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Comparison of Joint Position Sense and Force-Reproduction in Female Racquet Athletes with and Without Scapular Dyskinesia

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Abstract

Background: Scapular dyskinesia (SD) is a common condition that affects racquet athletes, impacting their performance and predisposing them to injuries.
Objectives: This study aimed to compare joint position sense (JPS) and force reproduction in racquet athletes with and without SD.
Methods: This study was conducted as a cross-sectional study. The statistical population consisted of female student-athletes aged 18 to 30 who were engaged in badminton, tennis, and ping pong in Quchan city, both with and without shoulder dyskinesia. The sample included thirty athletes with shoulder dyskinesia and thirty without it, who were randomly selected. Joint Position Sense was assessed at 45 and 135 degrees of abduction. The tools employed in this research encompassed a consent form, an inclinometer (goniometer), the Kibler test, force-reproduction testing, and the McClure test. Data analysis was performed using the Shapiro-Wilk test and an independent *t*-test in SPSS version 23, with a significance level set at $P < 0.05$.
Results: The results revealed a statistically significant difference in JPS of the shoulder joint between athletes with and without SD at angles of 45 and 135 degrees ($P < 0.05$). Similarly, the independent *t*-test analysis demonstrated a significant difference in force reproduction of the shoulder joint between athletes with and without dyskinesis ($P < 0.05$).
Conclusions: These findings underscore the importance of addressing SD and its associated sensory impairments in racquet athletes to optimize performance and reduce the risk of injuries.

Keywords: Shoulder Joint, Dyskinesia, Scapula, Athletes

1. Background

Throughout their lifetime, 67 % of adults will experience shoulder pain (1). Several factors contribute to the development of shoulder pain, and one possible cause is scapular dyskinesis (SD) (2). Scapular dyskinesis involves alterations in the position of the scapula, both at rest and during movement, which can include increased superior scapular translation and decreased posterior tilt, upward rotation, and internal rotation (3). It is commonly observed in individuals engaged in sports or physical activities that involve repetitive overhead motions or muscle imbalances. Scapular dyskinesis can lead to functional limitations, reduced performance, and an elevated risk of shoulder injuries (4). Scapular dyskinesis, or changes in dynamic scapular control, is present in 67 to 100 % of athletes with shoulder injuries. However, it is also present in many asymptomatic individuals (5). The prevalence of SD varies among tennis players, ranging from 40 to 70 % (2), and volleyball players, ranging from 20 to 35 % (6). It remains unclear whether SD is a cause or a consequence of shoulder injuries (7, 8). Previous research has indicated that abnormal scapular movements can adversely affect shoulder function (9, 10), and correcting these movements can alleviate symptoms associated with shoulder injuries, such as full-thickness rotator cuff tears (9).

McClure et al. introduced the scapular dyskinesis test (SDT) as a widely used method for detecting SD and categorizing individuals into three levels: Normal motion, subtle dyskinesis, and obvious dyskinesis (11). Despite the reliability and validity of the SDT (11, 12), only a limited number of clinicians are trained to administer it, and there is a need for greater consistency in assessment methods (11). Moreover, there is insufficient evidence to support the idea that identifying and correcting SD can prevent

or treat shoulder pathology. Nevertheless, screening for SD is common in symptomatic and asymptomatic individuals, particularly in predicting or preventing injuries in overhead athletes (13). However, there is conflicting evidence regarding the relationship between SD and injuries in this population, and clinicians often focus on correcting SD even when it may be a normal variation in movement (14, 15).

Proprioception is a topic that straddles the fields of neurophysiology and neuropsychology. The term "proprioception" was initially introduced by Sir Charles Sherrington, who defined it as the perception of movement and body position in space without relying on visual feedback (16). Perception involves experiencing the external environment, while proprioception involves sharing one's body (17). Proprioception results from multiple neural feedback systems within the human body, playing a critical role in motor control and adaptation (18, 19). Joint Position Sense (JPS) in the shoulder refers to an individual's ability to accurately perceive and reproduce joint angles and movements within the shoulder joint. This proprioceptive skill is crucial for maintaining joint stability and ensuring correct movement patterns during physical activities (20). Proprioception, or JPS, is essential for motor control, coordination, and injury prevention. It provides valuable neural feedback that allows athletes to accurately sense the position and movement of their limbs during dynamic sporting activities. Force reproduction, another sensory function, is vital for maintaining grip force and optimizing racquet control during various strokes. Several studies have examined JPS in athletes participating in various sports, including tennis, badminton, ping pong, and volleyball.

