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RESEARCH

The relationship between the functional movement screen and isokinetic muscle strength around the knee in different sports

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Abstract
The aim of this study was to determine objective data of the relationship between the Functional Movement Screen (FMS) and isokinetic muscle strength around the knee in individuals engaged in different sports. The study included 60 athletes involved in volleyball, Greco-Roman wrestling, speed skating, athletics, and taekwondo. The functional movement of the athletes, and lower extremity isokinetic muscle strength were evaluated with FMS and ISOMED 2000® isokinetic device. The relationship was examined between the FMS total and sub-test scores and the lower extremity isokinetic muscle strength values. A correlation was found between the FMS total score and the hamstring peak torque of the dominant side at 60°/s angular velocity, and between the H/Q ratio and the difference in quadriceps isokinetic muscle strength between the dominant and non-dominant sides (r: − 0.277, r: − 0.330, r: 0.015). A correlation was determined between the FMS sub-test In-line Lunge and the difference between the H/Q ratio on the non-dominant side at 60°/s angular velocity and hamstring isokinetic muscle strength (r: -0.458, r: − 0.296). The In-line Lunge test was also determined to be correlated with the H/Q ratios on the dominant and non-dominant sides at 180°/s angular velocity and the hamstring isokinetic muscle strength difference (r:0.291, r:0.258, respectively). The FMS sub-test of Rotary Stability was correlated with the H/Q ratio on the dominant side at 60° angular velocity (r:-0.270). The relationships found between FMS and isokinetic analysis data showed that both types of assessments are valuable on their own. But we believe that using both together during athlete evaluation to prevent possible injuries will yield the best results for athletes' health.

Keywords Physical functional performance · Muscle imbalance · Isokinetic · Muscle strength

Introduction

Sport-specific performance tests are applied to evaluate performance in a sport and potential injuries. In addition to these performance tests, there are also sports tests that are used to determine injuries in athletes and to take precautions against these. Movement analysis systems are one of these evaluations. These systems are used as a guiding tool in the determination of injuries and for the taking of precautions against potential injuries [1]. There has been a recent increase in interest in screenings showing neuromuscular control during basic motor movements.

The Functional Movement Screen (FMS) is an evaluation system, developed by Gray Cook and Lee Burton in 1997, in which the basic movements of an individual are observed, and provides observations of basic locomotor, manipulative, and stabilising movements. The movement capability of an athlete, and weak aspects of movement and imbalance in muscle strength, if present, are determined as a result of the evaluation [2, 3]. In studies related to this topic, it has been reported that many athletes cannot perform these basic movements despite a high performance level [2, 4].

Another method used in the determination of muscle strength of athletes and the prediction of injuries that may develop is isokinetic systems. Muscle strength imbalance between the dominant-non-dominant sides and agonist–antagonist muscle groups is determined in these systems. These are accepted as an effective method that is used to determine

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muscle strength and to develop the muscle strength of individuals. With these measurements, the muscle is evaluated as isolated. Isokinetic measurement devices enable objective information to be obtained about muscle strength, power and resistance, and strength imbalances of the agonist–antagonist and dominant-non-dominant sides [5, 6].

The development of the performance of athletes currently aims for the athlete to participate in competitions with the same performance and without long-term injury. Therefore, although the evaluation of muscle strength alone provides gold standard information, it is just as important that this strength is reflected in movement and functional activities. Both isokinetic systems and the FMS are among the objective methods used on athletes. There are few studies in literature that have examined the relationship between isokinetic system evaluations and FMS scores. Therefore, the aim of this study was to determine objective data of the relationship of isokinetic muscle strength and FMS in different sports branches. In line with these objectives, our hypotheses are:

H1$_1$: The FMS total score is related to the isokinetic quadriceps-hamstring muscle strength of the athletes, was accepted.
H1$_2$: The sub-tests of FMS are related to the isokinetic quadriceps-hamstring muscle strength of the athletes, was accepted.
H1$_3$: The relationship between the FMS total score and the isokinetic quadriceps-hamstring muscle strength of the athletes is related to the sports branch.
H1$_4$: The FMS total score is related to the difference between the isokinetic muscle strength of the dominant side and the non-dominant side of the athletes.
H1$_5$: The sub-test of FMS concerning the lower extremities are related to the difference between the isokinetic muscle strength of the dominant side and the non-dominant side of the athletes.
H1$_6$: The relationship between the FMS total score and the difference between the isokinetic muscle strength of the dominant side and the non-dominant side of the athletes is related to the sports branch.
H1$_7$: There is a difference between the FMS total scores of different sports branches.
H1$_8$: There is a difference between the FMS total scores of sports branches that predominantly use the upper extremities and those that predominantly use the lower extremities.

Methods

Experimental approach to the problem

The study was carried out to reveal the relationship between FMS and isokinetic muscle strength with objective data. The study included athletes who presented at the Ministry for Youth and Sport, the Sports General Directorate, and the Department for Health Affairs (SESAM- Athlete Training and Health Research Center). The athletes included in the study were taken into FMS and then isokinetic measurement. Before the FMS analysis, the athletes were asked to not train and not to do any stretching exercises to affect the results of the analysis that required the test. The FMS analysis of the athletes was completed in an average of 20 min. After the FMS, it was allowed to recover around a 30-min rest. After 30 min of rest, the athlete was evaluated for isokinetic knee. The isokinetic measurement was completed in an average of 20 min.

Subjects

The study inclusion criteria were defined as being licensed for the sport for at least 3 years, and voluntary participation in the study. Athletes with a history of an orthopaedic problem within the last 6 months or which was currently ongoing and BMI < 18.5 and > 30 were excluded from the study.

A total of 71 athletes were interviewed and all were given detailed information about the study who aged 13 and older. After the exclusion of 11 athletes due to a previous or current orthopaedic problem, the study was completed with 60 athletes (Fig. 1). Written consent forms were obtained from the families of those under the age of 18 and from themself of those over the age of 18.

Permission and approval for the study were granted by the Social and Humanities Ethics Committee of Ankara Yildirim Beyazit University (decision no: 23, research code: 586, dated: 08.06.2017) and was registered at www.clinicaltrials.gov (NCT05964556).

