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RESEARCH

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Investigating the validity and reliability of the functional movement screening tool in tennis

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Abstract

Background Recently, researchers use functional movement tests and especially the functional movement screen (FMS) as a screening tool to prevent injuries in sports. However, limited studies are available to strongly support the validity and reliability of the FMS in different sports populations. Therefore, the FMS does not seem to be a comprehensive FMS tool in order to investigate asymmetry and limitations in all sports. Therefore, the aim of the present study was to design and evaluate the validity and reliability of the screening tool for functional movements in tennis.

Methods To determine validity and reliability, the results obtained from semi-structured and in-depth interviews with 18 tennis experts were used, which led to the selection of 27 tests out of 108 initial tests. Face validity was evaluated by 10 tennis players, content validity by 10 experts in this field, and construct validity of the questionnaire by 234 tennis players. The reliability of tool was estimated by test-retest method at a time interval of 2 weeks on samples consisting of 20 tennis players using the intraclass correlation coefficient (ICC).

Results Based on the results obtained from the calculation of the content validity ratio, 21 out of 27 tests had a content validity ratio higher than 0.62 and the rest of the tests were excluded. Exploratory factor analysis (EFA) extracted two latent factors that explained 54.05% of the total variance. Confirmatory factor analysis (CFA) confirmed the final construct model. The reliability of the tool was estimated: 95% CI: 0.53–0.92, $p=0.001$, ICC = 0.91.

Conclusion The FMS tool designed for tennis had acceptable validity and reliability with the aim of investigating asymmetry and limitations in this sport. Factor analysis showed that considering the correct features of psychometrics, this tool can be used as a predictor of injury in tennis.

Keywords Functional movement screening, Tennis, Validity and reliability, Confirmatory factor analysis, Exploratory factor analysis

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Introduction

Screening tools are used to various goals, one of these important goals in sports science is the prevention of athletes' injuries [1]. Screening can be used to help prevent injury by identifying functional defects and abnormalities related to the desired sport [2]. The screening process in many advanced countries is done in the pre-season training of sports competitions in many developed disciplines [3]. Pre-season screening can be important to determine and identify athletes who are at risk of injury.

Functional screening is an important tool for predicting and systematically examining injuries in various sports fields [4]. In this regard, in a study, performance screening tools that can be used as injury predictors in various sports have been reviewed [5]. This study was done on team sports. The findings of this study showed that most of the screening tools have been used to predict a specific type of injury, such as anterior cruciate ligament (ACL), ankle and hamstring injuries, instead of examining a set of different injuries of a specific sport. The tests used to predict these injuries were classified into a series of anthropometric, flexibility, range of motion and balance tests. Each of these classes covered some performance tests and not all of them [5]. The combination of this set of tests and information on the prevalence of injuries related to a specific sport can lead to the development of a functional screening tool [6].

Looking at the background literature in the field of functional movement screening, it can be seen that this tool has been developed in some sports such as football [7], gymnastics [8], Australian football [9], dance [10] and volleyball [11]. Sleeper, Kenyon and Casey [8] designed a tool to evaluate the functional fitness of gymnasts called gymnastics functional measurement tool (GFMT). By using tests that are specific to gymnastics, this tool has created unity among the variables of flexibility, speed, power, muscle strength, muscle endurance and balance and was approved by experts in this field. Also, the normative norm and validity of the GFMT tool has been investigated by studying gymnasts. Overall, the GFMT score had high validity. However, this tool is unable to determine the amount of injury and only reveals functional impairments and abnormalities [8]. From the point of view of these researchers, this recent finding was considered an improvement in the field of screening. In addition, Tabatabaei, Daneshmandi [12] designed a tool to evaluate the functional fitness of volleyball players by screening functional movements with the aim of predicting injury [11, 12]. Recognizing the importance of a functional movement screening (FMS) tool in volleyball, this study had designed a protocol that was able to identify functional limitations in the implementation of skills in this sport; And in this way, the injures related to these restrictions were predicted. This process led to the selection of 12 tests to be included in the functional screening tool of movement in volleyball. Afterwards, validity and reliability were examined and confirmed [11, 12]. Studies conducted on gymnastics and volleyball can serve as a guide and a cornerstone for the development of screening tools in various sports fields.

Recently, physiotherapists and trainers use functional movement tests and especially FMS as a screening tool in sports to predict injuries and then develop preventive strategies [13]. Cook, Burton [14] first developed FMS to identify individuals with compensatory movement patterns in their kinetic chain. This screening tool consists of seven movement tests, which require a balance between mobility and stability [14]. FMS is designed for all healthy people and not only sports populations, and some components specific to sports are neglected in it [15]. It seems that the component that FMS did not pay attention to and neglected is speed. Movements performed at high speed, which are an integral part of any sport, are ignored in FMS. Therefore, it seems that FMS cannot be a complete provider of exercise-induced movement patterns [16]. This issue was revealed by Parchman and McBride (2011) who compared FMS and back squat, and their relationship with 10/20m sprint, high jump and T agility test in golfers. By showing the lack of correlation between FMS and these executive tests, this study confirmed that FMS has a limited ability to predict physical performance evaluation, acceleration, power and agility, especially when compared to the maximum strength of the lower limbs [16].

Ignoring the variables of deceleration and external forces, which are possible risk factors for injury, is evident in these tests [17]. Taking this issue into consideration, it seems logical to use tests in order to evaluate the functional movements of athletes that can evaluate both the speed component and the ability to identify potential risk factors for injury. Performing this procedure can be a good supplement for FMS. Studies have emphasized that the assessment of basic movements through a functional approach should be more focused on adjusted sports movement patterns rather than being limited to the evaluation of specific joints or muscles alone [18]. Also, in a study, the importance of this issue was emphasized by suggesting that screening tests need to be designed based on the performance and skill of the players [19].

In fact, the evaluation should be done in such a way that it covers all the desired physical dimensions. Physical performance consists of many components. These components can be considered as consisting of tests that can include the evaluation of balance, proprioception, muscle strength, muscle endurance, muscle power, speed, agility, aerobic and anaerobic capacity, flexibility, muscle length tests and functional movement patterns [20, 21]. However, according to the needs of sports and the target community, the scope of these tests may vary. For example, in some cases, athletes may not need to evaluate balance and proprioception, and flexibility tests are more important for them. Especially for tennis, this topic includes upper and lower limb flexibility, dynamic balance, power, agility, movement speed and reaction speed [22]. The test set should also be able to monitor the progress of rehabilitation programs for injured athletes. It seems that the FMS designed by Cook, Burton [14] still needs to be subjected to rigorous tests of validity and reliability in different sports. Considering that FMS cannot be a complete provider of movement patterns caused by sports; And the fact that the validity and reliability of this test and its predictability of injury in sports populations are still unclear [18, 23]. The researcher sought to develop an FMS tool that has the ability to predict injury in the field of tennis by initially determining potential FMS tests through interviews with specialists and experts. Then check its validity and reliability in the form of a questionnaire. Therefore, the aim of this study was investigating the validity and reliability of the FMS tool in tennis.