Scapular dyskinesis is a prevalent condition among racquet athletes that can impact their performance and predispose them to musculoskeletal injuries. It is characterized by abnormal scapular movement and positioning, which can disrupt the dynamic stability of the shoulder joint. Previous research has highlighted the negative effects of SD on shoulder function and overall athletic performance (20). However, there is limited understanding of how SD may influence proprioception and sensory perception in racquet athletes.

This study investigates the comparison of JPS and force reproduction (FR) between racquet athletes with and without SD. By examining these sensory aspects, we aim to shed light on potential impairments in proprioceptive and FR abilities in athletes with SD. Understanding these differences will contribute to our knowledge of the impact of SD on sensorimotor function in racquet athletes. It may inform the development of targeted interventions and training strategies to optimize performance and reduce the risk of injury. We hypothesize that racquet athletes with SD will exhibit impaired JPS and altered FR compared to athletes without SD.

Additionally, we anticipate these sensory impairments may be associated with reduced performance, increased vulnerability to injuries, and compromised racquet control during various strokes. The findings from this study will provide valuable insights into the specific sensory deficits related to SD in racquet athletes. Such knowledge may guide the development of evidence-based interventions to improve proprioception and pressure perception abilities in athletes with SD, ultimately optimizing their performance and reducing the risk of musculoskeletal injuries. For example, research by Hübscher et al. highlighted the significant relationship between reduced proprioception and increased susceptibility to sports injuries, particularly in activities requiring rapid changes in direction and agility (21). Our study stands out for its comprehensive evaluation of JPS and force reproduction, specifically in female racquet athletes with and without scapular dyskinesia (SD). While previous research may have investigated similar measures in other athlete populations or focused solely on either JPS or force reproduction (2, 4, 8, 22-25), our study uniquely combines these assessments in the context of female racquet sports athletes.

Moreover, our study explores the intricate relationship between these parameters and SD, an area that has yet to be explored within the context of JPS and force reproduction in female racquet athletes. This unique focus enables us to gain potential insights tailored to this specific group, contributing to a deeper understanding of the impact of SD on JPS and force reproduction within the context of racquet sports. No studies have compared JPS and force reproduction in racquet athletes with and without SD, despite previous research on the relationship between proprioceptive deficits and sports injuries (20, 23, 24).

2. Objectives

This study aimed to compare JPS and force reproduction in racquet athletes with and without SD.

3. Methods

3.1. Study Design and Participants

This research received approval from the Ethics Committee of the Sport Sciences Research Institute in Tehran, Iran (approval number: IR.SSRC.REC.1402.013). It was a cross-sectional study that involved female

student-athletes aged 18 to 30 years participating in badminton, tennis, and ping pong in Khorasan Razavi province, specifically Qochan city. The study aimed to investigate SD in this population. Initially, all 302 female students regularly involved in racket sports were screened, and 64 students with scapular dyskinesia were identified based on inclusion and exclusion criteria. Among these, 30 students with SD were randomly selected as the experimental group. Also, among the students who did not have shoulder dyskinesia (238 students), 30 athletes were randomly selected as the control group.

3.2. Inclusion Criteria

- Gender and age: The study focused exclusively on female racquet athletes aged 18 to 30 to ensure a homogeneous age group.

- Scapular dyskinesia (for the dyskinesia group): Participants with a diagnosed SD were included. This allowed for the comparison between athletes with and without the condition (26).

- Engagement in racquet sports: Participants needed to have experience in racquet sports such as tennis, badminton, ping pong, or racquetball. This ensured that the athletes had a relevant background for the study's objectives.

- Three-year history in racquet athletes: Participants were included if they had at least 3 years of continuous experience in racquet sports. This criterion aimed to select athletes with sufficient experience and skill level within the specific sports.

- Absence of significant abnormalities: Individuals with significant abnormalities like kyphosis, scoliosis, swayback, or uneven shoulders were excluded. This criterion aimed to minimize the potential impact of pre-existing conditions that could confound the study results.

