 FMS-certified rater; reliability not reported	
Sprague et al,[73] 2014	Intervention	NCAA Division II collegiate soccer and volleyball athletes	57: 10 F (volleyball), 27 F (soccer), and 20 M (soccer)	20.1 ± 1.1 (M) and 19.3 ± 1.4 (W)	Part of preparticipation examination	14.80 ± 1.69 (volleyball), 15.78 ± 1.85 (W soccer), and 16.16 ± 1.54 (M soccer)	Seven raters (athletic trainers and physical therapists); reliability not reported Clearing tests not described as part of FMS administration	Study also provides scores after 3.5 months of in-season training and competition. Extracted data are only from preparticipation. Baseline FMS test was part of the athletes' preparticipation examination
Tee et al,[74] 2016	Prospective cohort	Professional rugby union players	62 M	Not provided	Preseason over 4 testing sessions	14.1 ± 1.7	One FMS-qualified rater (a registered biokineticist); reliability not reported Contrary to the FMS protocol,[5] scoring was completed by video using Dartfish video analysis software	Nonindependence of observations: 90 administrations of the test for 62 unique athletes; 22 athletes were tested and counted multiple times, with prehabilitation programs between testing sessions
Venter et al,[53] 2017	Cross-sectional	University level female netball athletes	19 F	19.95 ± 1.76	Start of season	14.5 ± 3.8	Two raters; interrater reliability reported (ICC = 0.775) Clearing tests not described as part of FMS administration Contrary to the FMS protocol,[5] scoring was completed by video, data were based on the average of the 2 raters' scores, and test order may have been altered	Physical performance tests also conducted: countermovement jump, speed test, 5-0-5 agility test, and repeated sprints
Waldron et al,[54] 2016	Cross-sectional	Elite male U19 rugby league players contracted to a professional club in England	13 M	18.2 ± 0.5	Preseason	Median: 14, 95% CI = 14-18	One rater with 1 year of FMS experience; test–retest reliability reported per test (percent agreement = 88.3-100%) Clearing tests not described as part of FMS administration Contrary to the FMS protocol,[5] test demonstrations were provided and only 2 trials were provided per test (instead of the normal 3)	Physical performance tests also conducted during subsequent days: speed test, countermovement jump, squat, and bench press Study also provided midseason and late season composite scores that were exactly the same

TABLE 1. Characteristics of Included Studies *(Continued)*

Reference	Study Design	Population	Number, Sex, and Type of Relevant Participants	Age (Mean ± SD, yrs)	Testing Conditions Specified (eg, Preseason)	Composite Score (Mean ± SD, Unless Otherwise Indicated)	Methodological Quality of FMS Administration	Additional Comments
Wiese et al,[75] 2014	Prospective cohort	NCAA Division I football players	144 M	18.9 ± 1.3	Beginning of 2010 and 2012 seasons in athletic training room at University of Kentucky	16.1 ± 1.9	Two raters (both certified athletic trainers but not FMS-certified) with 2 and 1.5 years of FMS experience; reliability not reported	
							Contrary to the FMS protocol,[5] the mode from 3 trials of each test was used (instead of the best trial)	
Willigenburg and Hewett,[76] 2016	Cross-sectional	NCAA Division I football players	59 M	18.0 ± 0.6	Preseason	14.3 ± 2.2	Two raters: one licensed athletic trainer with extensive FMS experience (~100 screens) and the other trained by the first; reliability not reported	Along with the FMS, hop testing, isokinetic knee strength, and isometric hip strength were conducted in a random order
Zalai et al,[77] 2015	Prospective cohort	Elite male professional Hungarian football (soccer) league athletes	20 M	23 ± 3	Preseason	14.75 ± 1.51	One rater (an FMS specialist); reliability not reported	
							Clearing tests not described as part of FMS administration	

ACL, anterior cruciate ligament; BMI, body mass index; ICC, intraclass correlation coefficient; IQR, interquartile range.