Procedures

FMS analysis

FMS is an analysis system which evaluates muscle strength balance and the functional performances on the dominant and non-dominant sides of athletes. It aims to determine stability and mobility which can be overlooked in an asymptomatic active population and in athletes. The FMS, developed by Gray Cook, consists of 7 parameters: deep squat-DS, hurdle step-HS, in-line lunge-ILL,

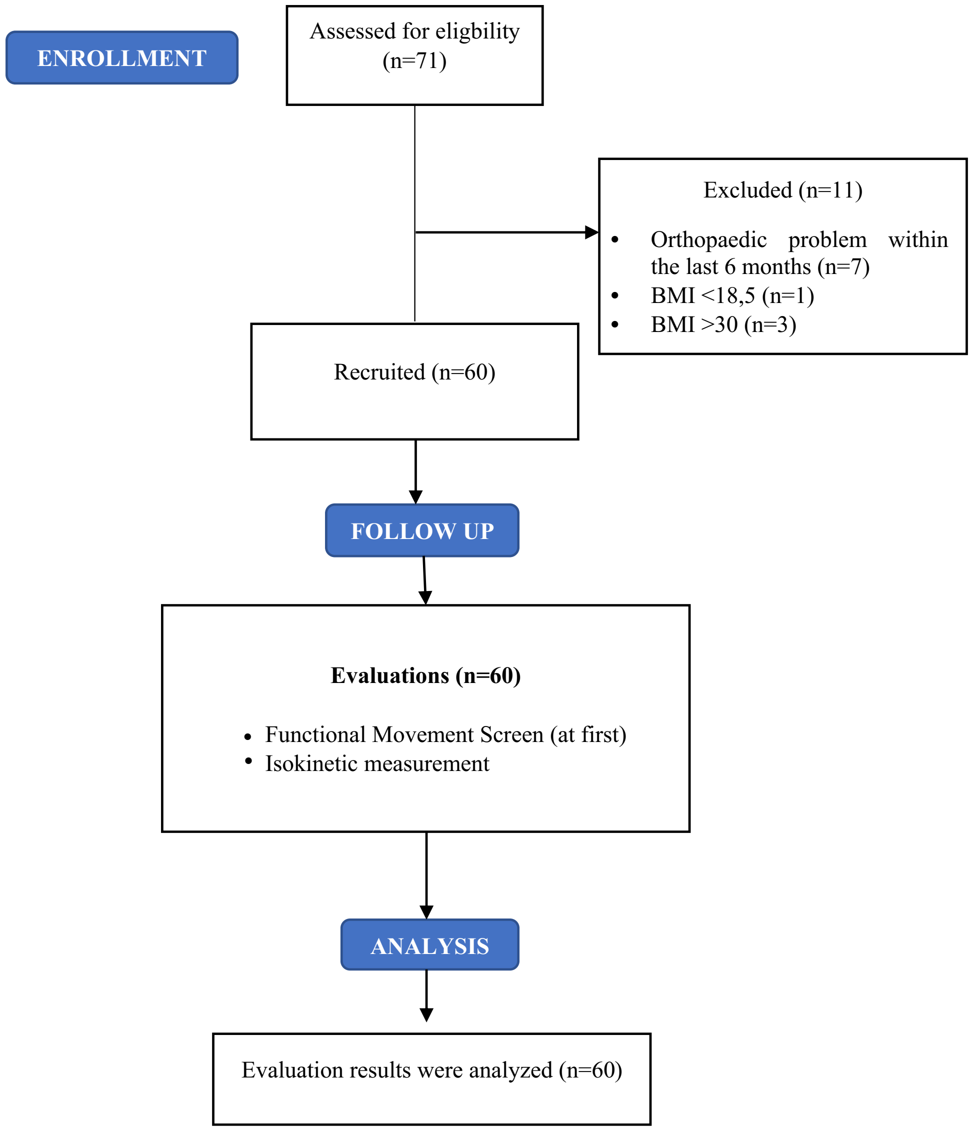

Fig. 1 The flowchart of sports

shoulder mobility-SM, active straight leg raise-ASLR, trunk stability push up-TS, and rotary stability-RS. After giving verbal directions to the athletes about head, trunk, knee, and foot positions, as defined by Gray Cook, the athletes were evaluated [7, 8]. A score was given for each parameter of 0–3 points, to provide a maximum total score of 21 points. Full completion of the movement without compensation is awarded 3 points, and 1 or 2 points are given according to the use of a compensation mechanism and disruptions to balance. When there is any pain during or at the end of the movement, a score of 0 points is made for the parameter evaluated. The movements were recorded with two cameras, one from the anterior and one lateral. After the examination of the recorded data by three researchers, the average FMS points were calculated for each athlete.

Isokinetic measurement

The isokinetic knee flexor and extensor group muscle strengths were measured on the dominant and non-dominant sides of each athlete in the study. The measurements were performed with an ISOMED 2000 isokinetic measurement device (D&R Ferstl GmbH, Hemau, Germany). The ISOMED 2000 isokinetic test device was calibrated at the start of each day as defined in the device software for the test to be applied. The test protocol was set to be concentric/concentric. The measurements were performed at 60°/s and 180°/s angular velocities. At 60°/s angular velocity, each athlete was instructed to perform voluntary knee flexion/extension at maximum strength for 10 repetitions. Then, after a 30-s rest period, 30 repetitions of knee flexion/extension were performed at 180°/s angular velocity. Before starting the test at both angular velocities, the athlete was permitted to make 3 trials of the movement [9].

Sample size

The sample size was calculated with the G*Power (v.3.9.1.7) program using the data of a pilot study. The effect sizes for the FMS and isokinetic evaluation of the knee showed that a sample of at least 60 participants was needed to provide 90% power with type 1 error of 0.05 and type 2 error of 0.10.

Statistical analysis

The calculations and statistical analyses in this study were performed using IBM SPSS Statistics vn. 21.0 (IBM SPSS Statistics for Windows, Version 21 (2012), Armonk, NY, USA) and MS-Excel 2007 software.

The gender, dominant side, and sport branch of the athletes in the study were stated as number (n) and percentage (%). Descriptive statistics of the sub-parameters of the FMS and isokinetic evaluations, and the variables of age, weight, height, and body mass index of the athletes were stated as mean ± standard deviation (SD), median, minimum and maximum values.