Method

Study design

This study employed a cross-sectional design with convenience sampling. By reviewing the background literature and taking into account the prevalence of injury, the type of movement patterns, and the functional and skill needs of tennis players, a questionnaire consisting of 108 tests in six categories of performance, agility, aerobic, non-aerobic, muscle length and anthropometric tests was designed (see supplementary file). Through interviews with tennis experts including coaches, doctors and physiotherapists, preliminary tests were extracted to be included in the tool, and then the final tool was compiled through the validity and reliability of these tests in the form of a questionnaire. This study has used the principles of the Declaration of Helsinki, the general guide to ethics in research with human subjects, and its governing regulations. Participants were informed about the nature of the study and were assured that the Measurement methods is not dangerous.

In the first stage, tennis experts were identified by the provincial tennis boards of the country. They were then contacted and the research process and purpose were presented to them. After collecting data through semi-structured interviews with tennis professionals, each data was independently transcribed after recording. Each transcript was imported into MAXQDA 11 ® software. Transcripts were coded and compared. In the next step, they were classified into categories and finally the items were extracted. The items were given to experts and tennis players in the form of a questionnaire to check validity and reliability. The required information was collected without including the names and surnames of the participants and with their informed consent.

Validity

Face validity

Evaluation of face validity was done with two qualitative and quantitative approaches. In order to evaluate the face validity of the questionnaire, 10 tennis players (4 males and 6 females; age 25 ± 5) were randomly selected from among the tennis players. They were then asked to give their opinion on the level of difficulty, appropriateness and ambiguity of the questionnaire. In the next step, in order to determine the importance, each of the items was evaluated quantitatively. For this purpose, the same 10 tennis players answered the items based on a 5-point Likert scale from score 5 (totally important) to 1 (not important at all). Then the impact score of the item was calculated based on the following formula [24].

Impact Score = Frequency × (%) Importance.

The meaning of frequency in terms of percentage is the number of people who gave 4 and 5 points to each item, and importance is the average score given to each item. If the impact score exceeds 1.5, the item is of sufficient importance [25].

Content validity

The validity of the content was also done by qualitative and quantitative methods by experts. To evaluate the qualitative content validity during interviews with experts, the questionnaire was evaluated in terms of grammar, use of appropriate words, importance, descriptiveness, placement of items in their proper place, and time to complete the designed tool. Then, the quantitative content validity was measured according to the opinions of ten experts and by calculating the content validity ratio (CVR) and the content validity index (CVI). The CVR is used to ensure that the most important content is selected, and the CVI is used to ensure that the items of the instrument are designed in the best way to measure the content [24]. The following formula was used to calculate the CVI.

$$CVI = \frac{The\ number\ of\ evaluators\ who\ gave\ 3\ and\ 4\ scores\ to\ the\ sub-concept}{Total\ number\ of\ assessors}$$

Construct validity

In order to evaluate construct validity with the help of exploratory factor analysis (EFA), items based on a 5-point Likert scale (strongly disagree-disagree-no opinion-agree-strongly agree) along with the executive instructions of the tests were administered to 234 tennis players, including 178 men and 56 women. It was placed in the age range of 19 to 36 years. An apriori power analysis was conducted to determine the sufficient sample size of study. The sample size was calculated based on a previous study by Tabatabaei, Daneshmandi [12] with an alpha level of 0.05, and an actual power (1-beta) of 0.80. The analysis (G × Power, Version 3.1.9.2, University of Kiel, Germany) revealed that a sample size of $n = 230$ would be adequate to identify significant effects among the variables.

Index (Kaiser-Meyer-Olkin) and Bartlett coefficient were calculated. 0.0–8.0 KMO is good and 0.0–9.0 is considered great. Then extraction of factors was done with the help of maximum likelihood estimation and using varimax rotation. The extracted factors were analyzed with the help of confirmatory factor analysis (CFA) and the most common goodness of fit indicators of the presented model based on the accepted threshold with the help of maximum likelihood estimation using SPSS-AMOS26 software. According to the recommendation of Meyers, Gamst and Guarino [26], chi-square goodness of fit index (GFI), root mean square approximation index, comparative fit index, normalized goodness-of-fit index, adjusted goodness-of-fit index, and in Finally, the ratio of chi square to degree of freedom (CMIN/DF) was checked [26].

Reliability

At first, reliability was evaluated by test-retest method. 20 tennis players (11 males and 9 females; age 26 ± 6.3) were randomly selected from among the tennis players completed the questionnaire at a two-week interval, and then the scores obtained in these 2 stages were checked using the intra-cluster correlation coefficient (ICC) test. ICC was estimated with two-way mixed effects model and with 95% confidence interval. Then, the standard error of measurement was checked using the SD×√1-ICC formula. The internal stability of the structure was done with the help of McDonald's Omega assessment. Finally, with the help of CFA, structural reliability was calculated [27, 28]. In fact, structural reliability or stability of factors is an alternative to Cronbach's alpha coefficient in structural equation model analysis, which in the present study, structural stability of more than 0.7 was considered acceptable [29].

Normal distribution, outliers and missing data

The normal distribution of data and the evaluation of outlier data were evaluated in both univariate and multivariate ways. Univariate normal distribution was evaluated using the skewness index (± 3) and skewness (± 7) and multivariate distribution was evaluated using the Mardia coefficient < 0.0001 [30]. On the other hand, univariate outlier data were evaluated with the help of descriptive indices and multivariate outlier data were analyzed with Mahalanobis coefficient. At first, the percentage of forgotten data was calculated and finally, the analysis was done by replacing it with the help of average response.

Results

The results of the interviews were analyzed to determine the items that were qualified to be included in the tool. In the process of analysis, the primary codes were identified and finally, 27 tests were extracted from among the 108 potential tests. Table 1 shows the list of extracted codes in the framework analysis process. After the framework analysis process, 27 sub-items were identified and specified for six main items. In the following, the validity and reliability of the items were investigated.

Validity

Qualitative face validity: The results showed that all of the 27 items were clear, readable, simple and understandable by the interviewees from the content point of view.

