Physiology International, Volume 104 (3), pp. 258–269 (2017)
DOI: 10.1556/2060.104.2017.3.1

Gender may have an influence on the relationship between Functional Movement Screen scores and gait parameters in elite junior athletes – A pilot study

N Magyari[1], V Szakács[2], C Bartha[3,4], B Szilágyi[1,2], K Galamb[1,2], MO Magyar[1], T Hortobágyi[5], RM Kiss[6], J Tihanyi[2], J Négyesi[1,2,7]

[1]Pain Clinic, Budapest, Hungary
[2]Department of Biomechanics, Kinesiology and Informatics, University of Physical Education, Budapest, Hungary
[3]Hungarian Olympic Committee, Budapest, Hungary
[4]Győri Audi ETO KC, Győr, Hungary
[5]Center for Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, The Netherlands
[6]Mechatronics, Optics and Mechanical Engineering Department, Faculty of Mechanical Engineering, Budapest University of Technology and Economics, Budapest, Hungary
[7]Department of Medicine and Science in Sports and Exercise, Tohoku University Graduate School of Medicine, Sendai, Japan

Received: February 22, 2017
Accepted: July 2, 2017

Aims: The aim of this study was to examine the effects of gender on the relationship between Functional Movement Screen (FMS) and treadmill-based gait parameters. *Methods:* Twenty elite junior athletes (10 women and 10 men) performed the FMS tests and gait analysis at a fixed speed. Between-gender differences were calculated for the relationship between FMS test scores and gait parameters, such as foot rotation, step length, and length of gait line. *Results:* Gender did not affect the relationship between FMS and treadmill-based gait parameters. The nature of correlations between FMS test scores and gait parameters was different in women and men. Furthermore, different FMS test scores predicted different gait parameters in female and male athletes. FMS asymmetry and movement asymmetries measured by treadmill-based gait parameters did not correlate in either gender. *Conclusion:* There were no interactions between FMS, gait parameters, and gender; however, correlation analyses support the idea that strength and conditioning coaches need to pay attention not only to how to score but also how to correctly use FMS.
Keywords: gait, locomotion, movement screens, motion analysis, feedback methods

Introduction

Physical therapists and strength and conditioning coaches often use movement screens to determine athletes' functional abilities. The goal of movement screens is to place athletes in movement situations that would allow therapists and coaches to identify limitations in particular muscles and joints and quantify underlying deficiencies in mobility and postural stability (9). The Functional Movement Screen (FMS) was developed to evaluate such motor abilities (9, 10). The FMS includes seven exercises: deep squat, hurdle step, in-line lunge, shoulder mobility, active straight-leg raise, trunk stability push-up, and rotary

Corresponding author: János Négyesi
Department of Medicine and Science in Sports and Exercise, Tohoku University Graduate School of Medicine
2-1, Seiryo-machi, Aoba-ku, Sendai 980-8575, Japan
Phone/Fax: +81 22 717 8588; E-mail: negyesi@dc.tohoku.ac.jp

stability (9, 10). The FMS was designed with the intent to identify mobility dysfunctions, functional limitations, and asymmetries that could increase the risk of injuries (8–10). In contrast, the FMS is not intended to predict injuries (3) and it indeed seems to have low efficacy for identifying movement deficiencies in complex tasks comprising multidirectional speed and jumping movement (19).

Whether FMS scores are related to athletic performance is a matter of debate. For example, FMS scores did not correlate with performance in 20-m sprint ($r = -0.107$), vertical jump ($r = 0.249$), or *t*-test ($r = -0.146$) in collegiate golfers (28). *t*-test is a measure of agility for athletes and includes cutting maneuvers in the form of forward, lateral, and backward sprinting. There was also no relationship between FMS scores and core stability and the relationships were only moderate between FMS scores and performance in the backward overhead medicine ball throw and *t*-test in recreationally active adults ($r = -0.383$ to -0.462) (28). One possible reason for the low correlations is the inclusion of a mix of male and female athletes in the sample (27, 28), even though previous studies have clearly demonstrated that gender has a strong effect on muscle strength and power (26) and movement biomechanics during certain actions (23) and such differences could affect the FMS scores (18). For instance, females displayed significant increases in peak hip flexion, knee flexion, and knee valgus compared with males (23) and demonstrated larger knee valgus angles during sidestep (22, 23) and jump-landing tasks (18). Second, scores on the FMS tests could be different between raters based on the previous training and experience (24). Furthermore, previous studies reported varying levels of reliability for FMS (25), which could contribute to the low relationship between FMS scores and performance measures.