The Shapiro Wilk test was applied to assess the conformity to normal distribution of the data of the FMS scores and the isokinetic muscle strength of the athletes. In the correlation analysis of variables showing normal distribution, the Pearson correlation coefficient was used, and for variables not showing normal distribution, Spearman rho correlation coefficient was applied. Whether or not there was any statistically significant difference in the FMS scores of the athletes according to the sport branch was examined with the non-parametric Kruskal Wallis test. Whether or not there was any statistically significant difference between volleyball and the other sport branches in respect of the FMS scores was examined with the non-parametric Mann Whitney U-test. The level of statistical significance was accepted as $p < 0.05$ and $p < 0.001$.

Results

This study was performed with the aim of determining objective data of the relationship between FMS and isokinetic muscle strength imbalance. Evaluation was made of 60 athletes with no injury or disability. The demographic data of the athletes included in the study are shown in Table 1.

The relationships between the total FMS score and hamstring-quadriceps isokinetic muscle strength of the athletes are shown in Table 2. A negative weak linear relationship was determined between the total FMS score and the dominant side hamstring peak torque strength at 60°/s angular velocity (rho = − 0.277, $p < 0.05$). As the FMS scores at 60°/s angular velocity increased, so the dominant side peak torque strength value decreased (Table 2).

The relationships between the FMS sub-tests of the athletes and the dominant side and non-dominant side H/Q ratio at 60°/s and 180°/s angular velocities are shown in Table 3. A negative, moderate level, direct linear correlation was determined between the ILL left-side values and the dominant side H/Q ratio at 60°/s angular velocity (rho = − 0.458, $p < 0.001$). As the dominant side H/Q ratio at 60°/s angular velocity increased, so the ILL left-side values decreased (Fig. 2) (Table 3).

As the ILL total scores of the athletes increased, the dominant side H/Q ratio at 60°/s angular velocity was determined to decrease (rho = − 0.455, $p < 0.001$) (Fig. 2) (Table 3). As the ILL total scores increased, the non-dominant side H/Q ratio at 60°/s angular velocity was determined to decrease (rho = − 0.267, $p < 0.05$) (Fig. 2) (Table 3). When the ILL left-side values were examined, it was seen that as the dominant side H/Q ratio at 180°/s angular velocity increased, the ILL left-side values decreased (rho = − 0.258, $p < 0.05$) (Fig. 3) (Table 3). As the ILL right-side values increased the non-dominant side H/Q ratio at 180°/s angular velocity was determined to decrease (rho = 0.291, $p < 0.05$) (Fig. 2) (Table 3).

A weak, negative, linear correlation was determined between the RS values and the dominant side H/Q ratio at 60°/s angular velocity (rho = − 0.270, $p = 0.037$). As the RS values increased, so the dominant side H/Q ratio at 60°/s angular velocity decreased (Table 3).

The relationships between the total FMS score and the dominant and non-dominant H/Q ratios at 60°/s and 180°/s angular velocities according to the sports branches are shown in Table 4. In the Greco-Roman wrestlers, a strong, negative, linear correlation was determined between the dominant side H/Q ratio at 60°/s angular velocity (rho = − 0.747, $p < 0.05$, $p = 0.013$). As the FMS scores of these athletes increased, so the dominant side H/Q ratio at 60°/s angular velocity decreased (Fig. 3) (Table 4). A strong, negative, linear correlation was determined between the FMS scores and the non-dominant side H/Q ratio at 60°/s angular velocity (rho = − 0.704, $p < 0.05$, $p = 0.023$). As the FMS scores increased, so the non-dominant side H/Q ratio at 60°/s angular velocity decreased (Fig. 3) (Table 4).

The relationships between the total FMS scores of the athletes and the difference between the dominant and non-dominant sides muscle strength are shown in Table 5. A weak, positive linear correlation was determined only between the total FMS scores and the differences in quadriceps muscle strength at 60°/s angular velocity (rho = 0.015, $p < 0.05$) (Table 5).

In the Greco-Roman wrestlers, a moderate level, positive linear relationship was determined between the FMS

Table 1 The physical characteristics of the athletes

Physical characteristics ($n = 60$)	Mean ± SD	Median (IQR)	Min–max
Age (years)	17.81 ± 3.38	16.00 (3.00)	14–29
Body weight (kg)	76.80 ± 11.48	75.50 (14.75)	53–104
Height (m)	1.85 ± .11	1.87 (0.18)	1.58–2.05
Body mass index (BMI) (kg/m^2)	22.34 ± 2.60	22.02 (3.61)	17.40–29.59
Years in the sport	5.70 ± 2.18	5 (3)	3.00–12.00
Greco-Roman wrestling ($n = 11$)			
Age (years)	23.40 ± 2.17	22 (4)	21–27
Body weight (kg)	75.20 ± 1.64	75 (15)	63–98
Height (m)	1.70 ± 0.06	1.69 (0.12)	1.62–1.82
Body mass index (BMI) (kg/m^2)	25.64 ± 1.83	25.36 (2.73)	23.5–29.59
Years in the sport	5.9 ± 1.5	5.5 (1.5)	4–9
Volleyball ($n = 40$)			
Age (years)	16.47 ± 2.47	16 (1.75)	14–29
Body weight (kg)	79.15 ± 1.52	79.50 (12.50)	55–104
Height (m)	1.91 ± 0.08	1.91 (0.10)	1.73–2.05
Body mass index (BMI) (kg/m^2)	2.40 ± 25.74	21.65 (2.32)	21.61–1.98
Years in the sport	5.42 ± 2.16	5 (3.88)	3–11
Speed skating ($n = 5$)			
Age (years)	17.80 ± .44	18 (.5)	17–18
Body weight (kg)	66.80 ± 7.29	66 (12)	58–78
Height (m)	1.74 ± 0.30	1.75 (0.06)	1.70–1.78
Body mass index (BMI) (kg/m^2)	21.97 ± 2.49	21.30 (4.71)	2.38–25.47
Years in the sport	5.30 ± 1.20	5 (2.25)	4–7
Taekwondo ($n = 4$)			
Age (years)	17.75 ± 1.50	17 (2.25)	17–20
Body weight (kg)	75.75 ± 17.44	71.50 (32.25)	60–100
Height (m)	1.84 ± 0.35	1.85 (0.07)	1.80–1.88
Body mass index (BMI) (kg/m^2)	23.10 ± 4.46	21.20 (8.19)	2.72–28.29
Years in the sport	8.5 ± 3.5	8.50 (6.50)	5–12

IQR interquartile range, *SD* standard deviation, *Min* minimum value, *Max* maximum value

scores and the differences in hamstring muscle strength of the dominant and non-dominant sides at 180°/s angular velocity (rho = 0.661, $p < 0.05$). This result showed that as the total FMS score of the Greco-Roman wrestlers increased, so the difference in hamstring muscle strength between the dominant and non-dominant side increased (Fig. 3) (Table 5).

