

Relationships Between Core Stability, Sex, and Movement Capacity

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ABSTRACT

Purpose: To examine relationships between sex, core stability endurance (CSE), and movement capacity in healthy, active adults.

Methods: Fifty-three adults performed the functional movement screen (FMS) and CSE tests (extension, flexion, and right/left side bridge) during the current study. A generalized linear mixed model with random effects was used to identify interactions between sex, CSE, and FMS composite scores.

Results: There was a significant triple interaction between CSE test, CSE score, and sex ($P < .001$), indicating the relationship between CSE test scores and FMS differed by CSE test and sex. Analyses of each CSE test found significant interactions between sex and FMS scores for the CSE extension and right side bridge tests. CSE extension and right side bridge accounted for 43% and 40% of the variance in FMS composite scores in women, compared to 9% and less than 1% in men, respectively.

Conclusions: CSE appears to contribute more to the movement capacity of women than men.

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The Functional Movement Screen (FMS) was created to assess movement capacity using seven movement tasks.^{1,2} Research has shown the FMS to be reliable, with intra-rater reliability coefficients ranging from 0.81 to 0.869 and inter-rater reliability coefficients ranging from 0.81 to 0.843.^{3,4} Reduced movement capacity, as measured by the FMS, has been identified as a factor contributing to injury risk in multiple populations, including firefighters,⁵ police officers,⁶ collegiate athletes,⁷⁻⁹ professional rugby players,¹⁰ and professional football players.^{11,12} A recent systematic review and meta-analysis reported that individuals with a score of 14 or less on the FMS were 2.74 times more likely to sustain injury.³ Additionally, the sensitivity and specificity of the FMS varied between men and women in a study of Coast Guard cadets; a score of 12 or less for women and 15 or less for men was suggested to maximize clinical utility values.¹³ There is conflicting evidence on whether the FMS can be used as a measure of change in movement capacity following an exercise intervention,¹⁴⁻¹⁶ and the FMS has not been shown to predict athletic performance.¹⁷⁻²⁰

The FMS was originally described as a screening tool to identify mobility and stability deficits and side-to-side asymmetries in healthy populations.^{1,2} Although a significant increase in FMS research has occurred, questions remain about the measurement properties of the FMS. For example, how do intrinsic factors such as mobility and stability contribute to the overall FMS composite score, and how do FMS task and composite scores differ between men and women?

Several studies examined relationships between the FMS and various intrinsic factors and yielded conflicting and inconsistent findings. Isolated joint range of motions at the hip,²¹ hip and ankle,²² and ankle²³ have demonstrated a limited correlation to FMS scores. Limited to no correlation between FMS scores and the Star Excursion Balance Test and Balance Error Scoring System has

been shown, suggesting that these instruments measure separate components of balance and function.²⁴ Lower extremity functional tasks of landing and hop performance appear to have some correlation with FMS composite scores.^{25,26} Specifically, athletes with higher FMS composite scores have been reported to hop further but not faster than those with lower scores, with hop performance representing 30% to 40% of FMS variance.²⁶ Core stability has been studied more extensively, and its correlation to FMS scores has shown mixed results.^{17,23,26}

Previous research examining differences in FMS composite and task scores between adult men and women has consistently shown no significant differences in the FMS composite score, but common differences in task scores. Women have been reported to score lower with the deep squat,²⁷ trunk stability push up,²⁷⁻²⁹ and rotary stability^{28,29} tasks, and to score higher with the shoulder mobility,²⁸⁻³⁰ active straight-leg raise,²⁷⁻³⁰ and inline lunge²⁸ tasks when compared to men. In addition to differences between FMS tasks, Gnacinski et al.³¹ reported the inability of the measurement invariance of the FMS to hold across sex, suggesting that the FMS is not measured equally in men and women.³¹ Based on this body of research, we wanted to explore possible intrinsic factors that have been hypothesized to contribute to FMS scores and shown to be different between men and women, including core stability endurance. Therefore, the purpose of the current study was to examine relationships between sex, core stability endurance, and movement capacity in healthy, physically active adults. We hypothesized that a positive correlation would exist between core stability endurance and FMS composite scores and that differences would exist between core stability endurance and FMS composite scores. Additionally, given the previously identified differences between men's and women's FMS scores²⁷⁻³¹ and core stability,^{32,33} we hypothesized that women would score lower on the FMS and core stability tests.