In line with FMS, gait analysis has also widely been used as a method to identify deficiencies, asymmetries, and compensations in locomotion. Postural instability, balance deficiencies during gait, and restricted range of motion can increase the risk of injuries (17). Walking is a fundamental yet complex task requiring integration of dynamic balance, visual flow, and a multitude of sensory inputs (36). The state of the central nervous system, muscle balance, and other factors defines the nature of the gait. Asymmetries in different gait parameters can be examined using a treadmill. For example, Kiss and Magyar (15) demonstrated that gender significantly affects gait variability presumably mediated in part by gender-related differences in joint flexibility (13).

Both FMS and gait analysis are widely used to identify asymmetries; however, none of the previous studies have measured the relationship between the two methods. Altogether, the purpose of this study was to determine the effects of gender on the relationship between outcomes in FMS and treadmill-based gait parameters. We hypothesized that asymmetry in FMS would correlate with low symmetric index of treadmill-based gait parameters; furthermore, we expected to demonstrate a gender effect on the relationship between FMS scores and gait (6). We expect that the results could increase the specificity of using the FMS to identify functional deficiencies in female and male athletes.

Materials and Methods

Study design

This study was designed to examine the effects of gender on the relationship between FMS test scores and gait parameters in elite junior athletes. Participants were tested at least 2 weeks after their competitive season in the fall of 2014. Foot rotation (°), step length (cm), and length of gait line (mm) were calculated from force distribution during gait measured on a

Zebris FDM-T-instrumented treadmill. Foot rotation (37) and step length (8) are the widely used spatial variables in gait analysis (29). Length of gait line is a frequently used biomechanical outcome and is determined as the length of the center of pressure (CoP) during the stance phase of gait (16, 32). Step length and length of gait line were normalized to body height. Spearman's correlations were used to quantify the relationships between the scores of FMS tests and gait parameters. A stepwise multiple regression model was conducted for the gait parameters with the FMS screens, to determine which could best predict the measured gait parameter. Multivariate analyses of variance (ANOVAs) were used to determine if there was an interaction between FMS, gait, and gender.

Participants

Table I shows the characteristics of the participants ($n = 20$). Participants were elite junior athletes, members of the Hungarian national team in a specific discipline. All of the athletes attended the Youth Olympic Games, the highest level of competition for junior athletes in Hungary. Participants were included if they were 18 years of age or younger; currently participated in a symmetric sport (i.e., track and field, swimming, triathlon, rowing, etc.), and trained at least five times per week over the last year. All of the athletes were free of neurological, cognitive, and orthopedic disorders, injuries, or conditions, which prevented sports participation for more than 3 days. Athletes were excluded in case of (1) pregnancy, (2) blurred vision, (3) cardiovascular disorders, (4) respiratory disorders, or (5) evidence, self-reported, or otherwise, for taking performance-enhancing drugs. After giving both verbal and written explanation of the experimental protocol, all athletes signed an informed consent that conformed to the Declaration of Helsinki and was approved by the local institutional Committee of Science and Research Ethics (TE-KEB/No5/04/2017). Written parental or guardian consent was also obtained.

Procedures

Testing was conducted in a biomechanics laboratory, which featured a Zebris FDM-T Treadmill (Zebris Medical GmbH, Germany). Athletes were instructed to refrain from intensive exercise, stimulants, and drugs during the 24-h period prior to testing and wear their own running shoes for all tests, except for the FMS test. The athletes' age, height, and body mass were recorded first. Walking freely over ground or on a treadmill represents even for athletes a different stimulus but gait kinematics tends to be similar while walking on a treadmill and over ground for 6 min (2). Participants were instructed to walk on the treadmill at their preferred walking speed for 1 min. Because gait velocity affects gait kinematics and

Table I. Participant characteristics

	Women	**Men**
Sample	10	10
Age (years)	17.1 ± 0.99 (range: 16–19)	17.6 ± 1.07 (range: 16–20)
Height (m)	1.7 ± 0.08	1.78 ± 0.06
Body mass (kg)	65.86 ± 6.44	79.49 ± 10.21

Values are mean ± standard deviation, unless denoted differently kinetics (4, 7), we administered the gait analysis at a fixed speed of 1.22 m/s, which was the average habitual gait speed for the group (14). Athletes performed the FMS tests following the gait analysis.