No correlation was determined between the total FMS scores of the volleyball, speed skating, and taekwondo athletes and the difference between the dominant and non-dominant sides hamstring and quadriceps muscle strength at 60°/s and180°/s angular velocities ($p > 0.05$) (Table 5).

The FMS scores of the athletes showed no significant difference according to the different sports ($p > 0.05$) (Table 6).

Discussion

This study was conducted with the aim of determining the relationship between FMS and isokinetic muscle strength imbalance with objective data. The results of the study demonstrated a relationship between the total FMS score and dominant side hamstring peak torque strength at 60°/s angular velocity, and with the H/Q ratio, and with the dominant-non-dominant side quadriceps isotonic muscle strength difference. From the ILL, which is one of the FMS sub-tests, there was determined to be a relationship with the dominant and non-dominant side H/Q ratios at

Table 2 Relationships between the total FMS score and the hamstring-quadriceps isokinetic muscle strength values

Variables ($n=60$)	Spearman rho correlation coefficient	p
FMS Score—60°/sc DS F-PT	− 0.277	**0.032***
FMS Score—60°/sc NDS F-PT	− 0.108	0.409
FMS Score—60°/sc DS F-PT/W	− 0.084	0.524
FMS Score—60°/sc NDS F-PT/W	0.135	0.303
FMS Score—60°/sc DS E-PT	0.090	0.493
FMS Score—60°/sc NDS E-PT	0.016	0.905
FMS Score—60°/sc DS E-PT/W	− 0.125	0.342
FMS Score—60°/sc NDS E-PT/W	0.207	0.113
FMS Score—180°/sc DS F-PT	− 0.237	0.068
FMS Score—180°/sc NDS F-PT	− 0.196	0.113
FMS Score—180°/sc DS F-PT/W	− 0.130	0.322
FMS Score—180°/sc NDS F-PT/W	− 0.89	0.148
FMS Score—180°/sc DS E-PT	− 0.075	0.570
FMS Score—180°/sc NDS E-PT	− 0.189	0.148
FMS Score—180°/sc DS E-PT/W	− 0.128	0.331
FMS Score—180°/sc NDS E-PT/W	− 0.182	0.164

FMS functional movement screen, *DS* dominant side, *NDS* non-dominant side, *F* flexion, *E* extension, *PT* peak torque, *PT/W* peak torque/body weight

*$p<0.05$

60°/s angular velocity and with the difference between the dominant-non-dominant side hamstring isokinetic muscle strength. There was also determined to be a correlation between the ILL score and the dominant and non-dominant side H/Q ratios at 180°/s angular velocity and with the difference between the dominant-non-dominant side hamstring isokinetic muscle strength. A significant correlation was also determined between the RS score from the FMS sub-tests and the dominant side isokinetic H/Q ratio at 60°/s angular velocity. In addition, when the sports branches were examined separately, a correlation was determined between the FMS score and the dominant and non-dominant side isokinetic H/Q ratios at 60°/s and 180°/s angular velocities in the athletes engaged in Greco-Roman wrestling.

The FMS is used to measure essential movement patterns in a dynamic and practical way and includes seven movements, which provide a detailed evaluation of joint movement, balance, symmetry, and core stability. From a maximum of 21 points, a score of ≤ 14 indicates a high risk of injury [7]. FMS is a tool designed to identify movement deficiencies that may predispose athletes to injury. Its use in analyzing the physiological effects on knee muscle strength after injury has gained attention. Here are some potential physiological effects, supported by recent studies:

Muscle imbalance detection FMS can help in detecting muscle imbalances, which are often present after a knee injury. According to a study by Kiesel et al. [10], FMS can identify asymmetries and movement dysfunctions that may contribute to decreased muscle strength in the knee following an injury.

Neuromuscular control After a knee injury, neuromuscular control is often compromised. FMS provides a comprehensive evaluation that includes tests for stability and mobility, which are critical for neuromuscular control. A study by Cook et al. [7, 8] indicates that FMS can assist in assessing and improving neuromuscular control, thus aiding in the recovery of knee muscle strength.

Rehabilitation and injury prevention Integrating FMS into rehabilitation programs can be beneficial for restoring knee muscle strength. It allows for the creation of tailored exercise programs that address specific deficiencies. Teyhen et al. [11] found that athletes who underwent rehabilitation programs that included FMS showed significant improvements in knee muscle strength and a lower risk of re-injury.

Functional mobility and stability FMS focuses on fundamental movement patterns that require both stability and mobility. These components are essential for knee joint function and muscle strength. Frost et al. [2] highlighted that improved functional mobility and stability through FMS protocols contribute to the strengthening of the muscles around the knee, enhancing overall joint function after an injury.

Predictive value for re-injury FMS scores can predict the likelihood of re-injury, which is closely related to muscle strength recovery. A study by Łyp et al. [12] demonstrated that lower FMS scores are associated with a higher risk of re-injury, emphasizing the importance of addressing movement deficiencies to improve knee muscle strength.

Holistic approach to recovery FMS provides a holistic approach to evaluating an athlete's movement patterns, which is crucial for comprehensive recovery. Assessing the whole body, rather than just the injured knee, ensures that compensatory movements that could hinder recovery are identified and corrected. Wang et al. [13] noted that this comprehensive evaluation helps in effectively targeting and improving knee muscle strength post-injury.

