Physical Therapy in Sport 16 (2015) 324–330

Contents lists available at ScienceDirect

Physical Therapy in Sport

journal homepage: www.elsevier.com/ptsp

Original research

An appraisal of the Functional Movement Screen™ grading criteria – Is the composite score sensitive to risky movement behavior?

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ARTICLE INFO

Article history:
Received 25 July 2014
Received in revised form
19 December 2014
Accepted 7 February 2015

Keywords:
Assessment
Exercise
Injury
Prevention

ABSTRACT

Objective: To examine the relationship between the composite Functional Movement Screen (FMS) score and performers' spine and frontal plane knee motion.
Design: Examined the spine and frontal plane knee motion exhibited by performers who received high (>14) and low (<14) composite FMS scores. Participants' body motions were quantified while they performed the FMS.
Setting: Biomechanics laboratory.
Participants: Twelve men who received composite FMS scores greater than 14 were assigned to a high-scoring group. Twelve age-, height- and weight-matched men with FMS scores below 14 were assigned to a low-scoring group.
Outcome measures: Composite FMS scores and peak lumbar spine flexion/extension, lateral bend and axial twist, and left and right frontal plane knee motion.
Results: Significant differences ($p < 0.05$) and large effect sizes (>0.8) were noted between the high- and low-scoring groups when performing the FMS tasks; high-scorers employed less spine and frontal plane knee motion. Substantial variation was also observed amongst participants.
Conclusions: Participants with high composite FMS scores exhibited less spine and frontal plane knee motion while performing the FMS in comparison to their low-scoring counterparts. However, because substantial variation was observed amongst performers, the FMS may not provide the specificity needed for individualized injury risk assessment and exercise prescription.

1. Introduction

The Functional Movement Screen™ (FMS) was developed as a low-cost, easy-to-use tool that could help identify painful patterns and movement impairments prior to participating in sport or beginning an exercise program (Cook, Burton, & Hoogenboom, 2006a, 2006b). Although not originally described as a means to assess injury risk or establish specific training recommendations, it is now also being used for these purposes. Since Kiesel, Plisky, and Voight (2007) first reported a relationship between composite FMS scores and injury reporting in American football players, scientists have been exploring the screen's utility as an injury prediction tool (Brown, 2011; Burton, 2006; Butler, Contreras, Burton, Plisky, Goode, & Kiesel, 2013; Chorba, Chorba, Bouillon, Overmyer, & Landis, 2010; Hoover, Killian, Bourcier, Lewis, Thomas, & Willis, 2008; Kiesel, Butler, & Plisky, 2014; Kiesel et al., 2007; Lisman, O'Connor, Deuster, & Knapik, 2013; Morrell, 2012; Munce et al., 2012; Sorenson, 2009; Winke, Dalton, Mendell, & Nicchi, 2012) and devising individualized exercise strategies to eliminate movement dysfunction (Cook, Burton, Kiesel, Rose, & Bryant, 2010; Kiesel, Plisky, & Butler, 2011). However, FMS tasks are graded on a scale of zero to three using task-specific criteria (Cook et al., 2010), many of which have not been linked (epidemiologically or biomechanically) to injury mechanisms or risk factors. For this reason, accurately interpreting the level of injury risk associated with specific FMS scores or seeking to establish evidence-informed training recommendations can be challenging, particularly when considering the many personal, task and environmental factors that

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http://dx.doi.org/10.1016/j.ptsp.2015.02.001
1466-853X/

influence movement behavior (Davids, Glazier, Araujo, & Bartlett, 2003; Frost, Beach, Callaghan, & McGill, Epub ahead of print-a).