We determined the spatiotemporal parameters of gait using a Zebris FDM-T Treadmill. This device is fitted with an electronic mat embedded underneath the belt. The dimension of each force sensor is 0.85 cm × 0.85 cm, sampling the force signal at 120 Hz. The treadmill's speed can be adjusted from 0.2 to 22 km/h in increments of 0.1 km/h. The effective measurement (contact) surface is 150 cm × 50 cm. Foot pressure is mapped at a high resolution, which allows the detection of small differences in force distribution and subtle adaptations between walking conditions. Dedicated software (Zebris FDM 1.6.2., Zebris, Germany) integrates the force signals and provides a 2D/3D graphical representation of major spatiotemporal parameters of gait. We extracted the following dependent variables from the gait data: foot rotation (°), step length (cm), and length of gait line (mm), which quantify the CoP path. The Shapiro–Wilk test indicated normal distribution of the data ($p = 0.938 - 0.979$).

The FMS has moderate to high reliability (24, 25) and uses seven tests and three clearing examinations (9, 10, 24, 27). Except for the deep squat and trunk stability push-up, each side of the body was unilaterally assessed.

The official scoring checklist published by Cook et al. (9, 10) was used in the study. Three repetitions of each screen were completed, and the best-performed repetition was scored. About 10 s of rest were given between trials and 1 min between tests. Participants were instructed to return to the starting position between each trial (27). Two movement analysts being experienced in the FMS test scoring observed the athletes and scored independently each movement on a scale from 0 to 3. Scores of 3, 2, 1, and 0 represented according to the relevant criteria: "performed without compensation," "performed with compensation," "could not perform," and "pain," respectively (9, 10, 12). A movement completed with a single compensation scored 2; more than one compensation scored 1 (12). If there was a discrepancy in scores between the investigators, they discussed the result just after the measurement until they made an agreed decision (18). However, there were no differences between the two investigators in scoring FMS ($t = 0.000$, $p = 1.000$). The highest overall score of the FMS test is 21. For tasks that required bilateral assessments, the lower score contributed to the overall score. For this study, individual scores for each side of the body were also considered.

Statistical analyses

We performed the statistical analyses using SPSS (IBM, version 22.0, IBM Corporation, Armonk, NY). We characterized each parameter with descriptive statistics (mean ± standard deviation; 95% confidence intervals). Between-gender differences in gait parameters were calculated using independent samples *t*-test ($p \leq 0.05$). For the FMS tests, we used independent samples Mann–Whitney *U* tests ($p \leq 0.05$). We quantified the relationship between FMS tests' scores and gait parameters using Spearman's correlation. Furthermore, relationship between FMS asymmetry and movement asymmetry during treadmill-based gait was determined by examining side-to-side asymmetries in FMS tests and calculating symmetry index (SI) (30) in treadmill-based gait parameters. For side-to-side examination, those FMS tests were used, which were bilaterally scored, such as in-line lunge, shoulder mobility, and active straight-leg raise. SI for each measured treadmill-based gait parameter was calculated as

$$\mathrm{SI} = \frac{(X_R - X_L)}{0.5\,(X_R + X_L)} \times 100\%.$$

Only strong correlations ($r = 0.7$ to 1 or -0.7 to -1) are reported. Stepwise multiple regression analyses ($p \leq 0.05$) were conducted for the foot rotation, step length, and length of gait line parameters (each acted as a dependent variable), with the FMS screens, to determine which could best predict the measured gait parameter. Finally, ANOVA was used to determine whether FMS would need to be differently used in males and females when looking for functional deficiencies.

To establish the number of participants required for the study, we performed power analysis using G*Power 3.1.7. According to the power analysis, 22 participants per group would be enough to detect changes in the measured variables (80% power); however, data only from 20 athletes will be reported in the present pilot study, suggesting a careful interpretation of the results.

Results

Table II shows that there were no between-gender differences in treadmill-based gait parameters. In addition, none of FMS tests revealed between-gender differences using Mann–Whitney *U* test. Figure 1 shows the mean individual FMS scores in female and male participants. The rotary stability scores were similar on the two sides of the body (14.5 ± 2.12 and 13.6 ± 1.78); hence, we show a pooled score.