Quantitative face validity: According to the results obtained from the calculation of quantitative face validity, all items had an impact score greater than 1.5.

Content validity ratio

Based on the results obtained from the calculation of the content validity ratio for the sub-items based on the information in Table 2 and comparing it with the values obtained by previous study [24], 21 test of the range of motion of internal and external rotation of the shoulder, range of motion of internal and external rotation of the hip in the prone position, cross adduction of the shoulder, lateral lunge, the strength of the shoulder rotators with a hand dynamometer at the angle of 90 degrees of abduction of the shoulder joint, Empty Can, stability of the scapula, range of motion of extension and flexion of the elbow, weight-bearing lunge, range of motion of extension and flexion knee, plank, one-leg stability, active leg raising, rotational stability, single-leg squat, bridging with one-sided knee extension, multi-directional hoping, core stability, Y-Balance, hexagon, and special endurance test with content validity ratio higher than were 0.62. The rest of the tests did not have content validity, so they were excluded.

Content validity index

The results obtained for CVI are given in Table 2.

Construct validity

Mean and standard deviation of age (26 ± 1.3 years), height (178 ± 2.5.8 cm), weight (77.9 ± 1.4 kg), weekly activity (9.7 ± 0.2) hours) and playing experience (12.4 ± 2.6 years) were tennis players. The frequency distribution of players according to gender, dominant leg, dominant hand, level of competition and history of injury is given in Table 3. The amount of KMO was 0.885 and

Table 1 Tests extracted in the interview stage

Main item (test type)	Sub-item (test title)
Functional tests	
- Shoulder internal and external rotation range of motion - Shoulder cross adduction - Strength of shoulder rotators with hand dynamometer at 90-degree abduction angle of shoulder joint - Strength of shoulder external rotators with manual dynamometer in neutral position - Empty Can - Stability of the scapula - Kibler test - Range of motion of extension and flexion of the elbow - Linear lung - Lateral lunge - Range of motion of internal and external rotation of the hip in the prone position - Weight-bearing lunge - Range of motion of extension and flexion knee - Active leg raising - Single leg squat - One-leg stability - Plank - Bridging with one-sided knee extension - Push up - Rotational stability - Multi-directional hoping - Core stability - Y-Balance - Hexagon	
Agility tests: - Reactive planned agility	
Anaerobic tests: - None	
Aerobic tests: - Special endurance test	
Muscle length tests: - Thomas	
Anthropometric tests: - None	

Bartlett's test was 1442.27, $p < 0.001$. The results of EFA showed that two hidden factors had values of 4.796 and 3.312, respectively. In total, the two extracted factors explained 54.05% of the total variance of the FMS tool (Table 4). Then, with the help of CFA and fit indices, the structural model of the structure was evaluated. Based on the goodness of fit test results, first the chi square index was evaluated [$p < 0.05$, $\chi2 = 134.67$. Then, in order to evaluate the fit of the model, other indices were examined, all indices were PCFI = 0.819, PNFI = 0.770, CMIN/DF = 1.513, RMSEA = 0.047, AGFI = 0.930, IFI = 0.967, that confirmed the good fit of the final model.

Convergent and divergent validity

As seen in Table 5, Average Variances Extracted (AVE) is two factors larger than Maximum Shared Squared Variance (MSV). Therefore, the results show that the construct has appropriate convergent and divergent validity (Table 5).

Reliability

Stability reliability.

The stability reliability of the instrument was estimated by the test-retest method at a time interval of 2 weeks on a sample of 20 tennis players using the internal correlation index (ICC) with the Two-Way Mixed model and a 95% confidence interval. The results in the general scale of the questionnaire showed (CI: 0.53–0.92, $p < 0.001$, ICC = 0.91) according to the values obtained between the scores of the first and second test, there is a significant agreement, which confirms the high reproducibility and stability of the developed functional movements screening tool.

Internal consistency reliability.

To check the internal consistency of the instrument, the alpha coefficient was calculated based on Cronbach's alpha and McDonald's omega. Based on the final structure of the structural model, Table 4 shows that the first factor has Cronbach's alpha 0.896 and MacDonald's Omega 0.898, and the second factor has Cronbach's alpha 0.801 and McDonald's Omega 0.812. Considering the fact

Table 2 The results of calculating the content validity ratio and content validity index of the sub-items of the tennis functional movements screening tool

Sub-item (test title)	CVR		CVI
- Shoulder internal and external rotation range of motion	0.8		0.1
- Shoulder cross adduction	0.8		0.1
- Strength of shoulder rotators with hand dynamometer at 90-degree abduction angle of shoulder joint	0.8		0.1
- Strength of shoulder external rotators with manual dynamometer in neutral position	0.4		0.7
- Empty Can	0.7		0.8
- Stability of scapula	0.8		0.8
- Kibler test	0.4		0.7
- Range of motion of extension and flexion of the elbow	0.8		0.8
- Linear lung	0.5		0.7
- Lateral lunge	0.7		0.8
- Range of motion of internal and external rotation of the hip in the prone position	0.8		0.8
- Weight-bearing lunge	0.8		0.1
- Range of motion of extension and flexion knee	0.8		0.8
- Active leg raising	0.1		0.1
- Single leg squat	0.8		0.8
- One-leg stability	0.7	0.8	
- Plank	0.1	0.1	
- Bridging with one-sided knee extension	0.8	0.1	
- Push up	0.4	0.7	
- Rotational stability	0.1	0.1	
- Multi-directional hoping	0.8	0.8	
- Core stability	0.7	0.8	
- Y-Balance	0.8	0.8	
- Hexagon	0.7	0.8	
- Reactive planned agility	0.4	0.7	
- Special endurance test	0.8	0.8	
- Thomas	0.3	0.7	

CVR: Content validity ratio; CVI: Content validity index

Table 3 Frequency distribution of tennis players according to gender, dominant leg, dominant hand, level of competition and history of injury

Variable	Type	Abundance	Percent
Gender	Men	178	76.06
	Women	56	23.93
Dominant leg	Right	166	70.9
	Left	68	29.05
Dominant hand	Right	169	72.2
	Left	65	27.7
Level of competition	Provincial	76	32.4
	National	131	55.9
	International	27	11.5
History of injury	Yes	219	93.5
	No	15	6.4

that coefficients above 0.70 are acceptable, it can be concluded that the designed tool has good internal consistency. Also, the final structure of the questionnaire model of the screening tool for functional movements in tennis is shown in Fig. 1. (Table 4; Fig. 1)