3.3. Exclusion Criteria

- Age: Participants outside the specified age range (below 18 or above 30) were excluded to ensure a consistent age group for comparison purposes.

- Gender: The study focused exclusively on female racquet athletes, so male participants were excluded. Previous injuries could potentially interfere with joint position sense and force-reproduction, which could confound the study results (26).

- Previous or current injuries: Individuals with a history of shoulder or scapular injuries were excluded.

- Other medical conditions: Participants with pre-existing medical conditions that could impact JPS or force reproduction, such as neurological disorders or musculoskeletal abnormalities, were excluded.

- Pregnancy or postpartum: Female participants who were pregnant or in the postpartum period were excluded due to potential influences on JPS and forced reproduction.

Our study focuses on the exposure of being a racquet athlete. The 2 main predictors we examine are SD and JPS. Participants are grouped based on whether they possess SD or not. Additionally, JPS plays a crucial role in determining the outcome. Confounding variables like age, training level, and previous injuries can affect the relationship between SD, JPS, and force reproduction.

3.4. Measuring Instruments

The research utilized several tools, including a consent form, a stadiometer for measuring height, a digital scale for measuring weight, the Kibler test to assess shoulder lateral slide, the McClure test to diagnose SD, an inclinometer for measuring shoulder JPS, a Baseline bubble inclinometer (model 12-1056, Fabrication Enterprises, White Plains, NY) for measuring range of motion (ROM) in the shoulder. The inclinometer resembles a flat goniometer with 360 degrees (marked in single-degree increments on the circumference). The inclinometer's intratester reliability was high (ICC = 0.98) (26). We employed a Kinetic Communicator (Kin Com) 125 AP isokinetic dynamometer (Chattanooga Group, Chattanooga, TN) integrated with a computer and suitable software to evaluate the reliability of FR. This instrument was reliable (26). The measurements in this study were done by one examiner.

3.5. Ethical Considerations

All participants provided informed consent, and their confidentiality and anonymity were strictly maintained throughout the study.

3.6. Procedure

The research began with participants completing informed consent forms. The scapular dyskinesis test (McClure test) (11, 12) was performed at the gym. The researcher placed 2 dumbbells (1.4 for individuals under 68 kg and 2.3 for over 68 kg) in both hands of the participants and asked them to raise their hands from zero degrees' flexion angle to 180 degrees' extension and then return their hands to the initial position after a 3-second pause. The researcher stood behind the participant at this time and observed the athlete's shoulder movement (the athlete did not wear any clothes on their shoulders). If the athlete had shoulder dysfunction, the inner edge of the scapular would separate from the torso, and the scapular would experience internal rotation. Now, the Kibler test (27) was performed on athletes to

measure scapular rhythm. The test was performed in 3 positions: 0, 45, and 90 degrees of arm abduction. At each angle of arm abduction, the distance between the inferior angle of the scapula and the closest spinous process was measured using a modified method. By subtracting the measurements at 45 and 90 degrees from the measurement at 0 degrees, differences greater than 1.5 mm were considered external rotation, and differences less than 1 mm were considered internal rotation (27).

3.6.1. Joint Position Sense Assessment

An inclinometer was used to measure the participants' shoulder JPS. During the JPS assessment, we provided active assistance to the subject's arm to reach the target angle, which was set at 45 and 135 degrees of abduction. The subject was instructed to hold the arm in that position for 3 s before returning it to the original position. This duration was (28) long enough for the subject to accurately identify position without fatigue. The subject was blindfolded to eliminate visual cues and was asked to concentrate on the arm's position in space at the target angle. Upon returning to the starting point, the subject was asked to immediately reposition the arm back to the target angle abduction (45 and 135 degrees) and indicate when they felt the position had been achieved. At this point, we recorded the angle observed on the inclinometer. This measurement was repeated twice, with a 30 s rest period separating each trial into 3 trials. We then calculated the error score by averaging all 3 trials' absolute differences between the target and observed angles.

3.6.2. Force-Reproduction Test

The Force-reproduction testing (FRT) was conducted while the subject was in a standing position, and the limb was positioned similarly to the JPS testing. The dynamometer's axis of rotation was aligned with the shoulder's frontal axis of rotation, with the limb placed at 90° of shoulder abduction and 90° of elbow flexion. The subject's wrist was securely fastened to the force transducer on the dynamometer arm using a wrist attachment. All tests were conducted in isometric mode, with the dynamometer set to record data accordingly (22, 26).

