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Original Article

Prediction of scapular dyskinesis through electromyographic index of scapulothoracic muscles and glenohumeral internal rotation range of motion in female overhead athletes

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Scapular dyskinesis (SD), due to the high prevalence in overhead athletes and the motor interaction between the scapula and the humerus, will affect the glenohumeral joint function and subsequently the athletic performance of these athletes. Therefore, the purpose of the study was to predict SD through electromyographic index of scapulothoracic muscles and glenohumeral internal rotation range of motion (ROM) in female overhead athletes. The present study was descriptive-correlational research on 60 athletic females in volleyball, handball, basketball, and badminton. The Lateral scapular slide test was used to examine the SD. the electromyography and goniometer were used to measure the activity of scapulothoracic muscles, including upper trapezius (UT), lower trapezius (LT) and serratus anterior (SA) and glenohumeral rotation ROM respectively. Data were analyzed by Spearman correlation and multiple regression tests. There were significant correlations between all the electromyographic variables with SD ($p <0.01$). The regression effects of all predictive variables on SD were significant ($p= 0.000$). In terms of predictive power, the UT-LT co-contraction ($\beta= 0.45$), UT-SA co-contraction ($\beta= 0.37$), UT activity ($\beta= 0.34$), glenohumeral internal rotation (ROM) ($\beta= 0.30$), LT activity ($\beta= 0.16$), SA activity ($\beta= 0.12$) have the highest regression effects on the SD, respectively. the independent variables set predict 78% of the variance of the criterion variable. screening and evaluation of overhead athletes for the reorganization of SD, and then participate in the corrective exercises for adjustment and treatment, must be taken into consideration.

Keywords: Scapular Dyskinesis, Electromyography, Scapulothoracic Muscles, Glenohumeral Internal Rotation, Overhead Athletes.

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Introduction

It is widely accepted that in overhead sports such as volleyball, handball, badminton and swimming, health and proper functioning of the shoulder and scapula are directly associated with how sports movements are performed. Given the central role of the scapula in shoulder movements, its position on the rib cage during arm movements is of immense importance for preventing shoulder injuries [1]. Scapular dyskinesis refers to abnormal changes in scapular position and movement, which is associated with various shoulder disorders such as shoulder impingement syndrome, multidirectional shoulder instability, and rotator cuff and labrum injuries [2-4,7,8]. Scapular movements can be affected by many neuromuscular and mechanical factors [3, 9]. Among the muscles attached to the scapula, serratus anterior plays a key role in the

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stability of the inner edge of the scapula on the rib cage and the dynamic stability of scapulothoracic movements [2]. When elevating the arm, upper and lower trapezius muscles and serratus anterior create a force-couple that causes upward and posterior rotations in the scapula [1, 10, 11]. Naturally, poor strength and activity of serratus anterior and lower trapezius muscles can undermine the upward and posterior rotations of the scapula, and this, in fact, is one of the major causes of scapular winging and dyskinesis [1,9,12,13]. Changes in the recruitment and coordination patterns of scapulothoracic muscles can also weaken the scapular stability during arm abduction, thereby leading to decreased subacromial space and a higher likelihood of shoulder impingement [14].

In a study by Huang et al. (2015), they investigated the relationship between three-dimensional scapular motions and the activity of scapular muscles in people with different types of scapular dyskinesis (protrusion in the inferior angle of the scapula, protrusion in the inner edge of the scapula, and a combination of these conditions) and healthy people. This study found that scapular dyskinesis is associated with changes in scapular muscle activity and scapular kinematics and observed different motion patterns and scapulothoracic muscle activity levels in healthy and unhealthy subjects [15]. A study by Cools et al. (2007) reported that overhead athletes with shoulder impingement syndrome had higher upper trapezius activity and lower-middle and lower trapezius activity than healthy overhead athletes. These athletes were also found to have a higher upper/middle and upper/lower trapezoidal co-contraction ratio than healthy athletes [16]. These reports suggest that there is an imbalance in the scapulothoracic muscles of athletes with shoulder disorders. The shoulder joint has high mobility and moves about 90 degrees in each internal and external rotation. However, overhead athletes also need high shoulder stability for their throwing movements [17]. This balance between shoulder mobility and stability has been described as the "thrower's paradox" and when compromised can lead to a shoulder injury [18]. For overhead athletes, one of the most important factors associated with a change in scapular movement pattern is the imbalance in the range of motion (ROM) of internal and external shoulder rotations. Throwing mechanics make the overhead athlete susceptible to an imbalance in ROM, especially decreased internal shoulder rotation [17, 19]. In this regard, a study by Shimpi et al. (2015) on a group of overhead athletes (racket sports) and a control group (non-racket sports) showed that the former group had lower internal rotation ROM and higher scapular dyskinesis than the latter [18]. Also, in a prospective study conducted on handball players, Clarsen et al. (2014) found that scapular dyskinesis and reduced shoulder ROM are the most important risk factors for shoulder injuries [20]. Cools et al. (2015) also reported that scapular dyskinesis and reduced shoulder ROM are associated with the risk of re-injury and returning to exercise after a shoulder injury [17]. A review study by Hickey et al. (2018) also reported that scapular dyskinesis increases the risk of shoulder pain by 43% Considering the high prevalence of scapular dyskinesis in overhead athletes and its effect on athletic performance and shoulder health, this study aimed to investigate the relationship of scapular dyskinesis with scapulothoracic muscle activity and rotation ROM in female volleyball, handball, basketball, and badminton players and determine the ability of each factor to predict scapular dyskinesis in these athletes [21]. The results of this study can contribute to the planning of injury prevention strategies for sports with overhead throwing motions.