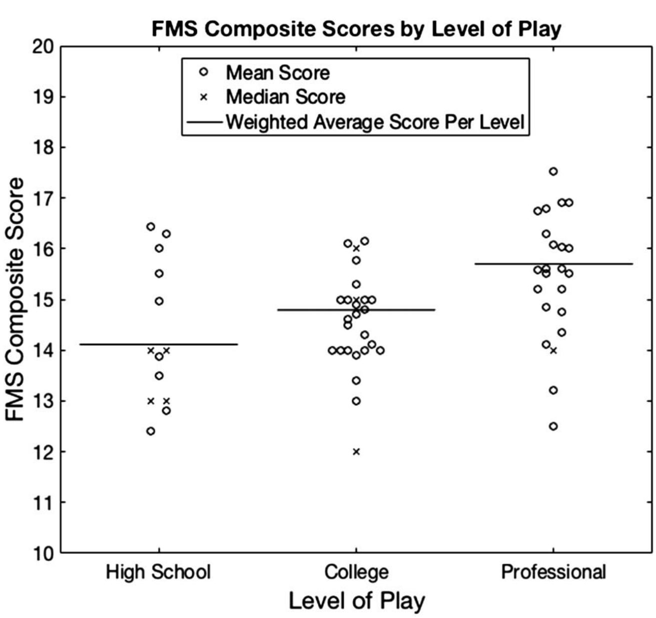

Figure 2. Dot-density plot of normative FMS composite scores for competitive athletes by competition level. Of the 62 scores included, 38 of them fall (61%) between 14 and 16. Despite higher injury rates for higher levels of play, the differences in weighted average scores per level of play (14.1 for high school, 14.8 for college, and 15.7 for professionals) likely do not exceed measurement error.

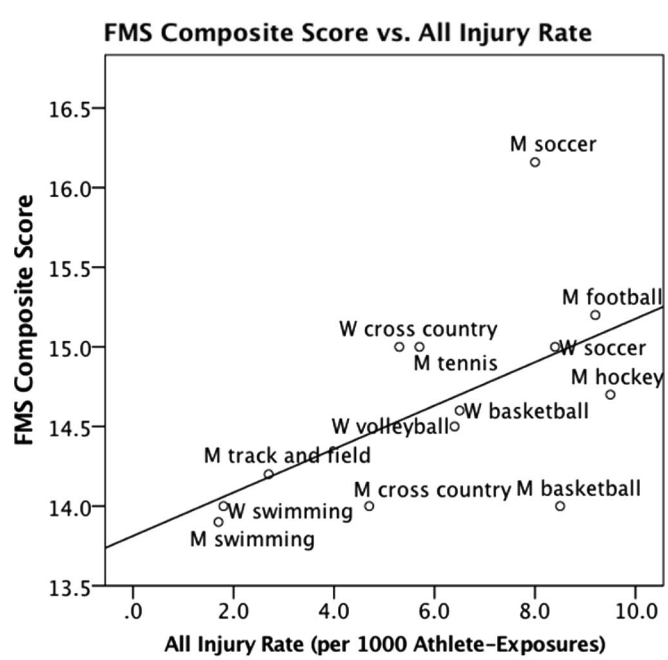

Figure 3. Scatterplot of FMS composite score versus all injury rate. At α = 0.025, there was no significant relationship between FMS composite scores and the rate of all injuries in college sports[31] (r(11) = 0.57, P = 0.041).