For the sole purpose of predicting who will sustain or has sustained a musculoskeletal injury, some reports have suggested that the FMS may be an effective tool (Brown, 2011; Butler et al., 2013; Chorba et al., 2010; Kiesel et al., 2007, 2014; Lisman et al., 2013) while others have shown limited utility (Burton, 2006; Hoover et al., 2008; Morrell, 2012; Munce et al., 2012; Sorenson, 2009; Winke et al., 2012). The conflicting evidence may stem from the fact that body movements are not directly analyzed during the FMS and thus “risky” movement behaviors (e.g. uncontrolled frontal plane knee motion) may go undetected during the screening process or preferentially transfer to certain activities. Using task-specific criteria such as “dowel and hurdle remain parallel” (Cook et al., 2010) to describe an individual's movement patterns can be advantageous if the objective of the screen is to identify the provocation of pain (but not the source), gross movement asymmetries (but not the cause), and to aid the observer in assigning grades. However, as a means to make training recommendations or assess injury risk, such an approach may be limited given that the task-specific criteria are insensitive to intra- and inter-individual variability in movement coordination and control (i.e. there are many ways a score of 2 can be achieved). This variation may also help explain the low sensitivity reported by several authors who have found a link between composite FMS scores and injury (Kiesel et al., 2007, 2014; O'Connor, Deuster, Davis, Pappas, & Knapik, 2011; Peate, Bates, Lunda, Francis, & Bellamy, 2007); while effective at the group level, the FMS may have missed individuals who were at risk of becoming injured. Scientists seeking to predict and prevent the incidence of ACL injury have had some success by targeting the movement behaviors shown to influence ACL loading (Hewett, Lindenfeld, Riccobene, & Noyes, 1999; Hewett et al., 2005; Hewett, Myer, Ford, Paterno, & Quatman, 2012; Hewett, Torg, & Boden, 2009; Irmischer, Harris, Pfeiffer, DeBeliso, Adams, & Shea, 2004; Myer, Ford, Brent, & Hewett, 2007; Myer, Ford, Brent, & Hewett, 2012; Myers & Hawkins, 2010; Noyes, Barber-Westin, Smith, Campbell, & Garrison, 2012; Noyes & Westin, 2012; Padua, Marshall, Boling, Thigpen, Garrett, & Beutler, 2009), likely in part because visually detectable observations made while screening (e.g. uncontrolled frontal plane knee motion) have been translated into coaching instruction and feedback cues (e.g. maintain knee alignment while squatting, lunging, jumping and cutting).

Given that the FMS comprises seven whole-body tasks, it is possible that the current grading criteria are insensitive to the presence/absence of undesirable and risky movement behaviors such as uncontrolled spine (Callaghan & McGill, 2001; Marshall & McGill, 2010) and frontal plane knee (Chaudhari & Andriacchi, 2006; Hewett et al., 2005, 2009) motion. However, it also plausible that these behaviors could be detected by trained observers if they were included as additional grading criteria. The objective of this investigation was to quantify spine and frontal plane knee motion while low- and high-scorers (i.e. composite FMS score <> 14) performed the FMS tasks. Given the task-specific nature of the current grading criteria, it was hypothesized that the composite FMS score would not be sensitive to variability in spine and frontal plane knee motion.

2. Methods

2.1. Participant selection

From an existing data set in which firefighters performed the FMS while instrumented for motion capture, data from 12 men who achieved composite FMS scores greater than 14 were randomly extracted for inclusion in this investigation. Data from 12 age-, height- and body mass-matched men with composite FMS scores below 14 were included for comparison. A cut-off score of 14 was used given the suggestion that the probability of sustaining a musculoskeletal injury is higher amongst individuals who receive a composite FMS score below 14 (Chorba et al., 2010; Kiesel et al., 2007). The age, height, body mass and FMS score of participants in the high- and low-scoring groups are described in Table 1. Participants were free of musculoskeletal injury or pain at the time of testing and were on full active duty. The University's Office of Research Ethics, the Baptist Hospital Institutional Review Board and the City of Pensacola each approved the investigation and all participants gave their informed consent.