Table III summarizes the correlations between the FMS tests and the different gait parameters. The nature of correlations was different in men and women. However, there were no significant correlations in either gender between the SI of gait parameters and compensations in FMS measured by examining side-to-side asymmetries (Table IV). Stepwise multiple regression analysis (Table V) showed that deep squat for the left ($r = 0.79$, $p = 0.01$) and for the right ($r = 0.76$, $p = 0.01$) predicted only step length in women. Furthermore, different FMS test predicted the length of gait line of the left- (right-leg hurdle step, $r = 0.82$, $p = 0.00$), and of the right-leg (deep squat, $r = 0.81$, $p = 0.00$). However, different FMS test scores predicted different gait parameters in male athletes: right-leg foot rotation degree and right-leg step length were both predicted by rotary stability ($r = 0.70$, $p = 0.02$; $r = 0.73$, $p = 0.02$, respectively). We found no interaction effect between FMS, gait parameters, and gender (all p values are ≥ 0.05).

Discussion

Although recent studies have examined the relationship between the FMS and athletic performance (27, 28), this is the first study to report on the relationship between FMS scores and treadmill-based gait parameters in elite junior athletes. Correlation analyses revealed that the relationships between outcomes in FMS and treadmill-based gait parameters are different between genders; however, we found no significant interaction between FMS, treadmill-based gait parameters, and gender. Finally, there were no correlations between FMS asymmetry and movement asymmetries measured by treadmill-based gait parameters in either gender. Because of the small sample size, this study

Table II. Mean, standard deviation (SD) of foot rotation (°), step length normalized for standing height, and length of gait line normalized for standing height; and *t* value, *p* level, and 95% confidence interval of the difference between elite junior female (*n* = 10, upper values) and male (*n* = 10, bottom values) athletes, respectively

					95% confidence interval of the difference	
	Mean	**SD**	***t***	**Sig.**	**Lower**	**Upper**
Foot rotation left (°)	4.07	2.61	1.652	0.116	−0.80	6.70
	7.02	5.01				
Foot rotation right (°)	6.24	1.48	0.477	0.641	−1.64	2.59
	6.71	2.75				
Step length left	36.96	2.42	0.621	0.776	−1.50	2.75
	36.33	2.09				
Step length right	36.99	2.22	0.365	0.890	−1.85	2.63
	36.61	2.54				
Length of gait line left	121.78	8.70	−1.006	0.329	−9.94	3.51
	125.00	5.18				
Length of gait line right	123.80	6.85	−0.395	0.893	−7.37	5.04
	124.97	6.34				

t: *t* value of independent samples *t*-test; Sig.: *p* level of *t*-test.

provides only preliminary data on the effects of gender on the relationship between FMS scores and gait.

It is well known that females versus males have lower muscle mass, body height, and weight, shorter limbs (34, 35), and also lower absolute muscle strength, and generate less muscle power (1). The wide pelvis and short thighs (20) give rise to valgus-knee gait that is typical of females (21). Females show larger knee valgus angles during sidestep (22, 23) and jump-landing tasks (11). Furthermore, the female lower extremity alignment may cause disproportional strains and impact on the hip and knee joints and lower back, increasing the risk of injuries (31). For example, decreased activation of the hip abductors and greater hip adduction in the supporting limb were shown during soccer kick, which is associated with increased risk of anterior cruciate ligament injury in female athletes (5). We observed no between-gender differences in length of gait line; however, FMS tests significantly predicted this parameter only in female athletes, suggesting an insensitivity of the FMS tests to gender. Length of gait line is the length of the CoP path computed based on ground contacts on one side. This parameter comprises the path of the force distribution for all the steps recorded for one side of the body. Length of gait line was normalized to body height; however, this parameter is largely dependent on the landing strategy (heel strike vs. flat foot), which may suggest that any gender differences are caused by differences in landing strategy.