Discussion

The primary objective of this study was to evaluate the validity and reliability of the FMS tool as a predictor of injury in tennis. A comprehensive questionnaire comprising 108 tests was developed, categorized into six domains: functional, agility, anaerobic, aerobic, muscle length, and anthropometric assessments, grounded in existing literature. Interviews with tennis experts facilitated the refinement of this questionnaire, resulting in the selection of 27 tests. Following the initial design, the researcher assessed the validity and reliability of these items. Factor analysis revealed that 15 items exhibited factor loadings exceeding 0.3 ($p = 0.001$), indicating statistical significance, while six items demonstrated insufficient loading and were consequently excluded. Ultimately, 15 tests were retained for inclusion in the tool, among which two—rotational stability and active leg raising—were adapted from the FMS framework established by Cook, Burton [14]. Expert selection of these tests was primarily influenced by their relevance to tennis-specific movement patterns and anatomical regions vulnerable to injury. The findings confirmed the instrument's validity and reliability, indicating that the selected

Table 4 Cronbach's alpha and McDonald's Omega coefficients of the obtained factors

Factor	Sub-item (test title)	Cronbach's alpha	Mc-Don-ald's Omega
First	2-Range of motion of extension and flexion of shoulder	4.796	31.970
	13- Plank		
	4- Shoulder cross adduction		
	16- Rotational stability		
	8- Empty Can		
	7- Strength of shoulder rotators with hand dynamometer at 90-degree abduction angle of shoulder joint		
	10- Range of motion of extension and flexion of the elbow		
	9- Stability of scapula		
Second	20- Bridging with one-sided knee extension	3.312	22.080
	17- Single leg squat		
	15- Active leg raising		
	12- Range of motion of extension and flexion knee		
	11- Weight-bearing lunge		
	3- Range of motion of internal and external rotation of the hip in the prone position		
	21- Multi-directional hoping		

Table 5 Convergent validity and divergent validity of the questionnaire

Indicator Factor	AVE	MSV	CR	α	Ω
…….	0.541	0.004	0.904	0.896	0.898
…….	0.388	0.004	0.811	0.801	0.812

AVE: Average Variances Extracted; MSV: Maximum Shared Squared Variance; CR: Composite Reliability

items collectively measure a cohesive construct without conceptual dispersion.

The results indicated that the reliability of the questionnaire is acceptable, with an intraclass correlation coefficient (ICC) of 0.91 obtained after a two-week interval, demonstrating strong test-retest reliability. These findings align with those of Frohm, Heijne [31], who assessed the reliability of a nine-test battery in soccer players, reporting ICC values of 0.80 and 0.81 after a one-week interval among 26 elite athletes. Similarly, Tabatabaei, Daneshmandi [11]reported an ICC of 0.88 for the FMS tool in volleyball players over a two-week period, further supporting the reliability of this assessment tool.

The exploratory factor analysis (EFA) results indicated that the factor structure of the Functional Movement Screen (FMS) in tennis is two-dimensional. Koehle, Saffer [32] employed both EFA and confirmatory factor analysis (CFA) in adults, identifying two latent factors: the first focused on shoulder mobility and active leg raising, while the second encompassed complex movements such as full squat, lateral lunge, and push-up. Rotational stability appeared in both factors during the CFA, and its exclusion had minimal impact on the model. In the current study, principal factor analysis with Varimax rotation extracted two factors with eigenvalues greater than one, accounting for 54.05% of the total variance. Notably, the factor loadings for the first factor were higher than those for the second, reinforcing the intended factorial structure of the FMS.

The first factor consisted of 8 items, based on the order of the highest factor load, including tests of range of motion of extension and flexion of shoulder, plank, shoulder cross adduction, rotational stability, Empty Can, strength of shoulder rotators with hand dynamometer at 90-degree abduction angle of shoulder joint, range of motion of extension and flexion of the elbow, and stability of scapula were. In the following, these tests are discussed in order.

The range of motion (ROM) for internal and external rotation of the shoulder joint was assessed in a supine position with the arm in 90-degree shoulder abduction, using a goniometer. The athlete's elbow was maintained in 90-degree flexion during passive measurement of shoulder rotation, while the examiner stabilized the scapula to prevent extraneous movement [33]. The final ROM was determined by the weight of the limb and gravity, ensuring that excessive pressure was not applied by the examiner. Total shoulder rotation was calculated as the sum of internal and external rotation measurements. It is crucial to perform this assessment bilaterally to facilitate comparison with the non-dominant arm. In tennis, the repetitive nature of movements, particularly during forehand and serve shots, increases the likelihood of muscle imbalances in the shoulder joint, which can lead to pain and injury. Reports from the Elite Tennis Players Association have established normative values for internal and external shoulder rotation in professional players [33]. Previous studies have investigated the test-retest