2.2. Functional Movement Screen (FMS)

The FMS comprises the following seven tasks: 1) Deep squat (SQT) – individuals place a dowel overhead with outstretched arms and squat as low as possible, first with the heels on the floor and then with the heels raised by approximately 4 cm; 2) Hurdle step (HRD) – individuals place a dowel across their shoulders and step over a hurdle placed in front of them; 3) In-line lunge (LNG) – individuals perform a split squat with their feet aligned and a dowel contacting their head, back and sacrum; 4) Shoulder mobility (SHR) – individuals attempt to touch their fists together behind their back (internal and external shoulder rotation); 5) Active straight leg raise (SLR) – individuals actively raise one leg as high as possible while lying supine with their head on the ground; 6) Trunk stability push-up (PSH) – individuals perform a push-up with their hands shoulder width apart, first with their thumbs at forehead height and then at the level of the chin; 7) Rotary stability (ROT) – individuals assume a quadruped position and attempt to touch their knee and elbow, first on the same side of the body and then on the opposite. “Clearing” tests are also included with the SHR, PSH and ROT to expose other painful movements that may be overlooked while performing the primary FMS tasks. Additional details of each task have been published previously (Butler et al., 2013; Cook et al., 2006a, 2010, 2006b; Cowen, 2010; Frost, Beach, Callaghan, & McGill, 2012; Onate et al., 2012). Composite FMS scores are reliable when graded by experienced observers using video recordings (Gribble, Brigle, Pietrosimone, Pfile, & Webster, 2013; Minick, Kiesel, Burton, Taylor, Plisky, & Butler, 2010).

2.3. Experimental protocol

Upon their arrival, participants were instrumented with reflective markers and familiarized with the tasks they would be asked to perform. Tasks were administered by an FMS certified instructor using the standardized procedures and verbal instructions outlined by Cook et al. (2010). Three repetitions of each task were performed and approximately 15 s and 60 s of rest were given between each repetition and task, respectively.

2.4. Data collection and signal processing

Three-dimensional motion data were measured using a passive optoelectronic motion capture system (Vicon, Centennial, CO,

Table 1
Mean (SD) age, height, body mass and total FMS score for participants assigned to the high- and low-scoring group. Significant differences are described by p-values less than 0.05.

Group	Age (years)	Height (m)	Body Mass (kg)	FMS score (/21)
High	34.7(8.6)	1.78(0.06)	83.5(12.0)	16.4(1.0)
Low	35.1(9.2)	1.79(0.05)	85.3(10.0)	11.9(1.0)
p-value	*0.910*	*0.737*	*0.679*	*<0.001*

U.S.A.). Reflective markers were placed on 23 anatomical landmarks to define the proximal and distal endpoints of the trunk, pelvis, thighs, shanks and feet. Hip joint centers and knee joint axes were also determined "functionally" using similar methods to those described by Begon, Monnet, and Lacouture (2007) and Schwartz and Rozumalski (2005). Sets of 4 and 5 markers, fixed to rigid pieces of plastic, were secured to each body segment with Velcro® straps and used to track their three-dimensional positions and orientations throughout the collection. One standing calibration trial was collected such that the orientation of each segment's local axis system could be determined via a transformation from an axis system embedded within each rigid body. The marker data were collected at 160 Hz and smoothed with a low-pass filter (4th order, dual pass Butterworth) with an effective cut-off frequency of 6 Hz.

2.5. Data analyses

The movement patterns of the SQT, HRD, LNG, PSH and ROT were characterized with five variables, each chosen to reflect a visually observable feature that has been previously cited as a possible mechanism for low-back (Callaghan & McGill, 2001; Marshall & McGill, 2010) or knee (Chaudhari & Andriacchi, 2006; Hewett et al., 2005, 2009) injury. Spine flexion/extension (FLX), lateral bend (BND) and axial twist (TST) were computed by expressing the relative orientation of the rib cage with respect to the pelvis. The corresponding direction cosine matrix was decomposed with a Cardan rotation sequence of flexion/extension, abduction/adduction and axial rotation to compute the spine angle about each axis. The orientation of the lumbar spine in standing was defined as zero degrees. The position of the left (LFT) and right (RGT) knee joint center in the medial/lateral direction was described relative to a body-fixed plane created using the corresponding hip joint, ankle joint and distal foot. LFT and RGT were only computed for the SQT, HRD and LNG. Given constraints associated with the SHR (i.e. hands placed behind back) and SLR (i.e. lying down), it was not possible to compute participants' spine motion and thus the two tasks were not analyzed.