In summary, the Functional Movement Screen offers a valuable approach to understanding and improving knee muscle strength after an injury. By identifying and addressing movement deficiencies, enhancing neuromuscular control, and providing a comprehensive rehabilitation framework, FMS can significantly contribute to the recovery process and reduce the risk of future injuries. When combined with isokinetic assessments, it provides a more complete and realistic evaluation, optimizing injury prevention and rehabilitation outcomes. Isokinetic assessments are also crucial in the identification and prevention of sports injuries. They provide detailed information on muscle strength and endurance by measuring the force produced by muscles during constant-speed movements. According to a study by

Table 3 Relationships between the FMS sub-tests and the hamstring/quadriceps isokinetic muscle strength ratio

Variables	Dominant side		Non-dominant side	
	Spearman rho correlation coefficient	*p*	Spearman rho correlation coefficient	*p*
DS—60°/sc H/Q	− 0.085	0.516	0.079	0.550
DS—180°/sc H/Q	0.000	0.998	0.152	0.248
HS Right—60°/sc H/Q	− 0.123	0.350	− 0.094	0.473
HS Right—180°/sc H/Q	− 0.149	0.256	0.149	0.257
HS Left—60°/sc H/Q	− 0.183	0.161	− 0.232	0.075
HS Left—180°/sc H/Q	− 0.015	0.907	0.095	0.471
HS Total—60°/sc H/Q	− 0.183	0.161	− 0.232	0.075
HS Total—180°/sc H/Q	− 0.015	0.907	0.095	0.471
ILL Left—60°/sc H/Q	− 0.458	**< 0.001**[b]	− 0.209	0.109
ILL Left—180°/sc H/Q	− 0.258	**0.046**[1]	0.069	0.602
ILL Right—60°/sc H/Q	− 0.039	0.769	0.069	0.603
ILL Right—180 °/sc H/Q	0.174	0.184	0.291	**0.024**[a]
ILL Total—60°/sc H/Q	− 0.455	**< 0.001**[b]	− 0.267	**0.039**[a]
ILL Total—180°/sc H/Q	− 0.309	**0.016**[a]	− 0.021	0.874
SM Left—60°/sc H/Q	− 0.156	0.233	− 0.188	0.151
SM Left—180°/sc H/Q	− 0.074	0.573	0.058	0.661
SM Right—60°/sc H/Q	− 0.176	0.180	0.046	0.725
SM Right—180°/sc H/Q	0.169	0.195	0.117	0.373
SM Total—60°/sc H/Q	− 0.207	0.112	− 0.088	0.506
SM Total—180°/sc H/Q	− 0.060	0.651	0.120	0.363
ASLR Left—60°/sc H/Q	− 0.056	0.671	− 0.020	0.882
ASLR Left—180°/sc H/Q	0.164	0.210	− 0.057	0.667
ASLR Right—60°/sc H/Q	− 0.058	0.660	− 0.016	0.904
ASLR Right—180°/sc H/Q	0.044	0.741	0.012	0.929
ASLR Total—60°/sc H/Q	− 0.022	0.869	0.034	0.794
ASLR Total—180°/sc H/Q	0.096	0.464	0.005	0.968
TS—60°/sc H/Q	− 0.099	0.454	− 0.096	0.467
TS—180°/sc H/Q	0.088	0.505	− 0.041	0.754
RS—60°/sc H/Q	− 0.270	**0.037**[a]	− 0.211	0.106
RS—180°/sc H/Q	− 0.193	0.140	− 0.026	0.841

DS deep squat, *HS* hurdle step, *ILL* In-line lunge, *SM* shoulder mobility, *ASLR* active straight leg raise, *TS* trunk stability, *RS* rotatory stability, *H/Q* flexion/extension

[a] $p < 0.05$

[b] $p < 0.001$

Green et al. [5], isokinetic testing can effectively identify muscle imbalances and weaknesses that are often associated with a higher risk of injury. When combined with FMS, isokinetic assessments provide a comprehensive evaluation of an athlete's functional capacity and muscle performance. This dual approach ensures that both movement patterns and muscle strength are thoroughly assessed, leading to more accurate injury prevention strategies and tailored rehabilitation programs. The integration of FMS and isokinetic assessments offers the most realistic and effective results for athletes, as it addresses both neuromuscular control and muscular strength deficiencies, which are critical for preventing injuries and enhancing performance.

Another method used to measure muscle imbalances in the body is isokinetic assessment, and the knee is perhaps the joint most commonly tested [14]. Isokinetic testing can be used to evaluate quadriceps and hamstrings muscle strength, providing a determination of the magnitude of torque generated, and subsequently, the hamstrings to quadriceps (H:Q) strength ratio [5, 15].

In a study of 59 footballers by Willigenburg et al. isokinetic knee evaluations were made as 5 repetitions at 60°/s velocity and 10 repetitions at 300°/s velocity. While a significant correlation was reported between FMS and jumping performance, there was determined to be no significant correlation between the isokinetic data and the FMS scores