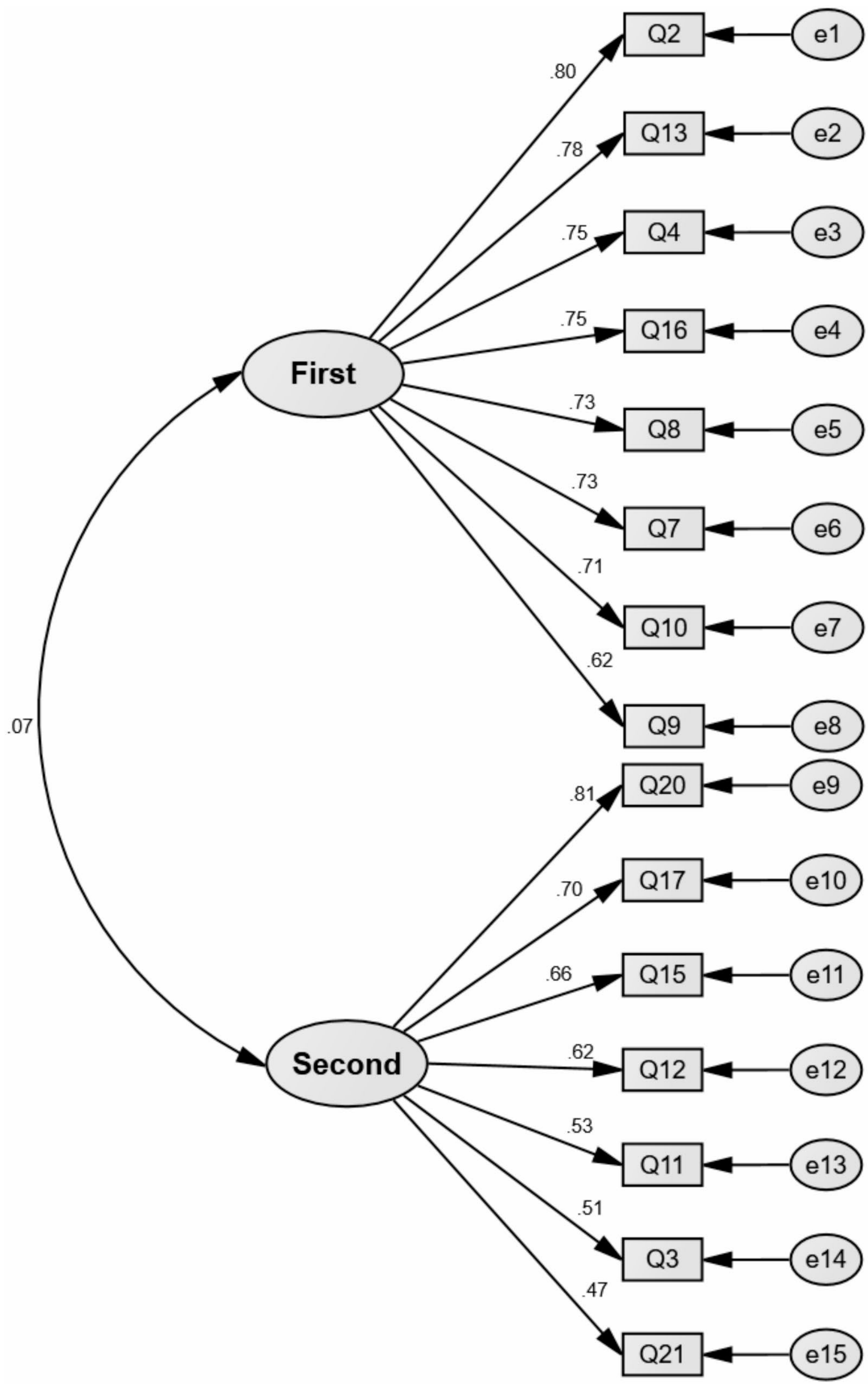

Fig. 1 The final structure of the questionnaire model for screening functional movements in tennis

reliability of shoulder internal rotation ROM with the arm abducted to 90° and scapular stabilization, reporting intra-examiner correlation coefficients of 0.62 and inter-examiner coefficients of 0.43 [34]. Given the frequent internal and external rotation patterns in forehand and backhand strokes, there is a significant risk of injury to the elbow in tennis players and golfers. Therefore, based on expert opinions, this assessment can be considered a critical component in predicting such injuries.

In the plank test, the athlete must maintain stability in various positions—prone, right side, and left side—while ensuring proper alignment and control. Each position is held for 30 s, allowing for the identification of postural disorders linked to weaknesses in core stabilizing muscles and the gluteal region. The movement pattern of the plank test is similar to that of the push-up test, one of the seven components of the FMS developed by Cook, Burton [14]. Therefore, the plank test may serve as a valuable supplement or alternative for assessing postural impairments related to core stability in tennis athletes [35, 36].

The shoulder cross adduction test was conducted using a digital inclinometer while the athlete was in a supine position. The shoulder was passively positioned at 90 degrees of flexion in the sagittal plane, with no additional pressure applied during horizontal adduction. The endpoint was determined using the weight of the limbs against gravity [37]. Bilateral measurements were recorded based on the inclinometer's readings relative to the vertical starting position. During discussions, tennis experts acknowledged that the mechanics of forehand and backhand strokes can lead to muscle imbalances in shoulder abduction range of motion. This imbalance often results in significant discrepancies between the dominant and non-dominant shoulders in tennis players. Consequently, the shoulder cross adduction test is effective in identifying unilateral muscular imbalances, particularly during the implementation of the forehand technique, where the horizontal adduction movement is frequently repeated [38].

Another item identified in the first factor, confirmed by experts for inclusion in the injury prediction instrument, is the rotational stability test. This test, part of the FMS, resembles the basic movement pattern of a baby crawling on all fours [39]. Cook, Burton [14] posited that weaknesses in the core stabilizer muscles of the trunk, which can be revealed during the symmetrical movements of the rotational stability test, significantly contribute to postural impairments [39]. The test was also included in the research conducted by Tabatabaei, Daneshmandi [11], highlighting its relevance in volleyball and underscoring the critical role of core stability in energy transfer to distal body parts for improved movement efficiency [40]. The rotational stability test evaluates the multi-dimensional movement patterns of the pelvis, trunk, and thoracic scapular region, while also assessing glenohumeral joint stability, lumbo-pelvic control, and hip joint mobility [40]. It can identify changes in weight distribution, increased lumbar extension, and decreased shoulder flexion. In tennis, where power and speed in strokes—especially during serves—are paramount, effective energy transfer from the proximal body to the limbs is crucial. Achieving this requires optimal core stability, making the rotational stability test a valuable tool for assessing an athlete's readiness and potential for injury prevention.

The Empty Can test, assesses the integrity of the supraspinatus muscle. A positive result may indicate a potential muscle tear or damage to the tendon and suprascapular nerve. However, Boettcher, Ginn and Cathers [41] caution against using this test as a definitive diagnostic tool for supraspinatus pathology, although it can be beneficial in shoulder muscle strengthening programs [41]. Research on overhead performance in throwing sports reveals that these movements are often abnormal and highly dynamic, frequently exceeding the physiological limits of the shoulder joint [42]. This overload can lead to injuries due to the strain on various anatomical structures. Optimal shoulder function necessitates effective kinetic chain dynamics, stability, and scapular coordination during overhead activities [43]. The balanced function of the rotator cuff muscles and capsular structures is crucial for maintaining a stable center of rotation [44]. In tennis, shoulder injuries related to overhead movements closely resemble those seen in throwing athletes, particularly since many tennis shots occur within the scapular plane. Given that the Empty Can test evaluates function in this plane, and considering the prevalence of upper limb injuries—especially among external rotator muscles—this test is well-justified for inclusion in tools aimed at predicting upper limb injuries in athletes.