To objectively define the start and end of each trial, event detection algorithms were created in Visual 3D™ by tracking the motion of the trunk, pelvis, right forearm and whole-body center of mass. Only the contralateral (opposite side) ROT variation was analyzed, as 17 of the 24 participants could not perform at least one balanced ipsilateral (same side) repetition. To verify that events were defined as intended, model animations of all trials were inspected visually. Maximums and minimums of the five dependent variables were computed. The "peak" of each variable was described as the deviation (maximum, minimum or range) hypothesized to be most relevant to the types of injuries sustained by firefighters (i.e. FLX – flexion, BND and TST – range, LFT and RGT – medial displacement).

2.6. Statistical analyses

Mann–Whitney tests were used to examine the between-group differences for each screening task and the composite FMS score. The between-group differences in spine and frontal plane knee motion were computed using participants' three repetition means and comparisons were made using a general linear model with one between-group factor (IBM SPSS Statistics, Version 20.0, Armonk, NY, U.S.A.). Statistical differences were described by p-values less than 0.05. The high-low differences were also evaluated using the biological variability observed between subjects, by computing an effect size (ES). Specifically, the high-low differences in FLX, BND, TST, LFT and RGT were expressed as a function of the pooled between-subject variation. A positive effect implied that less spine or frontal plane knee motion was observed in the high-scoring FMS group. A score of one implied that the between-group difference was equal to the variation observed between participants. The strength of the ES was interpreted using the general guidelines offered by Cohen (1988), whereby values of 0.2, 0.5 and 0.8 corresponded to small, moderate and large differences, respectively.

3. Results

With the exception of HRD and ROT, members of the high-scoring FMS group achieved a higher ($p < 0.05$) grade on each of the component tasks (Table 2). When viewing the between-group differences in spine and frontal plane knee motion using the biological variability amongst participants, a positive effect was found in 30 of the 39 variables investigated across the five FMS tasks, 23 of which were of a magnitude greater than 0.30 (Fig. 1). When performing the SQT, the high-scorers exhibited less RGT and LFT both with the heels down (ES = 1.20 and 0.58 for RGT and LFT, respectively) and when they were raised (ES = 0.75 and 0.30 for RGT and LFT, respectively). However, a biological difference in FLX was only noted during the raised heels condition (ES = 0.37). Right and left side differences were noted in the magnitude of the ES for HRD and LNG, but in both screening tasks, the ES was greater than 0.38 for every variable examined. No between-group differences were found in FLX when participants performed the PSH, although the high-scorers did exhibit less BND and TST during both PSH conditions. Positive and negative effects greater than 0.30 were computed for ROT, reinforcing the finding that the ROT score could not distinguish the high- and low-scoring groups.

Statistically significant between-group differences were also noted in several spine and frontal plane knee motion variables for the SQT, HRD, LNG and PSH tasks (Table 2). In these cases, the high-scoring group was found to exhibit less motion despite substantial variation amongst participants. For example, there were firefighters from the high- and low-scoring groups who performed the SQT with both more than 60 degrees and less than 20 degrees of FLX. Similarly, despite a significant between-group difference in RGT during the right side LNG, 2 of the 3 most lateral knee positions (less medial displacement) were displayed by low-scoring participants. Fig. 2 illustrates the variation in FLX and RGT seen amongst participants for the SQT, HRD and LNG.