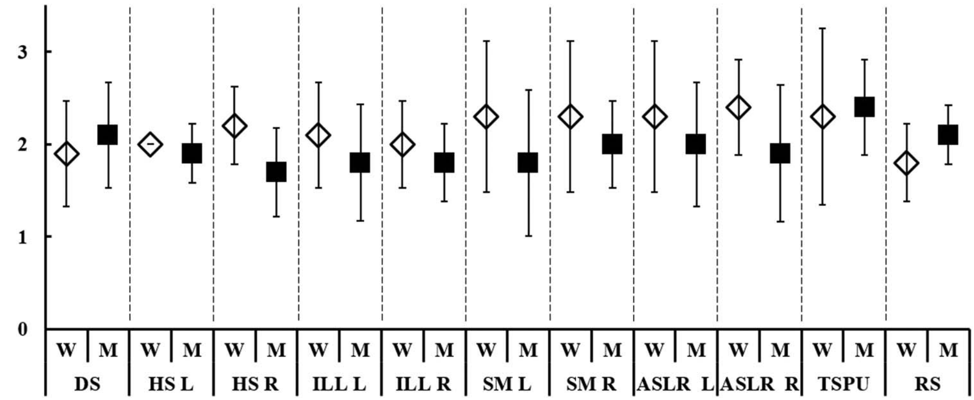

Fig. 1. Scores (mean ± standard deviation) for the Functional Movement Screen assessments for the left and right of the body in elite junior female ($n = 10$) (filled square) and male (open diamond) athletes. DS: deep squat; HS: hurdle step; ILL: in-line lung; SM: shoulder mobility; ASLR: active straight-leg raise; TSPU: trunk stability push-up; RS: rotary stability

Spearman's correlation analyses showed strong inverse relationships between different FMS test scores and gait parameters in women and men. For example, significant inverse correlation was found between left-leg step length and deep squat ($r = -0.798$, $p = 0.008$) in women. The FMS test scores well characterize the motor performance but do not identify participant-specific compensations during the test. For example, the peak sagittal plane joint angles and joint moments of the lower extremity can differ between participants during the deep squat, resulting in participant-specific dorsiflexion-, knee flexion-, and hip-extension excursions. The relationship between length of gait line of the left-leg and right-leg hurdle step ($r = -0.824$, $p = 0.002$) supports the idea that rotation occurs at the level of the pelvis, which causes a compensatory movement during deep squat. Stepwise multiple regression analysis also supports this idea, showing that right-leg hurdle step significantly predicted length of gait line of the left leg ($r = 0.82$, $p = 0.000$).

Our results are in line with a previous study (26), demonstrating gender specificity in movement technique, which affected the relationship between FMS scores and gait parameters. For example, we found a significant inverse relationship only between rotary stability and right-leg step length ($r = -0.728$, $p = 0.008$) in men. Furthermore, rotary stability had been shown as a key factor predicting right-leg step length ($r = 0.73$, $p = 0.002$) and right-leg foot rotation degree ($r = 0.70$, $p = 0.002$).

FMS is widely used in several sports fields as a standardized method to measure the seven fundamental movement patterns. For example, the results from a previous study suggest that CrossFit produce marked symmetry in some fundamental movements compared with weight lifting or bodybuilding (33). Furthermore, FMS prescreening system found lower limb asymmetry in 40% of the members of one of Hungary's first league soccer clubs when examined the quality of functional movement patterns (38). Previous studies have described that gender could affect the FMS scores (18) through the differences in muscle strength and power (26) and movement biomechanics during certain actions (22, 23). In this study, we found no significant interaction between FMS, treadmill-based gait parameters, and gender. Although significant correlations were not found in either gender between the SI of gait parameters and compensations in FMS,

Table III. Spearman's correlations (r) between Functional Movement Screen assessments for the left and right sides of the body, and unilateral treadmill-based gait parameters, such as foot rotation (°), step length normalized for standing height, and length of gait line normalized for standing height in elite junior female ($n = 10$) and male ($n = 10$) athletes

	DS	HS L	HS R	ILL L	ILL R	SM L	SM R	ASLR L	ASLR R	TSPU	RS
Women											
Foot rotation left (°)	0.28	0.33	−0.02	0.19	0.45	0.13	0.36	0.14	0.20	0.49	0.18
Foot rotation right (°)	−0.06	0.58	−0.51	−0.36	−0.05	0.19	0.22	−0.34	−0.59	0.44	0.26
Step length left	−0.80*	0.05	−0.30	−0.64	−0.73*	−0.10	0.03	−0.02	−0.20	0.33	0.18
Step length right	−0.76*	−0.22	−0.48	−0.49	−0.73*	−0.32	−0.15	0.01	−0.18	0.34	0.07
Length of gait line left	−0.59	0.04	−0.82*	−0.56	−0.65	0.06	−0.05	−0.26	−0.72*	0.27	−0.16
Length of gait line right	−0.81	0.18	−0.68	−0.77*	−0.81	0.05	−0.04	−0.35	−0.71*	0.12	0.02
Men											
Foot rotation left (°)	0.40	0.11	−0.17	0.22	−0.40	−0.01	0.14	0.49	0.64	−0.10	0.26
Foot rotation right (°)	0.46	0.05	0.05	0.02	−0.27	−0.31	−0.08	0.33	0.51	0.21	0.37
Step length left	0.45	−0.16	0.12	0.42	0.26	0.55	0.45	0.07	−0.04	0.16	−0.56
Step length right	0.48	−0.02	0.08	0.58	0.27	0.48	0.22	−0.02	−0.05	0.27	−0.73*
Length of gait line left	0.04	−0.20	−0.14	0.51	0.03	0.08	−0.06	−0.29	−0.09	0.20	−0.56
Length of gait line right	0.01	−0.11	0.13	0.30	0.30	−0.10	−0.22	−0.52	−0.33	0.46	−0.57