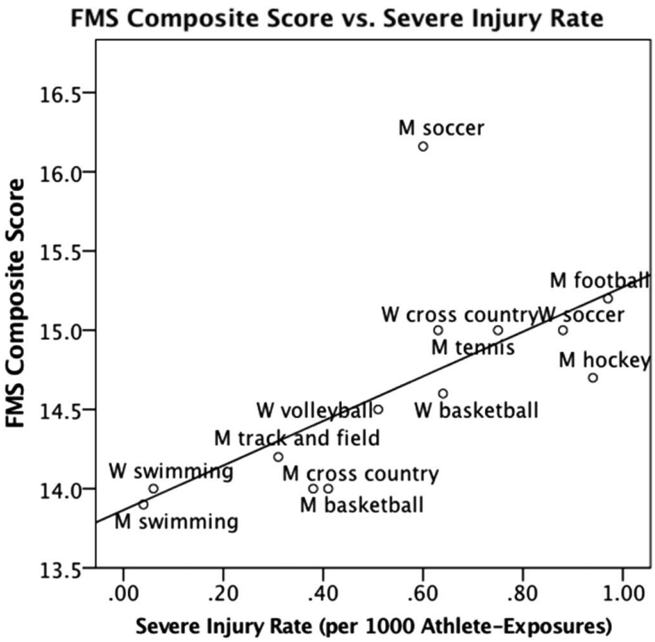

Figure 4. Scatterplot of FMS composite score versus severe injury rate. There is a significant positive relationship between normative FMS composite score and severe injury rate in college sports[32] (r(11) = 0.66, P = 0.014). As composite score increases, severe injury rate also increases. This relationship is the opposite of what would be expected if the FMS composite score was predictive of injury.

some evidence that suggests the FMS may be useful as part of a multifactorial prediction model.[41,42] For example, Lehr et al[42] created an injury prediction algorithm using the FMS, the Y-Balance Test,[43] and injury history. For athletes that the prediction algorithm identified as high risk, the investigators found a RR of 3.4 for noncontact lower extremity injury. In another prospective study, Teyhen et al[41] found pain provocation on the FMS clearing tests to be one of several factors associated with increased risk of musculoskeletal injury in US Army Rangers. The FMS can serve purposes unrelated to injury prediction, as well. For example, the creators of the FMS have consistently recommended it be used to (1) identify individuals who should be referred to medical professionals for further examination due to painful movements[4,44] and (2) establish a baseline of body weight movement competency.[1,3,4] The movement baseline can guide strength and conditioning professionals in selecting movements that can be loaded safely in training.[22,45] It can also be used for comparison after training or rehabilitation interventions to evaluate their efficacy.[3]

This critical review has several limitations. First, although we included a large number of athletes and sports, we were forced to exclude 48 relevant studies that failed to report individual composite scores per sport. Moreover, because many of the included studies did not report SDs, we could not conduct a true meta-analysis including confidence intervals for the pooled statistics for each level of play. We recommend that future studies report means and SDs sport-by-sport to improve upon existing normative data. For the secondary aim, there is a strong possibility that the FMS composite scores reported in the literature do not represent all athletes who play each sport, especially when scores were based on a small sample of athletes. Similarly, although the injury rates used in this review were drawn from large-scale national studies, they may not always be representative of the particular samples of athletes on whom the FMS scores were based. Notwithstanding, if low scores on the FMS were associated with increased injury rates, we would expect that correlation. Instead, we found the exact opposite. In addition, it should be noted that at the level of the individual studies, there were inconsistencies in FMS administration (Table 1). Notably, contrary to the FMS manual instructions,[5] some studies provided a warm-up.[46–49] In 14 studies, the FMS was part of a larger test battery, whereas in the others it was performed in isolation. Fourteen of the studies even failed to report administering the clearing tests. Only 5 studies reported reliability.[50–54] This heterogeneity may weaken the ability to compare between and synthesize studies. Finally, injury rates cited in this study were for all injury mechanisms; results may differ with noncontact injuries only.

CONCLUSIONS

This critical review provides further evidence against the composite score for injury prediction in competitive athletes. Across levels of play, normative FMS composite scores did not differ beyond measurement error. Within college sports, as reported composite scores increased, national average severe injury rates also increased, which undermines the FMS's predictive validity. Despite these findings, the FMS may still have merit, potentially in conjunction with additional risk factors for injury prediction as well as in other contexts such as establishing a baseline of body weight movement competency.

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