4. Discussion

On average, firefighters who received a composite FMS score greater than 14 exhibited less spine and frontal plane knee motion while performing the FMS, in comparison to their height- and weight-matched low-scoring counterparts. Assuming that less controlled spine and frontal plane knee motion during FMS task performance reflects a higher level of risky movement behavior, the current findings offer support for the notion that the FMS could provide a viable means to make generalized training recommendations (e.g. interventions to enhance the control of spine and frontal plane knee motions at the group level). However, given the substantial movement variability within the high- and low-scoring groups caution should be exercised when using FMS scores to make individualized training recommendations.

FMS scores are based on several task-specific criteria and reflect the lower grade assigned to either the left or right side of the body in five of the seven component tasks. As such, it was not unexpected to note the heterogeneity in spine and frontal plane knee motion within each group for a given task score. It is also for this reason that if the FMS is used as it was originally described (Cook et al., 2006a, 2006b), and information regarding performers' body segment and joint kinematic patterns are not explicitly

Table 2
The peak (mean and SD) spine flexion, spine lateral bend, spine axial twist, and right and left frontal plane knee position for participants receiving a high and low total FMS score. Peak lateral bend and twist reflect the maximum range (i.e. peak-to-peak). The groups' FMS task scores were graded qualitatively using published criteria. A negative value for the right knee implies a medial position. Statistically significant differences are described by p-values less than 0.05. Although not shown, participants in the high-scoring group also achieved higher scores on the shoulder mobility ($p = 0.008$) and active straight leg raise ($p = 0.001$) screens.

FMS task	Group	Task score	FLX (°)	BND (°)	TST (°)	RGT (cm)	LFT (cm)
SQT	High	2.2 (0.8)	42.9(16.4)	3.9(1.8)	3.9(1.1)	−3.7(3.0)	1.7(2.6)
	Low	1.1 (0.3)	42.7(14.4)	3.7(1.5)	3.6(1.3)	−9.0(5.5)	3.5(3.5)
	p-value	*0.001*	0.979	0.784	0.598	*0.007*	0.167
SQT (Heels)	High		39.7(12.9)	3.6(1.8)	3.9(1.1)	−1.8(2.6)	0.3(1.9)
	Low		44.6(13.6)	3.4(1.3)	3.6(1.5)	−5.1(5.5)	0.8(1.9)
	p-value		0.369	0.684	0.616	0.079	0.472
HRD (Left)	High	2.1 (0.3)	21.0(5.8)	17.0(2.5)	9.7(2.9)	−3.3(2.2)	9.6(15.3)
	Low	1.9 (0.3)	22.2(6.4)	17.7(2.5)	9.9(4.5)	−3.4(1.6)	17.9(13.7)
	p-value	0.166	0.645	0.512	0.935	0.963	0.175
HRD (Right)	High		19.7(4.3)	17.5(3.5)	7.6(2.9)	−12.2(13.0)	2.0(2.0)
	Low		23.7(6.3)	19.5(3.4)	9.3(2.3)	−24.7(12.2)	2.7(1.5)
	p-value		0.086	0.183	0.121	*0.025*	0.367
LNG (Left)	High	2.6 (0.5)	8.7(7.7)	9.7(4.2)	4.3(1.9)	−15.2(7.7)	7.8(5.5)
	Low	2.0 (0.0)	16.8(11.1)	10.0(5.1)	5.5(3.4)	−16.3(8.6)	11.8(5.0)
	p-value	*0.002*	*0.049*	0.894	0.309	0.745	0.075
LNG (Right)	High		10.5(6.6)	7.9(2.5)	3.9(1.0)	−11.3(1.8)	9.7(8.2)
	Low		16.6(9.8)	10.3(3.3)	5.3(2.3)	−15.0(5.5)	11.2(5.9)
	p-value		0.088	0.066	0.058	*0.035*	0.603
PSH	High	2.7 (0.7)	17.2(5.2)	2.3(1.0)	2.8(0.6)		
	Low	1.8 (0.9)	17.0(6.1)	3.3(1.1)	3.1(0.4)		
	p-value	*0.011*	0.938	*0.040*	0.108		
PSH (Chin)	High		13.4(5.2)	2.0(0.5)	3.0(1.2)		
	Low		14.0(6.0)	2.6(0.8)	3.4(1.0)		
	p-value		0.814	*0.023*	0.341		
ROT	High	2.1 (0.7)	63.6(7.3)	25.3(6.0)	27.4(6.4)		
	Low	2.3 (0.6)	65.1(8.3)	23.4(6.1)	30.0(6.0)		
	p-value	0.534	0.631	0.440	0.328		