METHODS

Study Design

A cross-sectional study design was used in the current study. The independent variable was core stability endurance and was measured by the extension endurance test, flexion endurance test, and side bridge endurance test on the right and left sides. The dependent variable was functional movement capacity, which was measured by the FMS composite score and individual task scores.

Participants

The current study used convenience sampling to recruit potential participants through flyers, e-mails, and word of mouth communications on a university campus. Participants were required to be 18 years or older and to self-report being physically active, which was operationally defined as engaging in activities at or above the intensity level of a brisk walk at least two times per week. Participants were excluded if they did not meet the inclusion criteria or if they had symptoms or dysfunction from a current musculoskeletal or head injury or a history of vestibulocochlear or balance disorders. The study procedures were described, questions were answered, and informed consent was obtained prior to participation. The local institutional review board approved the current study.

Procedures

Study participants each attended a single 1-hour testing session at a university-based research laboratory. After informed consent was given, participants completed a health history questionnaire, height and weight tests, the FMS, and four core stability endurance tests.

Health History Questionnaire. The health history questionnaire was used to collect the demographic information of participants related to previous musculoskeletal injury history, current activity levels and injury history, and history of respiratory function and smoking. Responses were used to describe participant characteristics and determine study eligibility based on identified inclusion and exclusion criteria.

FMS. The FMS included seven individual tasks: deep squat, hurdle step, in-line lunge, shoulder mobility, active straight-leg raise, trunk stability push-up, and rotary stability.^{1,2} Three clearing tests for shoulder impingement, spinal extension, and spinal flexion patterns were also included. The composite scoring method described by Cook et al.^{1,2} was used in the current study. The individual tasks were scored with a numeric value ranging from 0 to 3 points. Three points were awarded when the participant completed the task without compensation, 2 points were awarded when the task was completed with compensation during the movement, 1 point was awarded when the participant was unable to complete the task, and 0 points were given for the presence of pain at any time during the task. For the five bilateral individual tasks, the lower of the right or left side scores was used. All individual task scores were summed to calculate the FMS composite score, which had a possible range from 0 to 21 points.