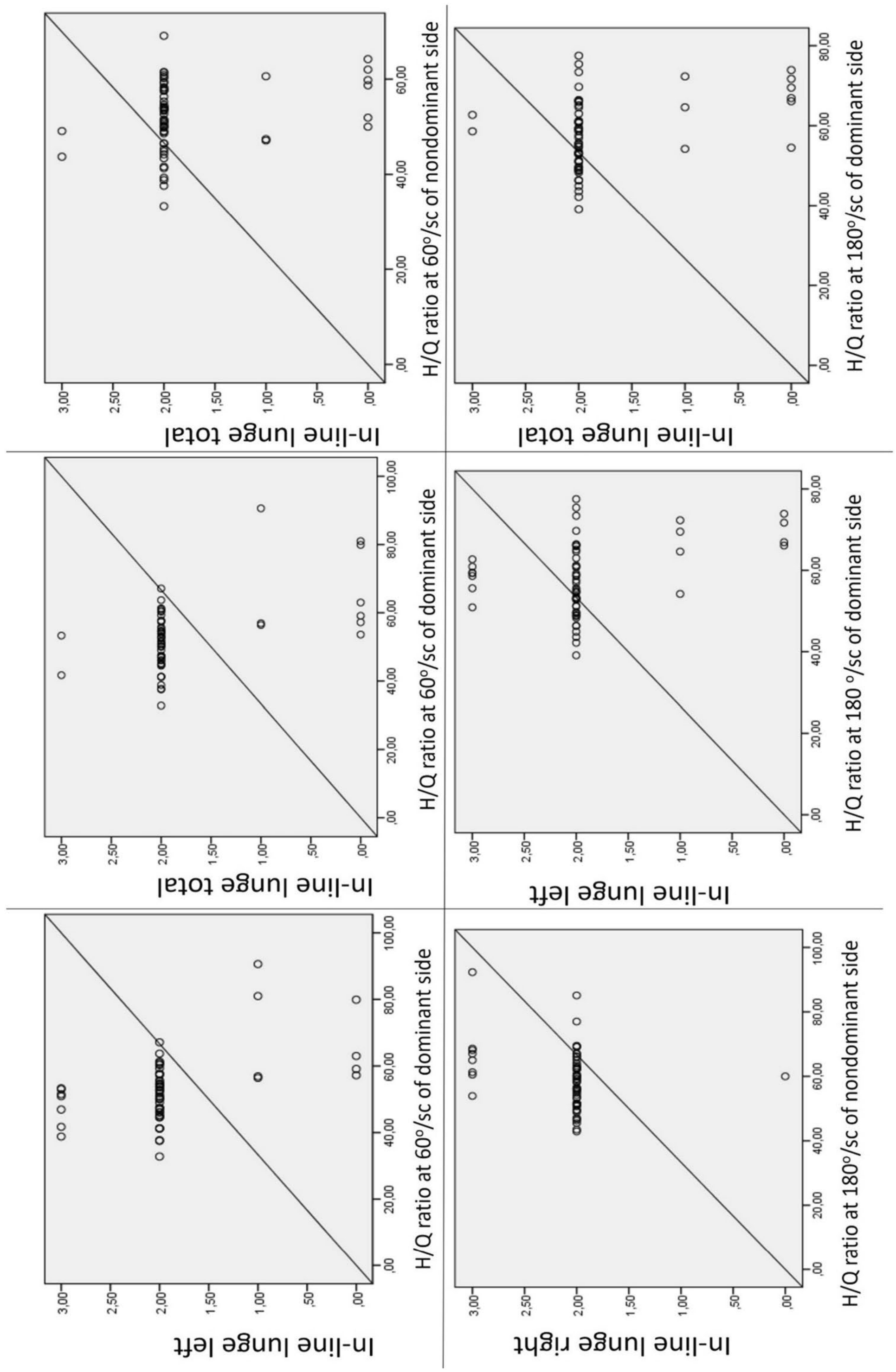

Fig. 2 The relationship between ILL values and H/Q ratios of athletes

[16]. In a similar study by Oliveira et al. [17] of 32 runners, the athletes were separated into 2 groups as those with a dysfunctional total FMS score of ≤ 14 points (*n*:16) and those with a functional FMS score of > 14 points (*n*:16). In addition to other performance tests, both groups were evaluated with an isokinetic dynamometer with 5 repetitions at 60°/s velocity and 15 repetitions at 300°/s velocity. As a result of statistical analyses, there was determined to be no difference between the isokinetic knee measurement values and the FMS scores of the two groups.

In contrast to these studies in literature, the current study was conducted at 60 and 180°/s angular velocity, and unlike those two studies, there was determined to be a relationship between the isokinetic values and the FMS scores, with the

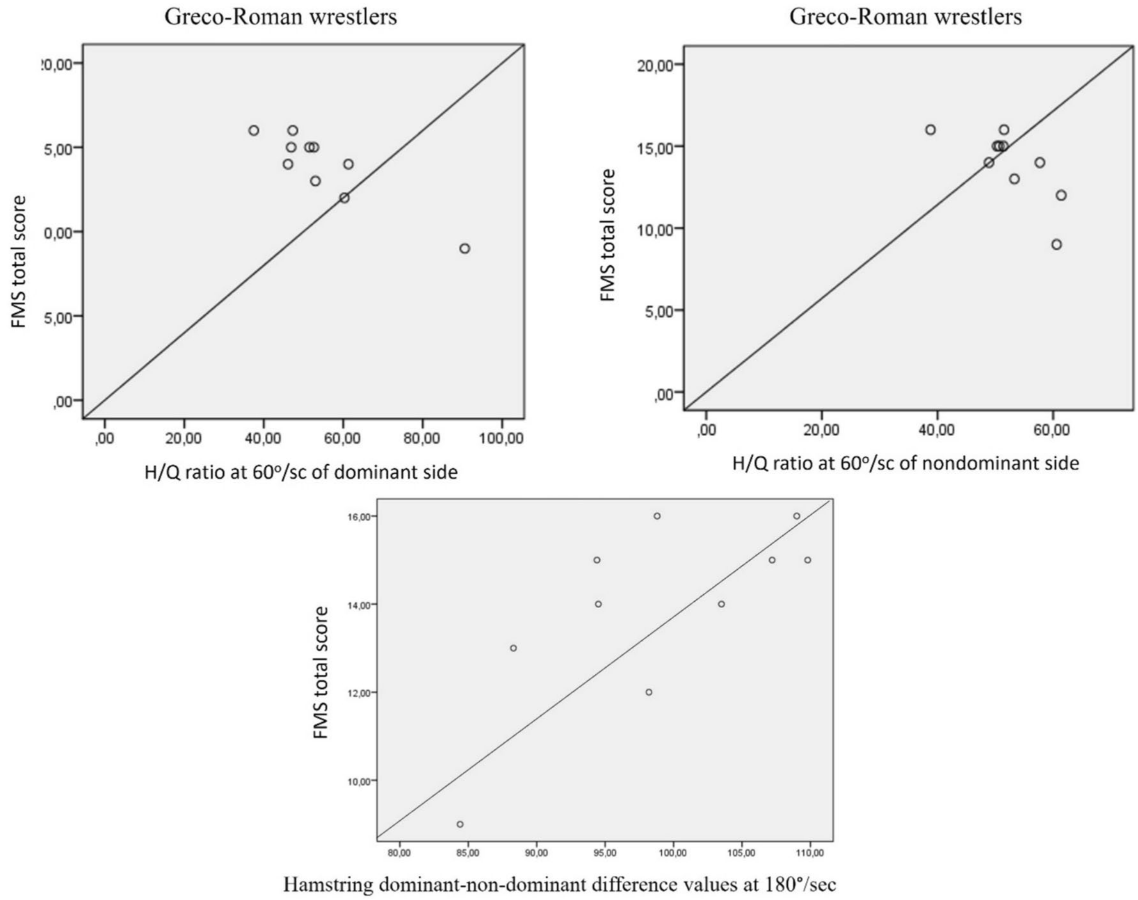

Fig. 3 The relationship between total FMS scores and isokinetic measurements of Greco-Roman athletes