Abbreviations: SQT, Deep squat; HRD, Hurdle step; LNG, In-line lunge: PSH, Stability Push-up; ROT, Rotary Stability; FLX, Spine flexion; BND, Spine lateral bend; TST, Spine axial twist; RGT, Position of right knee; LFT, Position of left knee.
p-values are italicized to help the reader discriminate the means and statistical comparisons in each column.

documented, attributing low FMS scores to the presence/absence of movement impairments would be inappropriate. This also implies that the current FMS grading approach may leave potentially risky movement behaviors undetected at the individual level.

Because there were several instances where the between-group differences in spine and frontal plane knee motion were characterized by large effect sizes, the FMS may indeed offer a low-cost and expedient means to assess the prevalence of musculoskeletal complaints in select occupational and athletic populations (Brown, 2011; Butler et al., 2013; Chorba et al., 2010; Kiesel et al., 2007, 2014; Lisman et al., 2013). Although not explicitly captured by the current grading criteria, the composite FMS score could reflect a group's tendency to employ risky movement behaviors when performing physically demanding work/sport tasks. For example, in comparison to firefighters with high FMS scores (i.e. above 14), Beach, Frost, and Callaghan (Epub ahead of print) found that those

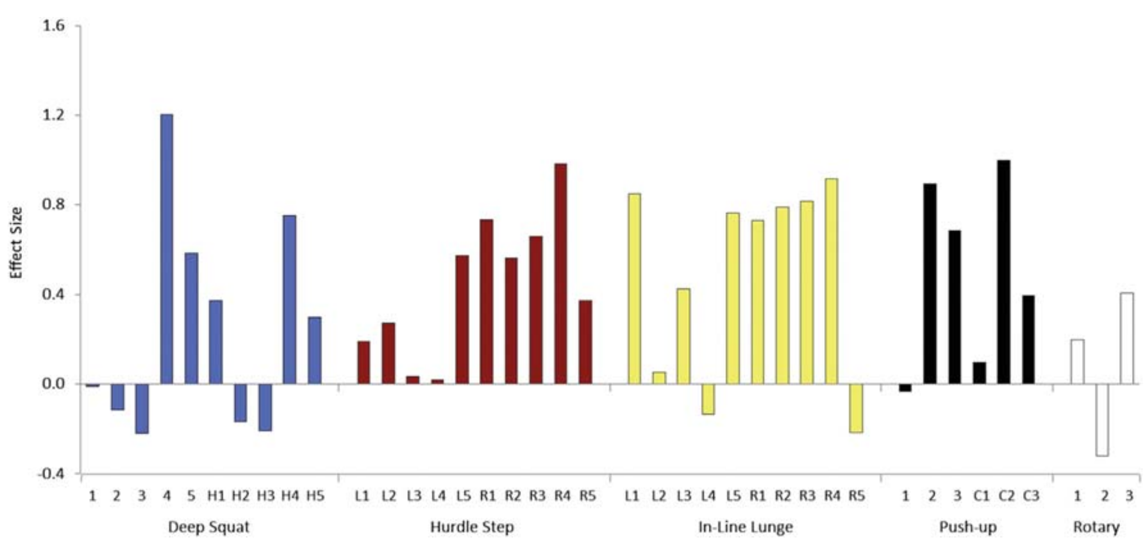

Fig. 1. Effect sizes for the high scoring group − low scoring group differences in peak spine flexion (1), spine lateral bend (2), spine axial twist (3), and right (4) and left (5) medial knee displacement. A positive effect size implies that the high-scoring group exhibited less aberrant joint motion. Effect sizes for the raised heel deep squat condition, left and right side hurdle step and in-line lunge, and push-up from the chin are denoted with an 'H', 'L' and 'R', and 'C', respectively.