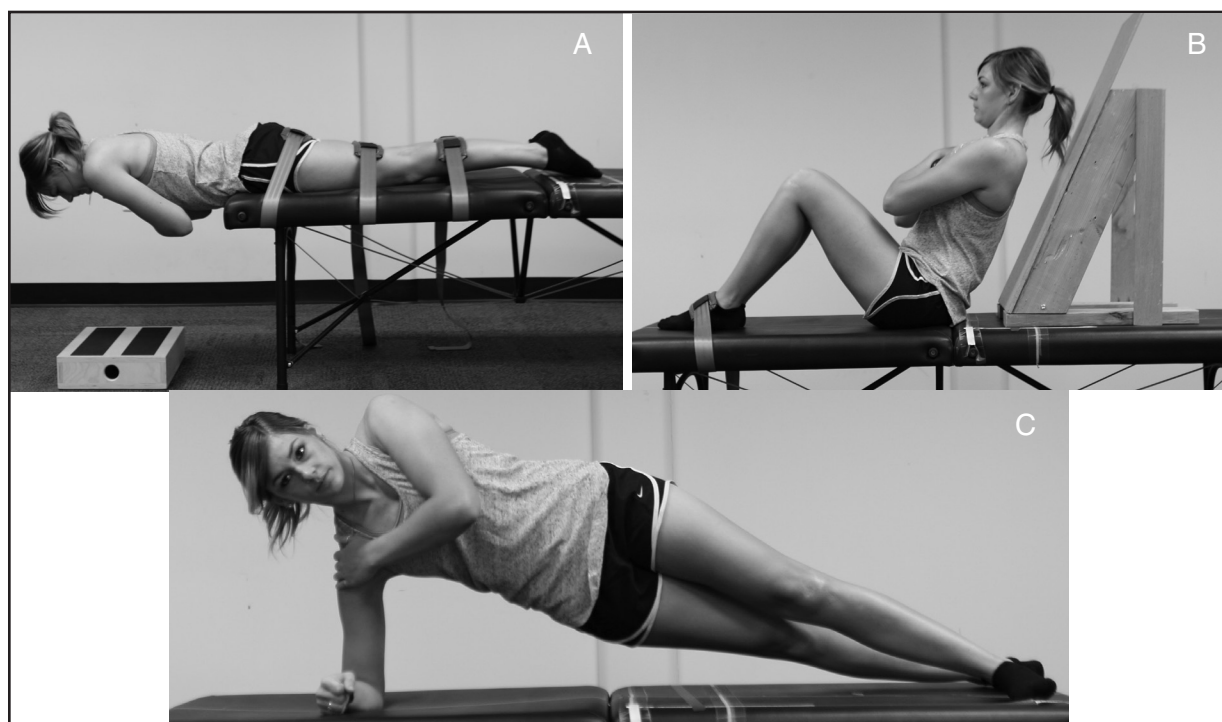


Figure 1. (A) Extension, (B) flexion, and (C) side bridge test positions.

Extension Endurance Test.³⁴ Participants were positioned prone on an examination table with straps securing their ankles, knees, and hips (**Figure 1A**). The participants' upper torso extended beyond the table and their arms were used for support until the test began. To begin the test, participants crossed their arms over their chest and aligned their body horizontally with the floor. The rater started the timer, and participants remained in the test position for as long as possible. The test was completed when participants were no longer able to maintain the test position and placed their hands on the support surface. The rater stopped the timer and recorded the test time in seconds.

Flexion Endurance Test.³⁴ Participants were seated on an examination table with their feet flat, knees flexed to 90°, and a strap securing their feet (**Figure 1B**). Participants crossed their arms over their chest and leaned back onto a solid wedge support to ensure a 60° angle between the table and their torso. To begin the test, participants were instructed to hold their position as the wedge support was moved 10 cm away from them. The rater started the timer, and participants maintained the position for as long as possible. The test was completed when participants were no longer able to hold the test position and leaned back to contact the wedge support. The rater stopped the timer and recorded the test time in seconds.

Side Bridge Endurance Test.³⁴ Participants were positioned in lying on their side on an exercise mat with their top foot aligned on the mat in front of the bottom foot (**Figure 1C**). Supporting themselves on the elbow closest to the ground, participants began the test by lifting their hips off the mat, creating a straight line through the torso and legs. The inactive arm was placed across their chest with the hand resting on the opposite shoulder. The rater started the timer, and participants maintained the position for as long as possible. The test was completed when participants were no longer able to hold the test position and their hips returned to the mat. The rater stopped the timer and recorded the test time in seconds.

Three raters were involved with data collection in the current study. Prior to data collection, raters participated in training sessions on administering and scoring the tests. The same two raters (BEA, KKB) administered and scored the FMS, and the same two raters (KCHB, KKB) administered the core stability endurance tests. Interrater reliability of the FMS was calculated using raters' scores of real-time and videotaped performance of FMS tasks prior to the study and found to be excellent (intraclass correlation coefficient = 0.95). For the core stability endurance tests, raters used standardized instructions and provided minimal feedback or encouragement to par-

Test	Female (n = 34)	Male (n = 19)
Extension	112.65 $\pm$ 43.88	100.63 $\pm$ 34.86
Flexion	152.85 $\pm$ 93.57	166.54 $\pm$ 108.64
Right bridge	56.80 $\pm$ 29.58	76.36 $\pm$ 19.77
Left bridge	54.17 $\pm$ 25.72	71.52 $\pm$ 23.82
FMS	14.15 $\pm$ 2.08	15.63 $\pm$ 2.03

SD = standard deviation; CSE = core stability endurance; FMS = Functional Movement Screen
^aOut of 21 possible points.

Test	Flexion ^a	Right Bridge ^b	Left Bridge ^b	FMS
Extension	.333	.514	.438	-0.042
Flexion		.411	.458	-0.054
Right bridge			.858	-0.029
Left bridge				-0.004

CSE = core stability endurance; FMS = Functional Movement Screen
^aCorrelation significant at the .05 level (2-tailed).
^bCorrelation significant at the .01 level (2-tailed).

ticipants during testing. To reduce rater bias, raters of the FMS scores were blinded to the core stability endurance test results and vice versa during test sessions.