DS: deep squat; HS: hurdle step; ILL: in-line lunge; SM: shoulder mobility; ASLR: active straight-leg raise; TSPU: trunk stability push-up; RS: rotary stability.
*$r = 0.7$ to 1 or −0.7 to −0.1

Table IV. Spearman's correlations (r) between Functional Movement Screen (FMS) asymmetry and movement asymmetries in foot rotation (°), step length normalized for standing height, and length of gait line normalized for standing height during treadmill-based gait in elite junior female ($n = 10$) and male ($n = 10$) athletes

	Foot rotation (°)	Step length (cm)	Length of gait line (mm)
Women	−0.089	0.266	0.040
Men	0.414	−0.607	−0.267

FMS asymmetry has been assessed by the average value of side-to-side asymmetry in FMS tests, which are scored bilaterally, such as in-line lunge, shoulder mobility, and active straight-leg raise. Movement asymmetries in treadmill-based gait parameters were assessed using a symmetry index (30)

Table V. Correlations between FMS test scores and selected gait parameters in elite junior female ($n = 10$) and male ($n = 10$) athletes using stepwise multiple regression model

Best predictors of the test	Women			Men		
	r	***r*²**	***p***	***r***	***r*²**	***p***
Foot rotation left (°)						
Right-leg ASLR	–	–	–	–	–	–
Foot rotation right (°)						
Rotary stability	–	–	–	0.70	0.49	0.002
Step length left (cm)						
DS	0.79	0.63	0.001	–	–	–
Step length right (cm)						
DS	0.76	0.58	0.001	–	–	–
Rotary stability	–	–	–	0.73	0.53	0.002
Length of gait line left (mm)						
Right-leg HS	0.82	0.68	0.000	–	–	–
Length of gait line right (mm)						
DS	0.81	0.66	0.000	–	–	–

Strong correlation is defined in $r = 0.7$ to 1 or −0.7 to −1. FMS: Functional Movement Screen; ASLR: active straight-leg raise; DS: deep squat; HS: hurdle step; r: multiple regression correlation coefficient; p: significance

different FMS test scores predicted different gait parameters in female and male athletes. Furthermore, the type of correlation was different in men and women, suggesting an influence of gender on the relationship between FMS scores and treadmill-based gait parameters. These findings support the idea that coaches and practitioners may need to use FMS differently in males and females when looking for functional deficiencies. On the other hand, small sample size of this study limits the interpretation of the results;

therefore, clear arguments for practical applications cannot be described. However, strength and conditioning coaches should be cognizant that the FMS scores may have limited application to sport-specific performance and may indicate different compensatory training in female and male athletes.

One limitation of this study is that the correlation analyses cannot reveal cause–effect relationships and there is a need to verify the conclusions drawn from the present cross-sectional study using data from interventions. Another limitation is that we measured only gait as a general measure of motor output but did not measure discipline-specific performance that could have provided perhaps deeper insights into the gender–FMS performance relationship. However, previous studies have demonstrated low correlation between FMS scores and athletic performance (18, 27, 28). Prestudy statistical power calculation revealed that 44 subjects would be optimal to detect changes in the measured variables; therefore, the small sample size may have prevented us from detecting the effects of gender on all of the relationships we considered between gait parameters and FMS scores.

In conclusion, our preliminary data suggest that gender could affect the relationship between FMS scores and treadmill-based gait parameters. Furthermore, stepwise multiple regression analysis showed that different FMS test scores predicted different gait parameters in women and men. The FMS test was developed to provide an indication of movement compensation only with scoring. This scoring is interpreted so that a high score on the left compared with the right leg reflects compensation and imbalance. In contrast, this study is in agreement with previous data, which suggest that there is no significant relationship between FMS asymmetry and movement asymmetries measured by symmetry indices of treadmill-based gait parameters, reflecting insensitivity to any underlying compensations. We surmise that FMS could determine deficiencies, functional limitations, or asymmetries; however, strength and conditioning coaches need to pay attention not only to how to score but also to how to use FMS. Nevertheless, the sample size was too small to discern whether gender affects the relationship between FMS asymmetry and movement asymmetries. Future studies need to increase sample size and also measure discipline-specific performance to obviously detect the effects of gender on the relationship between gait parameters and FMS scores.