Among the items selected in the first factor, the strength of shoulder rotators, assessed with a hand dynamometer at a 90-degree abduction angle, was confirmed as a valuable test for inclusion in the injury prediction tool. This measurement method parallels the assessment of internal and external rotation range of motion in the shoulder joint. Rotator cuff injuries in tennis players are typically progressive overuse injuries, varying from partial or pericapsular tears to full tears, with most being partial and full tears more common in older athletes. The serve, constituting 45–60% of all strokes in a tennis match, significantly increases the risk of shoulder overuse injuries and rotator cuff tears. Research indicates that impairments in shoulder range of motion and scapular dyskinesia frequently arise following a tennis match. In contrast to rotator cuff treatments for non-athletes, elite tennis players experience less favorable return-to-sport rates at the same performance level [45]. This suggests that the strength of the rotator cuff muscles plays a critical role in mitigating injuries associated with frequent strokes, particularly serves. Additionally, tennis players often encounter changes in upper limb joint mobility due to the extreme range of motion required by the sport. The muscles acting on the upper limb traverse multiple joints, causing their length and tension to vary based on joint positioning. Alterations in the passive range of motion of these joints can lead to postural impairments from repetitive strokes, potentially affecting the muscular demands essential for stability or dynamic strength of the upper extremity. Such changes may contribute to the development of lateral epicondyle tendinopathy [46]. Therefore, maintaining shoulder stability and ensuring an appropriate range of motion in the elbow across various movements are crucial factors in reducing overuse injuries in tennis.

The second factor consisted of bridging with one-sided knee extension, single leg squat, active leg raising, range of motion of extension and flexion knee, weight-bearing lunge, range of motion of internal and external rotation of the hip in the prone position and multi-directional hoping. In the following, these tests are discussed in order.

The second factor comprised several tests, including bridging with one-sided knee extension, single-leg squat, active leg raising, range of motion assessments for knee extension and flexion, weight-bearing lunge, internal and external rotation of the hip in the prone position, and multi-directional hopping. Among these, bridging tests with one-sided knee extension exhibited the highest factor load, while multi-directional hopping had the lowest [40]. The musculoskeletal core, encompassing the lumbar spine, abdominal wall, back extensors, quadratus lumborum, diaphragm, and pelvic floor, functions as a muscle box, providing essential proximal stability for distal movements, particularly in sports requiring overhead actions like tennis [47]. The bridging movement pattern engages these core muscles, making it a valuable test for diagnosing muscle weakness-related disorders and predicting injuries in tennis players.

Additionally, the single-leg squat test was identified as suitable for inclusion in the injury prediction tool. This test is crucial for assessing athletes' performance techniques, revealing muscle imbalances, functional flexibility, and balance [48]. Variants like the overhead squat and full squat are also effective for diagnosing issues related to muscle imbalances and overall stability in high performance tennis players [49]. The active leg raising test was another approved measure, focusing on hamstring flexibility through methods such as assessing passive hip flexion with a straight knee using a goniometer [50]. This test is vital as forward movements in tennis can disrupt the balance between knee flexor and extensor muscles, often leading to hamstring issues [51].

The weight-bearing lunge test was recognized for its role in predicting injuries, as reduced ankle dorsiflexion is a known risk factor for lower limb injuries, particularly lateral ankle sprains in tennis players [52]. This test effectively evaluates ankle dorsiflexion while bearing weight, highlighting muscle imbalances in the ankle region [53, 54]. Furthermore, assessing the range of motion for internal and external hip rotation in the prone position is critical, given the importance of rotational movements in tennis. Research indicates that asymmetrical hip rotation can signal postural abnormalities that warrant further evaluation and flexibility training [55–57].

The multi-directional hopping test was also validated for inclusion, demonstrating reliability in identifying functional defects in athletes with chronic ankle instability [58]. Studies have shown it effectively predicts the risk of non-contact lateral ankle sprains, which are prevalent due to the rapid directional changes and deceleration required in tennis [59, 60]. The findings from experts and prior research underscore the test's relevance for injury risk assessment in the sport.

To ensure the construct validity of the questionnaire used in this study, both EFA and CFA were employed. CFA aimed to evaluate the predefined factor model against observed data, confirming whether the anticipated number of factors and variable loadings aligned with theoretical expectations. This method facilitated the removal of items with low factor loadings that did not correspond to specific factors [61]. The chi-square goodness of fit test was significant across various sample sizes, affirming the final model's appropriate fit.

The exclusion of anaerobic or anthropometric tests from the FMS tool developed for tennis was primarily based on the study's focus on identifying movement patterns and functional deficits directly related to injury risk rather than performance metrics. Anaerobic tests, while valuable for assessing explosive strength and power, do not specifically evaluate the biomechanical and neuromuscular factors that contribute to injuries in tennis players. Similarly, anthropometric tests, which measure body composition, height, weight, and limb lengths, were deemed less relevant in the context of this study. The emphasis was placed on dynamic movement assessments that reflect the specific demands of tennis, such as agility, stability, and flexibility. By concentrating on functional movements, the study aimed to create a more targeted screening tool that could effectively identify asymmetries and limitations that predispose players to injury, thereby enhancing the overall utility of the FMS in injury prevention within the sport.

Limitations and future scope

The study aimed to investigate the validity and reliability of an FMS tool specifically designed for tennis. While it successfully identified and validated 15 relevant tests from an initial pool of 108 based on expert interviews, the study's limitations include a relatively small sample size for reliability testing and the focus on a single sport, which may affect the generalizability of the findings to other athletic populations. Future research should expand the participant pool, explore the tool's applicability across different sports, and incorporate longitudinal studies to assess its predictive capabilities over time. Additionally, the integration of speed and agility assessments could enhance the comprehensiveness of the screening tool.

Conclusion

In the present study, the appropriate psychometric properties and validity of the factorial structure of the questionnaire were confirmed. In total, the face validity, content and structure of the tool were approved by experts and tennis players. Then, after reducing the tests from 27 tests to 15 tests, the reliability of the tool was also confirmed. Afterward, by determining the normative norm for the tests and specifying a cut-off point, it is possible to check the reliability of predicting the injury of this tool by implementing the tests. More research is needed in the future to use this tool as an intervention tool in tennis. Also, prospective and follow-up research on different levels of tennis players will show the ability of this tool in predicting tennis injuries.

Supplementary Information

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Supplementary Material 1

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Author contributions
S.K. & MH.A. & H.D.: data acquisition and analysis. S.K. & MH.A. & H.D.: data interpretation. S.K. & MH.A. & H.D.: wrote the main manuscript text and prepared the figures. S.K. & MH.A. & H.D.: conception/design of the work. All authors reviewed and contributed to the manuscript.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Compliance with ethical guidelines
This study has used the principles of the Declaration of Helsinki, the general guide to ethics in research with human subjects, and its governing regulations. Also, the need for ethics approval was deemed unnecessary by the Institute of Physical Education and Sport Sciences (Iran). The Institute of Physical Education and Sport Sciences in Iran is a reference for issuing ethical code of human and animal studies. The institution has an ethics committee that decides on requests for a code of ethics. Considering that the present study did not use dangerous tools and also did not apply a protocol, for this reason this committee considered issuing a code of ethics unnecessary.