Statistical Analysis

Summary data are reported using means $\pm$ standard deviations and counts (percentages), when appropriate. Pearson correlation coefficients were calculated between scores for each of the core stability tasks and FMS composite scores. Coefficients were interpreted using the following scale: 0.00 to 0.25, little or no correlation; 0.25 to 0.50, fair correlation; 0.50 to 0.75, moderate to good correlation; and 0.75 and above, good to excellent correlation.³⁵

A generalized linear mixed model approach with random effects for participants was adopted to accommodate the multiple, correlated measurements of core stability endurance (flexion, extension, right side bridge, and left side bridge) for each participant. A preliminary (omnibus) analysis was conducted to determine if core stability endurance test results were predictive of the FMS composite score and if the strength of the relationship differed across core stability endurance category and sex of the participant. The FMS composite score was used as the criterion variable, and core stability endurance category and sex were entered (fixed factors), along with core stability endurance test score (a covariate), as predictors. A full factorial model was specified. Following this analysis, four generalized linear models were constructed, one for each core stability endurance test category, to determine if the strength of the relationship between core stability endurance test score and the FMS composite score differed across sex. Again, the FMS composite score served as the criterion, and core stability endurance test score,

sex of the participant, and the interaction between these two terms served as predictors.

For all of the analyses noted above, a gamma distribution with log link was required to achieve best model fit. A nominal *P* value of .05 was used as the criterion for statistical significance. Data were analyzed using SPSS software (version 24; IBM Corporation, Armonk, NY).

RESULTS

Fifty-three participants, 34 (64.2%) women and 19 (35.8%) men aged 26.5 $\pm$ 4.6 years (range: 19 to 41 years), completed the study. Means $\pm$ standard deviation for core stability endurance tests and the FMS composite scores are provided in **Table 1**. Pearson correlations between core stability endurance tests and FMS are provided in **Table 2**.

Results of the preliminary, full factorial analysis revealed a significant triple interaction (core stability endurance test category $\times$ core stability endurance score $\times$ sex), ($P < .001$). This indicated that the relationship between test scores and the FMS differed by core stability endurance category and sex. To examine these relationships further, the data were divided by test category, and four follow-up models were constructed to test the interaction of test score and sex in predicting the FMS composite score.

Extension Endurance Test. The interaction between sex and core stability endurance score during the extension endurance test was significantly associated with the FMS composite score ($P < .001$) (**Figure 2A**). The main effect of sex was also significant ($P < .001$), but core stability endurance score was not ($P = .408$). The core stability endurance score during the extension endurance test accounted for 43% of the variance in the FMS composite score in women and 12% in men.