Acknowledgements

CB, MOM, and JN contributed in study conception and design. NM, VS, BS, KG, MOM, and JN contributed in acquisition of data. TH, RMK, and JN contributed in analysis and interpretation of data. MOM, TH, RMK, and JN contributed in drafting of manuscript. TH, RMK, TJ, and JN contributed in critical revision. The research was conducted at Pain Clinic, Budapest, Hungary. The authors would like to thank the athletes for their time and effort to participate in this study. The research project was supported in part by the Hungarian Olympic Committee. The results of this study do not constitute endorsement for or against the FMS by the authors. They declared no conflict of interest regarding the publication of this manuscript.

REFERENCES

1. Alizadehkhaiyat O, Hawkes DH, Kemp GJ, Howard A, Frostick SP: Muscle strength and its relationship with skeletal muscle mass indices as determined by segmental bio-impedance analysis. Eur. J. Appl. Physiol. 114(1), 177–185 (2014)
2. Alton F, Baldey L, Caplan S, Morrissey MA: Kinematic comparison of over ground and treadmill walking. Clin. Biomech. 13, 434–440 (1998)

3. Bardenett SM, Micca JJ, DeNoyelles JT, Miller SD, Jenk DT, Brooks GS: Functional Movement Screen normative values and validity in high school athletes: can the FMS™ be used as a predictor of injury? Int. J. Sports Phys. Ther. 10(3), 303–308 (2015)
4. Bejek Z, Paróczai R, Illyés A, Kiss RM: The influence of walking speed on gait parameters in healthy people and in patients with osteoarthritis. Knee Surg. Sports Traumatol. Arthrosc. 14(7), 612–622 (2006)
5. Brophy RH, Backus S, Kraszewski AP, Steele BC, Ma Y, Osei D, Williams RJ: Differences between sexes in lower extremity alignment and muscle activation during soccer kick. J. Bone Joint Surg. Am. 92(11), 2050–2058 (2010)
6. Chimera NJ, Smith CA, Warren M: Injury history, sex, and performance on the Functional Movement Screen and Y balance test. J. Athl. Train. 50(5), 475–485 (2015)
7. Chiu MC, Wang MJ: The effect of gait speed and gender on perceived exertion, muscle activity, joint motion of lower extremity, ground reaction force and heart rate during normal walking. Gait Posture 25(3), 385–392 (2007)
8. Chorba RS, Chorba DJ, Bouillon LE, Overmyer CA, Landis JA: Use of a Functional Movement Screening tool to determine injury risk in female collegiate athletes. N. Am. J. Sports Phys. Ther. 5(2), 47–54 (2010)
9. Cook G, Burton L, Hoogenboom B: Pre-participation screening: the use of fundamental movements as an assessment of function – part 1. N. Am. J. Sports Phys. Ther. 1(2), 62–72 (2006a)
10. Cook G, Burton L, Hoogenboom B: Pre-participation screening: the use of fundamental movements as an assessment of function – part 2. N. Am. J. Sports Phys. Ther. 1(3), 132–139 (2006b)
11. Ford KR, Myer GD, Hewett TE: Valgus knee motion during landing in high school female and male basketball players. Med. Sci. Sports Exerc. 35(10), 1745–1750 (2003)
12. Frost DM, Beach TA, Callaghan JP, McGill SM: Using the Functional Movement Screen™ to evaluate the effectiveness of training. J. Strength Cond. Res. 26(6), 1620–1630 (2012)
13. Hausdorff JM: Gait variability: methods, modeling and meaning. J. Neuroeng. Rehabil. 2, 19 (2005)
14. Kang HG, Dingwell JB: Separating the effects of age and walking speed on gait variability. Gait Posture 27(4), 572–577 (2008)
15. Kiss R, Magyar O (2014): Effect of gender and walking speed on gait variability in healthy young subject. In: ISEK 2014: XX Congress International Society of Electrophysiology and Kinesiology, Rome, Italy, p. 312
16. Ko DY, Lee HS: The changes of COP and foot pressure after one hour's walking wearing high-heeled and flat shoes. J. Phys. Ther. Sci. 25(10), 1309–1312 (2013)
17. Konradsen L: Factors contributing to chronic ankle instability: kinesthesia and joint position sense. J. Athl. Train. 37(4), 381–385 (2002)
18. Lockie R, Schultz A, Callaghan S, Jordan C, Luczo T, Jeffriess MA: A preliminary investigation into the relationship between Functional Movement Screen scores and athletic physical performance in female team sport athletes. Biol. Sport 32(1), 41–51 (2015)
19. Lockie RG, Schultz AB, Jordan CA, Callaghan SJ, Jeffriess MD, Luczo TM: Can selected functional movement screen assessments be used to identify movement deficiencies that could affect multidirectional speed and jump performance? J. Strength Cond. Res. 29(1), 195–205 (2015)
20. Lovejoy CO: The natural history of human gait and posture. Part 2. Hip and thigh. Gait Posture 21(1), 113–124 (2005)
21. Lovejoy CO: The natural history of human gait and posture. Part 3. The knee. Gait Posture 25(3), 325–341 (2007)
22. Malinzak RA, Colby SM, Kirkendall DT, Yu B, Garrett WE: A comparison of knee joint motion patterns between men and women in selected athletic tasks. Clin. Biomech. (Bristol, Avon) 16(5), 438–445 (2001)
23. McLean SG, Lipfert SW, van den Bogert AJ: Effect of gender and defensive opponent on the biomechanics of sidestep cutting. Med. Sci. Sports Exerc. 36(6), 1008–1016 (2004)
24. Minick KI, Kiesel KB, Burton L, Taylor A, Plisky P, Butler RJ: Interrater reliability of the Functional Movement Screen. J. Strength Cond. Res. 24(2), 479–486 (2010)
25. Moran RW, Schneiders AG, Major KM, Sullivan SJ: How reliable are Functional Movement Screening scores? A systematic review of rater reliability. Br. J. Sports Med. 50(9), 527–536 (2016)
26. Nimphius S, McGuigan MR, Newton RU: Relationship between strength, power, speed, and change of direction performance of female softball players. J. Strength Cond. Res. 24(4), 885–895 (2010)
27. Okada T, Huxel KC, Nesser TW: Relationship between core stability, functional movement, and performance. J. Strength Cond. Res. 25(1), 252–261 (2011)
28. Parchmann CJ, McBride JM: Relationship between Functional Movement Screen and athletic performance. J. Strength Cond. Res. 25(12), 3378–3384 (2011)
29. Reed LF, Urry SR, Wearing SC: Reliability of spatiotemporal and kinetic gait parameters determined by a new instrumented treadmill system. BMC Musculoskelet. Disord. 14, 249 (2013)