3.7. Statistical Analysis

Descriptive statistics, including mean and standard deviation, were calculated for demographic variables. The normality of the data was assessed using the Shapiro-Wilk test, and an independent *t*-test was employed to compare means between groups in SPSS version 23. The significance level was set at $P < 0.05$.

4. Results

The descriptive information regarding the participants' age, height, and weight is presented in Table 1.

The Kolmogorov-Smirnov test was employed to assess the normality of the data distribution. The results of this test indicated that the distribution of all research variables was normal.

Table 2 displays the mean and standard deviation of JPS and FR variables in athletes with and without SD.

To compare JPS and FR of the shoulder joint in athletes with and without SD, an independent *t*-test was conducted, and the results are presented in Table 3.

The results of the independent *t*-test demonstrated a significant difference in the JPS of the shoulder joint at angles of 45 and 135 degrees between athletes with and without SD ($P < 0.05$). Furthermore, the results of the independent *t*-test indicated a significant difference in the FR of the shoulder joint between athletes with and without dyskinesis ($P < 0.05$).

5. Discussion

This study aimed to compare JPS and FR between racquet athletes with and without SD. The study included 30 female participants with SD and 30 female participants without SD, randomly selected as the sample. The results of the independent *t*-test revealed a statistically significant difference in JPS of the shoulder joint between athletes with and without SD at angles of 45 and 135 degrees ($P < 0.05$). Similarly, the independent *t*-test analysis demonstrated a significant difference in FR of the shoulder joint between athletes with and without SD ($P < 0.05$). This study showed that racquet athletes with SD had significantly poorer JPS and FR compared to those without SD, indicating reduced accuracy in perceiving joint position and pressure applied to their shoulders. Scapular dyskinesis commonly affects racquet athletes, leading to shoulder pain, instability, and decreased performance. It is caused by abnormal movement patterns of the scapula, which can disrupt the normal mechanics of the shoulder joint (20).

The independent *t*-test results indicated a significant difference in JPS of the shoulder joint at angles of 45 and 135 degrees between athletes with and without SD ($P < 0.05$). Notably, individuals with better proprioceptive sense tend to have lower JPS errors in their shoulder joint (26). Joint position sense is vital for optimal performance in racquet sports, enabling athletes to position their limbs and apply appropriate force during movements accurately. A study by Sood et al. investigated the impact of

Table 1. Distribution of Mean and SD of Age, Height, and Weight in Athletes with and Without Scapular Dyskinesia

Variables and Athletes	N	Mean ± SD
Age		
Without dyskinesia	30	22.80 ± 3.39
With dyskinesia	30	24.10 ± 3.85
Weight		
Without dyskinesia	30	59.36 ± 7.69
With dyskinesia	30	59.73 ± 7.43
Height		
Without dyskinesia	30	165.30 ± 10.39
With dyskinesia	30	164.23 ± 10.17

Table 2. Mean and Standard Deviation of JPS and FR Variables in Athletes with and Without SD

Variables, AM, and Athletes	Mean± SD
JPS	
45	
Without dyskinesia	3.76 ± 1.85
With dyskinesia	5.63 ± 2.20
135	
Without dyskinesia	4.73 ± 2.06
With dyskinesia	6.70 ± 1.80
FR	
Without dyskinesia	6.43 ± 2.73
With dyskinesia	8.93 ± 3.30

Abbreviations: JPS, joint position sense; FR, force-reproduction; AM, angle of measurement.

electrical muscle stimulation with voluntary contraction and taping on JPS in patients with asymptomatic SD, revealing significant improvements in both JPS and SD. The findings suggested that this approach could enhance proprioception by increasing JPS (29). Sayaca et al. discovered that patients who underwent arthroscopic Bankart repair (ABR) exhibited SD and proprioceptive deficits. However, the functional level of these patients was similar to that of healthy individuals. The study suggests that postoperative rehabilitation should focus on correcting SD and improving proprioception in patients with preexisting dyskinesis and loss of proprioception before surgery or injury. The researchers also found a negative correlation between dynamic SD and JPS at 40° of shoulder elevation on the operated side. Therefore, exercises that enhance dynamic scapular control and proprioception below 90° of shoulder elevation should be recommended for these patients (24).