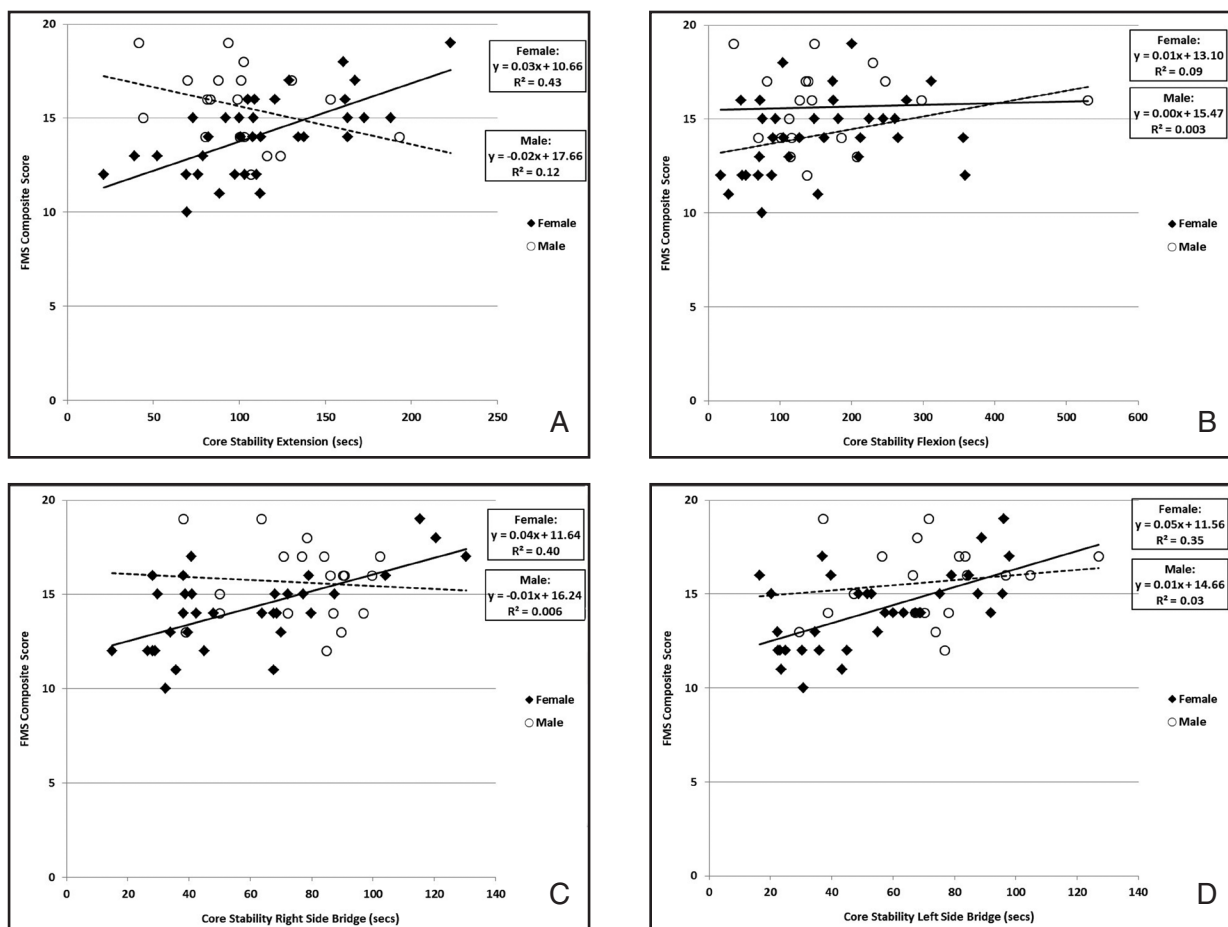


Figure 2. (A) Interaction between the Functional Movement Screen (FMS) and sex during the extension endurance test. (B) Relationship between the FMS and sex during the flexion endurance test. (C) Interaction between right side bridge test, endurance test, and sex. (D) Interaction between core stability score and sex during the left side bridge endurance test.

Flexion Endurance Test. The interaction between sex and core stability endurance score during the flexion endurance test was not significantly associated with the FMS composite score ($P = .294$) (Figure 2B). The main effect of sex was significant ($P = .025$), but core stability endurance score was not ($P = .165$). The flexion endurance test score accounted for 9% of the variance in the FMS composite score for women and less than 1% for men.

Right Side Bridge Endurance Test. The interaction between sex and core stability endurance score during the core stability right side bridge test was significantly associated with the FMS composite score ($P = .024$) (Figure 2C). The main effect of sex was also significant ($P = .009$), but the core stability endurance score was not ($P = .118$). Right side bridge endurance test score accounted for 40% of the variance in the FMS composite score in women and less than 1% in men.

Left Side Bridge Endurance Test. The interaction between sex and core stability endurance score during the left side bridge endurance test was not significantly associated with the FMS composite score ($P = .106$) (Figure 2D). The main effect of sex ($P = .038$) and the core stability endurance score ($P = .004$) was significant. Core stability endurance on the left side bridge endurance test accounted for 35% of the variance in the FMS composite score in women and 3% in men.