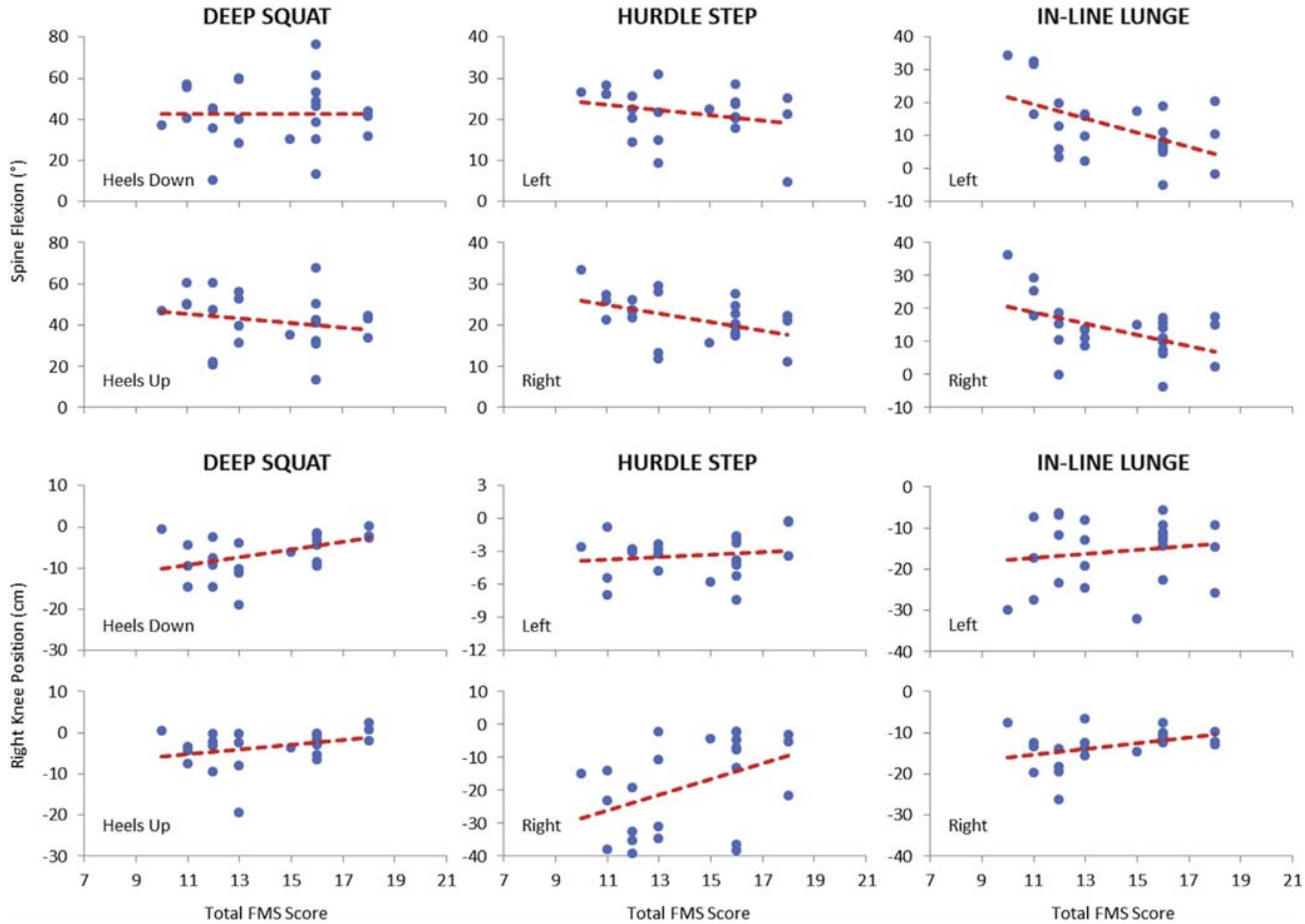

Fig. 2. The peak lumbar spine flexion and right knee position of each participant (circles) from the high- and low-scoring groups while they performed the deep squat, hurdle step and in-line lunge. A negative knee position denotes medial displacement relative to the frontal plane. The trendline is displayed for illustrative purposes only.