Additionally, the independent *t*-test results demonstrated a significant difference in FR of the shoulder joint between athletes with and without SD ($P < 0.05$). FR involves accurately perceiving the force applied to a joint or body part. Dover and Powers study on the reliability of JPS and FR measures during internal and external shoulder rotation found that both JPS and FR were reliable measures of shoulder proprioception. Clinicians may find FR to be a better measure of shoulder proprioception due to its ability to provide more muscle activity and afferent information than JPS. However, further research is necessary to determine the significance of FR in an injured population or during rehabilitation. Clinical measurements of JPS and FR can be valuable for tracking rehabilitation progress and motivating athletes to improve proprioception between visits (26).

This study's novelty lies in its comprehensive evaluation of JPS and force reproduction within the female racquet athlete population, with and without SD. While previous research may have explored similar measures in other athlete populations (2, 4, 8, 22-25) or focused exclusively on either JPS or force reproduction (26), our study uniquely combines these assessments within the specific context of female racquet sports athletes. Furthermore, our study delves into the nuanced relationship between these parameters and scapular dyskinesia, an area that has yet to be explored within the context of JPS and force reproduction in female racquet athletes. This unique focus allows us to uncover potential insights tailored to this specific population, ultimately contributing to a deeper understanding of the impact of scapular dyskinesia on JPS and force reproduction within the context of racquet sports.

These findings have important implications for the management of SD in racquet athletes. Improving scapular mechanics reduces pain and, enhances performance, and improves JPS and FR. This, in turn,

Table 3. The Results of the Independent *t*-test on JPS and FR of the Shoulder Joint in Racket Sports Athletes with and Without Dyskinesis

Degree	Leven's Test		Independent *t*-test			
	F	P-Value	MD	*t*	dF	P-Value
JPS						
45	1.07	0.303	-1.86	-3.55	58	0.001
135	0.78	0.380	-1.96	-3.92	58	0.0001
FR						
90	0.78	0.380	-2.50	-3.24	58	0.002

Abbreviations: JPS, joint position sense; FR, force-reproduction; MD, mean difference; dF, degrees of freedom.

could lead to more accurate shot placement and improved overall performance on the court. In conclusion, this study highlights the significance of scapular mechanics in racquet sports and its influence on JPS and FR. Further research is necessary to investigate the relationship between SD and other aspects of sensorimotor function in racquet athletes. Nonetheless, these findings provide valuable insights into the management of SD in this population.

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Footnotes

Authors' Contribution: TB and KK contributed to the study conception and design, and TB performed clinical examination and data collection. MS and KK participated in the methodological development and design of the statistical analysis. MS wrote the first draft of the manuscript and contributed to the comments and suggestions that greatly improved it. Finally, all the authors revised it critically for important intellectual content, agreed with the content, contributed to the current study's refinement, and approved the final manuscript.

Conflict of Interests: Authors declare no conflict of interest.

Data Availability: The datasets generated during and analyzed during the current study are available from the corresponding author upon reasonable request. The researchers interested in using the final dataset for scientific purposes may contact the corresponding author.

Ethical Approval: This research was approved by the ethics committee of Sport Sciences Research Institute, Tehran, Iran (approval number: IR.SSRC.REC.1402.013).

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Informed Consent: All participants provided informed consent, and their confidentiality and anonymity were maintained throughout the study.