DISCUSSION

The purpose of the current study was to examine relationships between sex, core stability endurance, and movement capacity in healthy, physically active adults. We hypothesized that we would find positive correlations between the core stability endurance tests and FMS scores, and that there would be differences between core stability endurance tests and FMS scores. We also hy-

pothesized that women would score lower than men on the core stability endurance tests. Our results confirmed portions of our hypothesis, with the core stability endurance tests for extension and right side bridge predicting FMS scores, dependent on sex. In both the extension endurance test and right side bridge endurance test, the core stability endurance score accounted for 43% and 40% of the variance in women's FMS composite scores, respectively. This is comparable to 12% and less than 1% for men. These results suggest that the intrinsic factors of core stability endurance in extension and right side bridge in women contribute to FMS composite scores in a greater capacity than in men. These results are in agreement with findings reported by Gnacinski et al.,³¹ who reported the measurement invariance of the FMS did not hold across sex, suggesting that the FMS composite score does not hold an equal meaning between women and men. Implications for these results are discussed below.

Previous research has suggested that core stability is an intrinsic factor affecting movement capacity.^{17,18,33,36} However, previous studies examining relationships between core stability and FMS composite scores have produced mixed results that may be due to the presence of covariates that were not accounted for in analyses. Okada et al.¹⁷ compared extension endurance, flexion endurance, and side bridge endurance tests to FMS composite scores and reported no significant correlations between core stability endurance and FMS scores. Our positive correlations contradict these results and may be explained by the differences in core stability extension and right side bridge endurance tests between women and men. Okada et al.'s study included both male and female participants, but the authors did not report an analysis of differences of sex across their tests; it is possible that the differences between men and women had a cancelling effect, resulting in the lack of significant findings.

In a similar study that examined relationships between health measures, fitness, and functional movement, correlations between one repetition squat max, Body Mass Index, and core stability endurance tests were reported.³⁷ However, this study only included analysis of data collected from male participants. Finally, Chimera et al.²³ found that the single-leg wall sit as a measure of core stability endurance was positively correlated with FMS scores, accounting for 30% to 40% of variance. However, no analysis accounting for possible differences between men and women was provided. The majority of studies exploring possible relationships between FMS scores and

core stability have not reported analyses for sex differences or included only male participants. The recent findings of measurement invariance across sex³¹ and the results of the current study suggest that more attention should be paid to the contribution of core stability endurance to FMS scores, especially in women.

Adequate strength and muscular control of the core has been shown to reduce symptoms in patients with low back pain^{38,39} and positively impact upper extremity³⁶ and lower extremity movement patterns.^{40,41} The findings of the current study suggest that core stability endurance may have a greater impact on movement capacity in women compared to men. Specifically, core stability endurance in extension accounted for 43% of the variance in FMS scores in women but only 12% in men, whereas core stability endurance in the right side bridge accounted for 40% in women and less than 1% in men. Previous research that has examined differences in FMS task scores between men and women has consistently identified decreased FMS task scores for women in the trunk stability push up²⁷⁻²⁹ and rotary stability^{28,29} tasks. Both of these FMS tasks require significant core stability to be performed without compensation.²

The current study was not without limitations. Standard instructions for holding the core stability endurance tests to fatigue were given, but it is possible some participants did not perform the tests with maximum effort. Another limitation is that our core stability endurance results for extension endurance and side bridge endurance tests were lower than the normative values reported by McGill et al.³⁴ and our flexion endurance tests were higher than the normative values. These differing normative values may be related to differences in study design or participant populations, but the differences make it more difficult to compare and generalize our results. Inclusion and exclusion criteria were used to control factors related to injury history and physical activity; however, factors such as fitness levels and motivation to perform the tests could have influenced our results. A larger sample size may help address both normative value and self-selection bias issues.

Future research should be conducted to further explore links between core stability and movement capacity to determine predictive relationships between core stability and movement tasks in men and women, and to identify how improvements in core stability affect movement capacity as measured by the FMS, especially in women.

IMPLICATIONS FOR CLINICAL PRACTICE

The results of the current study demonstrate relationships between sex, core stability endurance, and movement capacity measured by the FMS. Core stability endurance in extension and right side bridge accounted for 43% and 40% of the variance in FMS composite scores in women and 12% and less than 1% in men. These findings have implications for athletic trainers and strength and conditioning professionals because they reiterate the importance of core stability for functional movement. It also highlights the important role that core stability endurance may play in functional movement capacity in women. Athletic trainers and sports medicine professionals should ensure that all athletes, especially women, are engaging in adequate core stability endurance activities during their strength and conditioning sessions, in addition to other movement-based exercises.

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