Consent for publication
Not Applicable.

Competing interests
The authors declare no competing interests.

Informed consent
All participants were informed of the purpose and procedure of this study, and informed consent was obtained from all participants.

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References

1. Dorrel BS, Long T, Shaffer S, Myer GD. Evaluation of the functional movement screen as an injury prediction tool among active adult populations: a systematic review and meta-analysis. Sports Health. 2015;7(6):532–7.
2. Schneiders AG, Davidsson Å, Hörman E, Sullivan SJ. Functional movement ScreenTM normative values in a young, active population. Int J Sports Phys Therapy. 2011;6(2):75.
3. Alfarraj F, Bousie J, Witchalls J, Newman P. Is pre-season physical screening a waste of time? Just ask the coaches. J Sci Med Sport. 2022;25:S22.
4. Whittaker JL, Booysen N, De La Motte S, Dennett L, Lewis CL, Wilson D, et al. Predicting sport and occupational lower extremity injury risk through movement quality screening: a systematic review. Br J Sports Med. 2017;51(7):580–5.
5. Dallinga JM, Benjaminse A, Lemmink KA. Which screening tools can predict injury to the lower extremities in team sports? A systematic review. Sports Med. 2012;42:791–815.
6. Šiupšinskas L, Garbenytė-Apolinskienė T, Salatkaitė S, Gudas R, Trumpickas V. Association of pre-season musculoskeletal screening and functional testing with sports injuries in elite female basketball players. Sci Rep. 2019;9(1):9286.
7. Morehead EK. Development of a functional movement screening tool. for Football: University of Central Lancashire; 2014.
8. Sleeper MD, Kenyon LK, Casey E. Measuring fitness in female gymnasts: the gymnastics functional measurement tool. Int J Sports Phys Therapy. 2012;7(2):124.
9. Gabbe BJ, Finch CF, Wajswelner H, Bennell KL. Predictors of lower extremity injuries at the community level of Australian football. Clin J Sport Med. 2004;14(2):56–63.
10. Steinberg N, Hershkovitz I, Peleg S, Dar G, Masharawi Y, Heim M, Siev-Ner I. Range of joint movement in female dancers and nondancers aged 8 to 16 years: anatomical and clinical implications. Am J Sports Med. 2006;34(5):814–23.
11. Tabatabaei SM, Daneshmandi H, Norasteh AA, Sharif Nia H. Development of screening test battery for volleyball players: A mixed method study. Phys Treatments-Specific Phys Therapy J. 2017;7(3):163–74.
12. Tabatabaei SM, Daneshmandi H, Norasteh AA, Sharif Nia H. Functional movement screening tests for the prediction of injuries in volleyball: A qualitative study. Annals Appl Sport Sci. 2018;6(4):9–15.