References

1. Luime JJ, Koes BW, Hendriksen IJ, Burdorf A, Verhagen AP, Miedema HS, et al. Prevalence and incidence of shoulder pain in the general population; a systematic review. *Scand J Rheumatol*. 2004;**33**(2):73–81. [PubMed ID: 15163107]. https://doi.org/10.1080/03009740310004667.
2. Kibler WB, Ludewig PM, McClure PW, Michener LA, Bak K, Sciascia AD. Clinical implications of scapular dyskinesis in shoulder injury: the 2013 consensus statement from the 'Scapular Summit'. *Br J Sports Med*. 2013;**47**(14):877–85. [PubMed ID: 23580420]. https://doi.org/10.1136/bjsports-2013-092425.
3. Ratcliffe E, Pickering S, McLean S, Lewis J. Is there a relationship between subacromial impingement syndrome and scapular orientation? A systematic review. *Br J Sports Med*. 2014;**48**(16):1251–6. [PubMed ID: 24174615]. https://doi.org/10.1136/bjsports-2013-092389.
4. Burn MB, McCulloch PC, Lintner DM, Liberman SR, Harris JD. Prevalence of scapular dyskinesis in overhead and nonoverhead athletes: A systematic review. *Orthop J Sports Med*. 2016;**4**(2):2325967115627610. [PubMed ID: 26962539]. [PubMed Central ID: PMC4765819]. https://doi.org/10.1177/2325967115627608.
5. Pluim BM. Scapular dyskinesis: Practical applications. *Br J Sports Med*. 2013;**47**(14):875–6. [PubMed ID: 23973880]. https://doi.org/10.1136/bjsports-2013-092722.
6. Cools AM, Dewitte V, Lanszweert F, Notebaert D, Roets A, Soetens B, et al. Rehabilitation of scapular muscle balance: which exercises to prescribe? *Am J Sports Med*. 2007;**35**(10):1744–51. [PubMed ID: 17606671]. https://doi.org/10.1177/0363546507303560.
7. Clarsen B, Bahr R, Andersson SH, Munk R, Myklebust G. Reduced glenohumeral rotation, external rotation weakness and scapular dyskinesis are risk factors for shoulder injuries among elite male handball players: a prospective cohort study. *Br J Sports Med*. 2014;**48**(17):1327–33. [PubMed ID: 24948083]. https://doi.org/10.1136/bjsports-2014-093702.
8. Myers JB, Oyama S, Hibberd EE. Scapular dysfunction in high school baseball players sustaining throwing-related upper extremity injury: a prospective study. *J Shoulder Elbow Surg*. 2013;**22**(9):1154–9. [PubMed ID: 23419606]. https://doi.org/10.1016/j.jse.2012.12.029.
9. Harris JD, Pedroza A, Jones GL. Predictors of pain and function in patients with symptomatic, atraumatic full-thickness rotator cuff tears: a time-zero analysis of a prospective patient cohort