30. Robinson RO, Herzog W, Nigg BM: Use of force platform variables to quantify the effects of chiropractic manipulation on gait symmetry. J. Manipulative Physiol. Ther. 10(4), 172–176 (1987)
31. Shultz SJ, Nguyen AD, Schmitz RJ: Differences in lower extremity anatomical and postural characteristics in males and females between maturation groups. J. Orthop. Sports Phys. Ther. 38(3), 137–149 (2008)
32. Soltani N, Rahimi A, Naimi SS, Khademi K, Saeedi H: Studying the balance of the coper and non-coper ACL-deficient knee subjects. Asian J. Sports Med. 5(2), 91–98 (2014)
33. Tafuri S, Notarnicola A, Monno A, Ferretti F, Moretti B: CrossFit athletes exhibit high symmetry of fundamental movement patterns. A cross-sectional study. Muscles Ligaments Tendons J. 6(1), 157–160 (2016)
34. Wilmore JH, Behnke AR: An anthropometric estimation of body density and lean body weight in young men. J. Appl. Physiol. 27(1), 25–31 (1969)
35. Wilmore JH, Behnke AR: An anthropometric estimation of body density and lean body weight in young women. Am. J. Clin. Nutr. 23(3), 267–274 (1970)
36. Yogev-Seligmann G, Hausdorff JM, Giladi N: The role of executive function and attention in gait. Mov. Disord. 23(3), 329–342 (2008)
37. You YY, Chung SH: The effects of gait velocity on the gait characteristics of hemiplegic patients. J. Phys. Ther. Sci. 27(3), 921–924 (2015)
38. Zalai D, Panics G, Bobak P, Csáki I, Hamar P: Quality of functional movement patterns and injury examination in elite-level male professional football players. Acta Physiol. Hung. 102(1), 34–42 (2015)