Table 4 Comparisons of the relationships between the FMS scores and the defined variables according to the sports branches

Variables	Dominant side		Non-dominant side	
	Spearman rho correlation coefficient	*p*	Spearman rho correlation coefficient	*p*
Greco-Roman wrestling ($n = 11$)				
Total FMS—60°/sc H/Q	− 0.747	**0.013**[a]	− 0.704	**0.023**[a]
Total FMS—180°/sc H/Q	− 0.161	0.658	− 0.034	0.926
Volleyball ($n = 40$)				
Total FMS—60°/sc H/Q	− 0.275	0.086	− 0.005	0.978
Total FMS—180°/sc H/Q	− 0.132	0.418	− 0.130	0.424
Speed skating ($n = 5$)				
Total FMS—60°/sc H/Q	0.051	0.935	− 0.667	0.219
Total FMS—180°/sc H/Q	− 0.205	0.741	0.616	0.269
Taekwondo ($n = 4$)				
Total FMS—60°/sc H/Q	1.000	–	0.000	1.000
Total FMS—180°/sc H/Q	0.400	0.600	0.800	0.200

FMS functional movement screen, *H/Q* flexion/extension

[a]$p < 0.05$

Table 5 The relationships between the FMS scores of the athletes and the difference in muscle strength between the dominant an non-dominant sides

Variables ($n = 60$)	Hamstring		Quadriceps	
	Spearman rho correlation coefficient	*p*	Spearman rho correlation coefficient	*p*
Total FMS—60°/sc DS/NDS	− 0.215	0.099	0.015	**0.012**[a]
Total FMS—180°/sc DS/NDS	− 0.041	0.755	0.225	0.084
Greco-Roman wrestling ($n = 11$)				
Total FMS—60°/sc DS/NDS	− 0.142	0.696	− 0.093	0.799
Total FMS—180°/sc DS/NDS	0.661	**0.038**[a]	0.475	0.165
Volleyball ($n = 40$)				
Total FMS—60°/sc DS/NDS	− 0.266	0.098	0.128	0.430
Total FMS—180°/sc DS/NDS	0.017	0.916	0.041	0.801
Speed skating ($n = 5$)				
Total FMS—60°/sc DS/NDS	− 0.368	0.542	− 0.205	0.741
Total FMS—180°/sc DS/NDS	− 0.359	0.553	0.410	0.493
Taekwondo ($n = 4$)				
Total FMS—60°/sc DS/NDS	0.800	0.200	− 0.400	0.600
Total FMS—180°/sc DS/NDS	− 0.400	0.600	0.800	0.200

FMS functional movement screen, *DS* dominant side, *NDS* non-dominant side

[a] $p < 0.05$

Table 6 Comparisons of the FMS scores of the athletes according to the different sports

Sport branches						
Variables	Greco-Roman wrestling Mean ± SD	Volleyball Mean ± SD	Speed skating Mean ± SD	Taekwondo Mean ± SD	χ^2	p^a
FMS score	13.90 ± 2.13	13.22 ± 2.29	13.40 ± 1.51	12.00 ± 3.16	2.514	0.473

FMS functional movement screen, *SD* standard deviation

[a] Mann Whitney *U* test

total FMS score seen to be correlated with the dominant side hamstring peak torque strength at 60°/s angular velocity and the dominant side H/Q ratio. The deficiencies seen in performance of athletes when there is decreased muscle strength suggests that this is a biomechanical problem. In this respect, this suggests that the region of malalignment from which this biomechanical problem originates can be determined with examination of isokinetic values together with the FMS sub-tests.

In a study by Willigenburg et al. [16], there was reported to be a relationship between diagonal and vertical jumping performance and the 3 FMS parameters (DS, HS, ILL) involving the lower extremity, but there was no association between any parameter and hip or knee isokinetic strength values. In parallel with this, the current study results showed no relationship between the DS and HS FMS sub-parameters and the knee isokinetic evaluations, but there was determined to be a significant correlation with ILL. The ILL evaluates stabilisation of the muscles controlling the knee and hip joints. These relationships determined between this sub-test and the isokinetic measurements in the current study could be due to appropriate flexor–extensor muscle strength which can provide good stabilisation for balance control of the knee that remains posterior while loading is on the anterior knee during the ILL movement. The squatting movement requires both strength and stabilisation. If appropriate strength and stabilisation are correctly provided, a successful squatting movement is achieved [18]. That this relationship was found between muscle strength and the ILL as one of the FMS sub-tests from the functional movements observed in the current study supports this information in literature with objective data. Muscle strength around the knee joint helps functional movement to be performed with a regular pattern. It must also not be forgotten that biomechanical alignment is an important parameter in the correct performance of sporting activities.

From an examination of the relevant literature, it was reported in a study by Okada et al. [19] that there was relationship of FMS with some performance tests but there was no relationship with trunk performance. This was an unexpected result of the study and it was suggested that perhaps even a low level of strength in the trunk was sufficient for FMS. In the current study, the fact that a statistically significant relationship was determined between the dominant side

H/Q ratio at 60°/s and RS, which evaluates trunk stabilisation together with motor control as a sub-test of FMS, led to further questioning of the relationship between FMS and trunk performance.