scoring below 14 exhibited greater spine flexion at the instant when peak low-back compressive forces were imposed during lifting, potentially increasing their risk of injury (McGill, 1997), a loading scenario shown to result in lower compressive failure tolerance in the spine (Gunning, Callaghan, & McGill, 2001; Parkinson & Callaghan, 2009). In cases where a relationship has not been observed between FMS scores and injury (Burton, 2006; Hoover et al., 2008; Morrell, 2012; Munce et al., 2012; Sorenson, 2009; Winke et al., 2012), it is plausible that the seven component tasks were unable to expose the risky movement behaviors pertinent to the injuries sustained amongst the target population, perhaps because their demands (e.g. external loads) were too low (Frost, Beach, Callaghan, & McGill, Epub ahead of print-b) and/or the grading criteria were insensitive to variation in these movement behaviors. However, it should also be noted that two of the seven tasks (i.e. HRD and ROT) did not distinguish between the low and high scorers, which may comprise the utility of the composite FMS score as a predictor of injury or risky movement behavior.

Although the mechanics of injury are influenced by a number of factors, including the frequency, rate, intensity and duration of loading, in many contexts personal movement patterns are one of the only modifiable injury risk factors (McGill, 2004). For this reason, the ability to accurately and reliably screen for risky movement behaviors could be an important first step in the prevention and rehabilitation of injuries. However, before administering any screen it is likely necessary to first identify the movement patterns and associated injuries of interest and the degree to which a particular pattern must vary for it to become a concern (e.g. via biomechanical analyses). The results of this study provide some evidence to suggest that the composite FMS score could offer a means to differentiate general movement qualities across a population, although it is important to note that receiving a high FMS score did not imply that spine and frontal plane knee motion were controlled. It simply indicated that on average, the motions observed amongst the high scorers were of a smaller magnitude than those displayed by the low-scoring participants. In fact, for each of the tasks investigated, there were a number of high scorers who exhibited similar joint motions to their low-scoring counterparts. As such, given previously established or hypothesized links between spine and frontal plane knee motion and injury potential, there may be merit in proposing that these variables be included as FMS grading criteria if the scores are to be used to assess injury risk or guide recommendations for training.

5. Conclusions

Participants who received a composite FMS score higher than 14 exhibited less spine and frontal plane knee motion while performing the screening tasks in comparison to those who scored 13 or lower. However, substantial movement variability was observed amongst participants, suggesting that current FMS scoring criteria may be insensitive to potentially risky movement behavior. It is recommended that body segment and joint kinematics be documented when administering movement screens, particularly given that previous efforts to do so have yielded benefits (e.g. ACL screening has helped to inform exercise prescription and prevent future injury (Sugimoto, Myer, Bush, Klugman, Medina McKeon, & Hewett, 2012)).

Conflict of interest

None declared

Ethical approval

The University's Office of Research Ethics, the Baptist Hospital Institutional Review Board and the City of Pensacola each approved the investigation and all participants gave their informed consent.

Funding

Funding for this project was provided by the Natural Sciences and Engineering Research Council of Canada (NSERC) and the Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD). Dr. Jack Callaghan is also supported by the Canada Research Chair in Spine Biomechanics and Injury Prevention.

Acknowledgments

We would like to thank Athletes' Performance and the Andrews Research and Education Institute for their support and use of their facilities. We would also like to extend our gratitude to members of the Pensacola Fire Department for their commitment to this work.

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