enrolled in a structured physical therapy program. *Am J Sports Med*. 2012;**40**(2):359–66. [PubMed ID: 22095706]. [PubMed Central ID: PMC3632074]. https://doi.org/10.1177/0363546511426003.
10. Struyf F, Nijs J, Mottram S, Roussel NA, Cools AM, Meeusen R. Clinical assessment of the scapula: a review of the literature. *Br J Sports Med*. 2014;**48**(11):883–90. [PubMed ID: 22821720]. https://doi.org/10.1136/bjsports-2012-091059.
11. McClure P, Tate AR, Kareha S, Irwin D, Zlupko E. A clinical method for identifying scapular dyskinesis, part 1: reliability. *J Athl Train*. 2009;**44**(2):160–4. [PubMed ID: 19295960]. [PubMed Central ID: PMC2657031]. https://doi.org/10.4085/1062-6050-44.2.160.
12. Tate AR, McClure P, Kareha S, Irwin D, Barbe MF. A clinical method for identifying scapular dyskinesis, part 2: validity. *J Athl Train*. 2009;**44**(2):165–73. [PubMed ID: 19295961]. [PubMed Central ID: PMC2657032]. https://doi.org/10.4085/1062-6050-44.2.165.
13. Hogan C, Corbett JA, Ashton S, Perraton L, Frame R, Dakic J. Scapular dyskinesis is not an isolated risk factor for shoulder injury in athletes: A systematic review and meta-analysis. *Am J Sports Med*. 2021;**49**(10):2843–53. [PubMed ID: 33211975]. https://doi.org/10.1177/0363546520968508.
14. McQuade KJ, Borstad J, de Oliveira AS. Critical and theoretical perspective on scapular stabilization: What does it really mean, and are we on the right track? *Phys Ther*. 2016;**96**(8):1162–9. [PubMed ID: 26847012]. https://doi.org/10.2522/ptj.20140230.
15. Willmore EG, Smith MJ. Scapular dyskinesia: Evolution towards a systems-based approach. *Shoulder Elbow*. 2016;**8**(1):61–70. [PubMed ID: 27583003]. [PubMed Central ID: PMC4935167]. https://doi.org/10.1177/1758573215618857.
16. Levine DN. Sherrington's "the integrative action of the nervous system": A centennial appraisal. *J Neurol Sci*. 2007;**253**(1-2):1–6. [PubMed ID: 17223135]. https://doi.org/10.1016/j.jns.2006.12.002.
17. Radák Z. Fundamentals of strength training. *The Physiology of Physical Training*. Cambridge M, USA: Academic Press; 2018. p. 55–80. https://doi.org/10.1016/b978-0-12-815137-2.00004-8.
18. Buyukafsar E, Basar S, Kanatli U. Proprioception following the anterior cruciate ligament reconstruction with tibialis anterior tendon allograft. *J Knee Surg*. 2020;**33**(7):722–7. [PubMed ID: 30959535]. https://doi.org/10.1055/s-0039-1684010.
19. Hlaing SS, Puntumetakul R, Khine EE, Boucaut R. Effects of core stabilization exercise and strengthening exercise on proprioception, balance, muscle thickness and pain related outcomes in patients with subacute nonspecific low back pain: a randomized controlled trial. *BMC Musculoskelet Disord*. 2021;**22**(1):998. [PubMed ID: 34847915]. [PubMed Central ID: PMC8630919]. https://doi.org/10.1186/s12891-021-04858-6.
20. Kibler WB, Stone AV, Zacharias A, Grantham WJ, Sciascia AD. Management of scapular dyskinesis in overhead athletes. *Oper Tech Sports Med*. 2021;**29**(1). https://doi.org/10.1016/j.otsm.2021.150797.
21. Hubscher M, Zech A, Pfeifer K, Hansel F, Vogt L, Banzer W. Neuromuscular training for sports injury prevention: a systematic review. *Med Sci Sports Exerc*. 2010;**42**(3):413–21. [PubMed ID: 19952811]. https://doi.org/10.1249/MSS.0b013e3181b88d37.
22. Phillips D, Karduna A. No relationship between joint position sense and force sense at the shoulder. *J Mot Behav*. 2018;**50**(2):228–34. [PubMed ID: 28829277]. https://doi.org/10.1080/00222895.2017.1327415.
23. Saini SS, Shah SS, Curtis AS. Scapular dyskinesis and the kinetic chain: Recognizing dysfunction and treating injury in the tennis athlete. *Curr Rev Musculoskelet Med*. 2020;**13**(6):748–56. [PubMed ID: 32827302]. [PubMed Central ID: PMC7661674]. https://doi.org/10.1007/s12178-020-09672-6.
24. Sayaca C, Unal M, Calik M, Eyuboglu FE, Kaya D, Ozenci AM. Scapular dyskinesis, shoulder joint position sense, and functional level after arthroscopic bankart repair. *Orthop J Sports Med*. 2021;**9**(8). [PubMed ID: 34377720]. [PubMed Central ID: PMC8335837]. https://doi.org/10.1177/2325967120985207.
25. Zheng N, Tian Y, Zheng D, Yu Z, Cools AM. Scapular dyskinesis in relation to overhead activities: A systematic review. *Br J Sports Med*. 2015;**49**(14):886–92.
26. Dover G, Powers ME. Reliability of joint position sense and force-reproduction measures during internal and external rotation of the shoulder. *J Athl Train*. 2003;**38**(4):304–10. [PubMed ID: 14737211]. [PubMed Central ID: PMC314388].
27. Kibler WB, Uhl TL, Maddux JW, Brooks PV, Zeller B, McMullen J. Qualitative clinical evaluation of scapular dysfunction: a reliability study. *J Shoulder Elbow Surg*. 2002;**11**(6):550–6. [PubMed ID: 12469078]. https://doi.org/10.1067/mse.2002.126766.
28. Dover GC, Kaminski TW, Meister K, Powers ME, Horodyski M. Assessment of shoulder proprioception in the female softball athlete. *Am J Sports Med*. 2017;**31**(3):431–7. https://doi.org/10.1177/03635465030310031801.
29. Sood I, Sen S, Arfath U. Effect of electrical muscle stimulation with voluntary contraction and taping on joint position sense in asymptomatic scapular dyskinesic patients. *Int J Phys Med rehabil*. 2014;**2**:1–6.