13. Bonazza NA, Smuin D, Onks CA, Silvis ML, Dhawan A. Reliability, validity, and injury predictive value of the functional movement screen: a systematic review and meta-analysis. Am J Sports Med. 2017;45(3):725–32.
14. Cook G, Burton L, Hoogenboom BJ, Voight M. Functional movement screening: the use of fundamental movements as an assessment of function-part 1. Int J Sports Phys Therapy. 2014;9(3):396.
15. Chang W-D, Chou L-W, Chang N-J, Chen S. Comparison of functional movement screen, star excursion balance test, and physical fitness in junior athletes with different sports injury risk. Biomed Res Int. 2020;2020(1):8690540.
16. Martin M, Bennett H, Davison K, Arnold J. Movement capacity screening and assessment. Kinanthropometry and Exercise Physiology: Routledge; 2018. pp. 26–45.
17. McBurnie AJ, Harper DJ, Jones PA, Dos' Santos T. Deceleration training in team sports: another potential 'vaccine'for sports-related injury? Sports Med. 2022:1–12.
18. Dorrel B, Long T, Shaffer S, Myer GD. The functional movement screen as a predictor of injury in National collegiate athletic association division II athletes. J Athl Train. 2018;53(1):29–34.
19. Raya-González J, Bishop C, Gómez-Piqueras P, Veiga S, Viejo-Romero D, Navandar A. Strength, jumping, and change of direction speed asymmetries are not associated with athletic performance in elite academy soccer players. Front Psychol. 2020;11:175.
20. Armstrong R, Greig M. The functional movement screen and modified star excursion balance test as predictors of T-test agility performance in university rugby union and Netball players. Phys Ther Sport. 2018;31:15–21.
21. Armanfar MS, Rajabi R, Shahrbanian S, Alizadeh MH. The relationship of functional movement screen scores with flexibility, speed and agility in 17-15-year-old male students. Sport Sci Health Res. 2021;13(2):227–37.
22. Sahin M, Kirandi O. Functional movement scanning in elite level tennis players: total score, individual analysis, and asymmetries. Int J Acad Res. 2017;9(1):54–8.
23. Moran RW, Schneiders AG, Mason J, Sullivan SJ. Do functional movement screen (FMS) composite scores predict subsequent injury? A systematic review with meta-analysis. Br J Sports Med. 2017;51(23):1661–9.
24. Mohammadbeigi A, Mohammadsalehi N, Aligol M. Validity and reliability of the instruments and types of measurments in health applied researches. J Rafsanjan Univ Med Sci. 2015;13(12):1153–70.
25. Mohsen MM, Safaan NA, Okby O. Facilitating factors for overcoming barriers facing nurses for research utilization in clinical settings. Am J Nurs Res. 2016;4(1):13–24.
26. Meyers LS, Gamst G, Guarino AJ. Applied multivariate research: design and interpretation. Sage; 2016.
27. Fowler J, Jarvis P, Chevannes M. Practical statistics for nursing and health care. Wiley; 2021.
28. Gallagher MW, Brown TA. Introduction to confirmatory factor analysis and structural equation modeling. Handbook of quantitative methods for educational research: Brill; 2013. pp. 287–314.
29. Sarstedt M, Ringle CM, Hair JF. Partial least squares structural equation modeling. Handbook of market research. Springer; 2021. pp. 587–632.
30. Kline RB. Principles and practice of structural equation modeling. Guilford; 2023.
31. Frohm A, Heijne A, Kowalski J, Svensson P, Myklebust G. A nine-test screening battery for athletes: a reliability study. Scand J Med Sci Sports. 2012;22(3):306–15.
32. Koehle MS, Saffer BY, Sinnen NM, MacInnis MJ. Factor structure and internal validity of the functional movement screen in adults. J Strength Conditioning Res. 2016;30(2):540–6.
33. Cigercioglu N-B, Guney-Deniz H, Unuvar E, Colakoglu F, Baltaci G. Shoulder range of motion, rotator strength, and upper-extremity functional performance in junior tennis players. J Sport Rehabilitation. 2021;30(8):1129–37.
34. Cools AM, De Wilde L, Van Tongel A, Ceyssens C, Ryckewaert R, Cambier DC. Measuring shoulder external and internal rotation strength and range of motion: comprehensive intra-rater and inter-rater reliability study of several testing protocols. J Shoulder Elbow Surg. 2014;23(10):1454–61.
35. Tong TK, Wu S, Nie J. Sport-specific endurance plank test for evaluation of global core muscle function. Phys Ther Sport. 2014;15(1):58–63.
36. Behm DG, Daneshjoo A, Alizadeh S. Assessments of core fitness. ACSM's Health Fit J. 2022;26(5):68–83.
37. Gharisia O, Lohman E, Daher N, Eldridge A, Shallan A, Jaber H. Effect of a novel stretching technique on shoulder range of motion in overhead athletes with glenohumeral internal rotation deficits: a randomized controlled trial. BMC Musculoskelet Disord. 2021;22:1–10.
38. Guild T, Chen N. Examination of the shoulder. Clinical examination of the hand. CRC; 2022. pp. 248–54.
39. O'Brien W, Khodaverdi Z, Bolger L, Tarantino G, Philpott C, Neville RD. The assessment of functional movement in children and adolescents: A systematic review and meta-analysis. Sports Med. 2022:1–17.
40. Zemková E, Zapletalová L. The role of neuromuscular control of postural and core stability in functional movement and athlete performance. Front Physiol. 2022;13:796097.
41. Boettcher CE, Ginn KA, Cathers I. The 'empty Can'and 'full can'tests do not selectively activate supraspinatus. J Sci Med Sport. 2009;12(4):435–9.
42. Paraskevopoulos E, Pamboris GM, Plakoutsis G, Papandreou M. Reliability and measurement error of tests used for the assessment of throwing performance in overhead athletes: A systematic review. J Bodyw Mov Ther. 2023.
43. Economopoulos KJ, Brockmeier SF. Rotator cuff tears in overhead athletes. Clin Sports Med. 2012;31(4):675–92.
44. Kekelekis A, Nikolaidis PT, Moore IS, Rosemann T, Knechtle B. Risk factors for upper limb injury in tennis players: a systematic review. Int J Environ Res Public Health. 2020;17(8):2744.
45. Alrabaa RG, Lobao MH, Levine WN. Rotator cuff injuries in tennis players. Curr Rev Musculoskelet Med. 2020;13:734–47.
46. Lucado AM, Dale RB, Kolber MJ, Day JM. Analysis of range of motion in female recreational tennis players with and without lateral elbow tendinopathy. Int J Sports Phys Therapy. 2020;15(4):526.
47. Majewska J, Kołodziej-Lackorzyńska G, Cyran-Grzebyk B, Szymczyk D, Kołodziej K, Wądołkowski P. Effects of core stability training on functional movement patterns in tennis players. Int J Environ Res Public Health. 2022;19(23):16033.
48. Miranda JMQ, Polito LFT, Rica RL, Miranda MLJ, Bocalini DS, Figueira A. Muscle strength training and prescribing in competitive tennis players: a systematic review. Revista Brasileira De Med Do Esporte. 2020;26(1):87–92.
49. Kamalden TFT, Gasibat Q, Samsudin S, Joseph JA. Occurrence of muscle imbalance and risk of injuries in athletes using overhead movements: A systematic review. Sport Mont. 2021;19(3):115–22.
50. Willhuber GOC, Piuzzi NS. Straight leg Raise test. StatPearls [Internet]: StatPearls Publishing; 2023.
51. Olivencia O, Godinez GM, Dages J, Duda C, Kaplan K, Kolber MJ. The reliability and minimal detectable change of the Ely and active knee extension tests. Int J Sports Phys Therapy. 2020;15(5):776.
52. Almansoof HS, Nuhmani S, Muaidi Q. Role of ankle dorsiflexion in sports performance and injury risk: A narrative review. Electron J Gen Med. 2023;20(5).
53. Kaiser P, Stock K, Benedikt S, Ellenbecker T, Kastenberger T, Schmidle G, Arora R. Acute tennis injuries in the recreational tennis player. Orthop J Sports Med. 2021;9(1):2325967120973672.
54. Manoel LS, Xixirry MG, Soeira TP, Saad MC, Riberto M. Identification of ankle injury risk factors in professional soccer players through a preseason functional assessment. Orthop J Sports Med. 2020;8(6):2325967120928434.
55. Ellenbecker TS, Ellenbecker GA, Roetert EP, Silva RT, Keuter G, Sperling F. Descriptive profile of hip rotation range of motion in elite tennis players and professional baseball pitchers. Am J Sports Med. 2007;35(8):1371–6.
56. Young SW, Dakic J, Stroia K, Nguyen ML, Harris AH, Safran MR. Hip range of motion and association with injury in female professional tennis players. Am J Sports Med. 2014;42(11):2654–8.
57. Oliver GD, Downs JL, Barbosa GM, Camargo PR. Descriptive profile of shoulder range of motion and strength in youth athletes participating in overhead sports. Int J Sports Phys Therapy. 2020;15(6):1090.
58. Eechaute C, Bautmans I, De Hertogh W, Vaes P. The multiple hop test: a discriminative or evaluative instrument for chronic ankle instability? Clin J Sport Med. 2012;22(3):228–33.
59. Eechaute C, Leemans L, De Mesmaeker M, De Ridder R, Beckwée D, Struyf F, et al. The predictive value of the multiple hop test for first-time noncontact lateral ankle sprains. J Sports Sci. 2020;38(1):86–93.
60. Valleser CWM, Narvasa KEL. Common injuries of collegiate tennis players. Montenegrin J Sports Sci Med. 2017;6(2):43.
61. Nia HS, Ebadi A, Lehto RH, Mousavi B, Peyrovi H, Chan YH. Reliability and validity of the Persian version of templer death anxiety scale-extended in veterans of Iran–Iraq warfare. Iran J Psychiatry Behav Sci. 2014;8(4):29.

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