Huxel et al. [20] reported that because of the energy transfer of trunk strength between the upper extremity and lower extremity, the compensatory movement patterns and strength imbalance developing due to athletes with poor trunk strength not obtaining stabilisation because of the effect of contributing to neuromuscular control and obtaining trunk stabilisation during functional movements, could cause an increase in musculoskeletal system injuries. In the light of these findings reported by Huxel et al., the relationship determined between RS and the isokinetic H/Q ratio in the current study suggests that muscle strength imbalance in the knee could affect trunk balance.

In the Greco-Roman wrestlers of the current study, a strong, negative, significant correlation was determined between the total FMS score and the dominant and non-dominant side H/Q ratio at 60°/s angular velocity. Greco-Roman wrestling is a sport in which the upper extremities and upper trunk are used. To be able to obtain good strength in the upper extremity, there must be good transfer of the strength coming from the ground and the lower extremities. When there is good stabilisation in both lower extremities, it is inevitable that the transfer of strength will be successful [21, 22]. The relationship of the FMS scores with the isokinetic knee strength values demonstrates how the strength transformed to function. Moreover, as wrestling matches last up to 6 min, very high anaerobic strength and anaerobic resistance is required [23]. The need for explosive force and the use of anaerobic strength of athletes involved in this sport explains the relationship between the quadriceps peak torque strength and the FMS score. The result obtained in the current study of the relationship between the FMS scores and the hamstring dominant-non-dominant difference values at 180°/s angular velocity in the wrestlers can be associated with the fact that Greco-Roman wrestling is a sport that requires endurance and that endurance was evaluated at 180°/s angular velocity. The correlation of these values with the FMS scores proves with objective data the validity of the FMS in different sports branches. From this result, it can be said that for Greco-Roman wrestlers, however, small the difference is between the hamstring muscle strength of the two knees of the athlete, then the greater the function.

Results of the study hypotheses:

$H1_1$: The FMS total score is related to the isokinetic quadriceps-hamstring muscle strength of the athletes, was accepted.

$H1_2$: The sub-tests of FMS are related to the isokinetic quadriceps-hamstring muscle strength of the athletes, was accepted.

$H1_3$: The relationship between the FMS total score and the isokinetic quadriceps-hamstring muscle strength of the athletes is related to the sports branch, was accepted.

$H1_4$: The FMS total score is related to the difference between the isokinetic muscle strength of the dominant side and the non-dominant side of the athletes, was accepted.

$H1_5$: The sub-test of FMS concerning the lower extremities are related to the difference between the isokinetic muscle strength of the dominant side and the non-dominant side of the athletes, was accepted.

$H1_6$: The relationship between the FMS total score and the difference between the isokinetic muscle strength of the dominant side and the non-dominant side of the athletes is related to the sports branch, was accepted.

$H1_7$: There is a difference between the FMS total scores of different sports branches, was rejected.

$H1_8$: There is a difference between the FMS total scores of sports branches that predominantly use the upper extremities and those that predominantly use the lower extremities, was rejected.

To perform at a high level, athletes need their physiological and anatomical structures to be suited for success in their specific sport. Appropriately developing these characteristics will also lead to an increase in performance. As seen from the results obtained from the FMS and isokinetic evaluations in our study, even if the athletes do not have a problem with muscle strength, any issue with biomechanical alignment will negatively affect sports performance and injury risk. This result may be due to the type of training or a biomechanical problem. Although sports activities and exercises are aimed at strengthening the muscle, they are not sufficient to correct biomechanical alignment disorders. To eliminate these disorders, we must first identify which joint and which stability, mobility, and strength parameters the problem originates from and focus on solving that issue. In cases where there is no muscular problem but a biomechanical issue, addressing the biomechanical problem will result in an increase in sports performance.

Study limitations

- FMS is an analysis method which not only evaluates the lower extremity, but the whole body in a holistic framework. When planning the study, only the lower extremity isokinetic muscle strength and a single joint were evaluated. Isokinetic evaluations of other joints were not made.
- FMS is also an analysis system in which malalignment is interpreted. No evaluation with scoring was made of alignment in addition to the results which were thought to be due to malalignment.

- Although FMS movements generally require concentric-eccentric contractions in the agonist and antagonist muscles, the isokinetic evaluation of the athletes in this study was performed as concentric-concentric to avoid forcing the muscles before a competition. No concentric-eccentric isokinetic evaluations were made.
- Further limitations of the study can be considered to be the lower number of females than males, and that the number of athletes in the different sports branches were not equal, and that there were no athletes for some sports.

Practical applications

In this study, which was conducted with the aim of revealing objective data of the relationship between functional movement analysis and the isokinetic muscle strength around the knee, the following results were obtained;

- FMS evaluated functionality in the athletes, but when interpreting the scores, the characteristics of the sport must be taken into consideration.
- The FMS total and subscores were determined to be correlated with the isokinetic muscle strength values.
- The force occurring in the hamstring and quadriceps muscles disproportionately affects functionality. Good muscle strength does not mean that functionality is good. Insufficient functionality can be seen in athletes who are thought to have good isokinetic muscle strength. It can be recommended that when evaluating athletes, the focus should not only be on muscle strength but functionality should also be taken into consideration.
- The trunk region is affected by the disproportion in the hamstring and quadriceps muscles. A change occurring in the lower extremity muscle strength affects trunk functions. This interaction should be taken into account when creating training programs for athletes.
- Even if no deficiency in muscle strength is seen in athletes, neurodynamic and biomechanical malalignments in the trunk and lower extremities have a negative effect on sporting performance. The determination of biomechanical deficiencies before creating a training program for athletes is recommended to be able to add exercises to eliminate this deficiency to the program.
- Athletes in different sports branches can have similar functionality even if they exhibit joint and muscle differences specific to their own sport. In addition to sport-specific exercises, trunk stabilisation exercises that can be used in all sports can be included in the training programs of athletes in different sports.

National and international sports competitions push the upper limits of performance. Great efforts are made to increase the performance of professional teams in all sports. In addition to performance, the continuation of the sporting life of an athlete without injury is an increasingly important issue, of which there is increased awareness. Therefore, it can be recommended that movement analyses such as FMS, which evaluate biomechanical malalignment and the risk of injury, are performed together with isokinetic evaluations, as one of the objective evaluations of athletes.

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Declarations

Conflict of interest The authors declare no competing interests.

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