Materials and Methods

This study was descriptive-correlational research conducted on 60 female volleyball, handball, basketball and badminton players aged 18-25 years (age: 22.13±2.45years, weight: 62.5±6.29kg, height: 165±5.58cm, scapular asymmetry: 1.76±0.3) in Guilan province, Iran, in 2018. Subjects were selected by convenience sampling. Inclusion criteria were female gender, having at least three years of a regular volleyball, handball, basketball, or badminton exercise, and diagnosis of scapular dyskinesis. Exclusion criteria were: experiencing pain in shoulder girdle or neck in or out of exercise, history of fracture or dislocation in any of shoulder girdle bones, complete rupture of shoulder girdle muscles, any shoulder girdle condition such as impingement syndrome, long thoracic nerve palsy, spinal accessory nerve injury, and history of surgery in the shoulder girdle area [1,8,22,23]. Overall, 186 female athletes were examined by an experienced physiotherapist and 60 of them who had scapular dyskinesis and met the inclusion and exclusion criteria entered the study Scapular dyskinesis was diagnosed by the Lateral Scapular Slide Test (LSST) developed by Kibler [24]. In this test, the distance of the inferior angle of the scapula from the nearest vertebral spinous process was measured by tape measure in three postures with 0, 45 and 90 degrees of abduction. Each measurement was performed three times for each hand and the results were averaged. The difference of 1.5cm between the two scapulae was considered as the threshold of diagnosis [24, 25]. Kibler has reported an intra-group reliability 0.84-0.88 and inter-group reliability of 0.77-0.85 for LSST at different angles [8]. The activity of scapulothoracic muscles including the upper trapezius, lower trapezius, and serratus anterior during arm abduction in the scapular plane (30 degrees anterior to the frontal surface) was recorded [22, 26]. The test of arm abduction to the end of ROM in the scapular plane was performed with a 2-second concentric phase (raising the arm) and repeated three times with 30-second rests in between (Figure 1). Motion rhythm was controlled by a metronome at 60 beats per minute. Arm abduction was performed with the subject standing upright on a wooden board, with the elbow kept straight and thumbs facing up.

Figure 1. Arm abduction movement: a) posture of the subject on the wooden board, b) arm abduction in the scapular plane. Formulation and method of preparing oil-in-water cream

The electrical activity of the muscles was measured by an 8-channel electromyograph model ME6000 (Megawin, Finland) at a sampling frequency of 1000Hz and band-pass filter of 10-450Hz. The CMRR ratio was 110 dB and the gain of the device was 1000. Electromyographic signals were recorded by the surface electrodes made of silver/silver chloride alloy (SkinTact, Austria). The center-to-center distance of the two surface electrodes placed on each muscle was 2 cm. The placement of electrodes on trapezius muscles and serratus anterior was performed according to the instructions given in Stegeman el al. [27] and Seitz et al. projects [22], respectively (Figure 2). The root means square (RMS) of data collected from each muscle during arm abduction in the scapular plane was recorded. Maximum voluntary isometric contraction test was used to normalize electromyographic data.

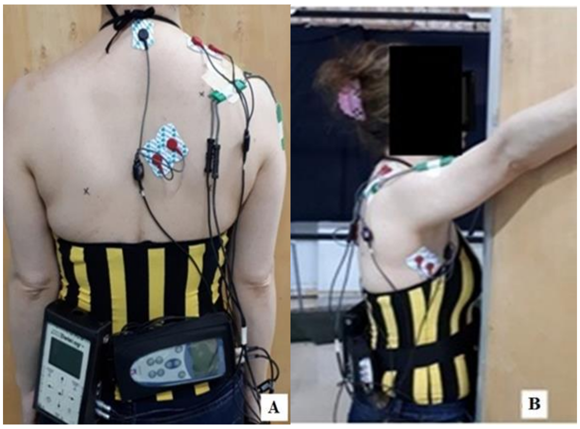

Figure 2. Placement of electrodes on target muscles and the setup of electromyography system: a) Posterior view, b) Lateral view

The co-contraction index of upper and lower trapezius muscles and that of the upper trapezius and serratus anterior were computed using the formula proposed by Radolf et al. [5, 28]. In this formula, EMG Low is the normalized electromyographic data of the muscle with lower RMS and EMG High is that of the muscle with higher RMS. ROM of the internal rotation was measured by 360-degree goniometer (Lafayette, USA). This measurement was performed in the supine position with 90-degree arm abduction and 90 degrees elbow flexion [26]. For this measurement, the goniometer axis was placed on the elbow protrusion, the fixed arm was held perpendicular to the ground and along the humerus, and the movable arm was held along the ulna. After stabilizing the scapula by applying pressure on the coracoid process (with the help of an assistant), the internal rotation of the arm was measured in degrees [17]. It should be noted that this measurement was performed on the dominant hand. The one-sample Kolmogorov-Smirnov test was used to check the normality of the distribution of the data. Since this distribution was found to be abnormal, the Spearman correlation test was used to investigate the relationship between variables and scapular dyskinesis. Finally, a simultaneous multiple regression test was used to determine the extent to which scapular dyskinesis can be predicted by each variable. All statistical analyses were performed in SPSS version 22 with 95% significance level and $\alpha<0.05$.

Results

The normalized electrical activity of the target muscles in the concentric phase of arm abduction in the scapular plane is described in Table 1.

Table 1. Normalized muscle activity (MVC) in the concentric phase of arm abduction in the scapular plane

Variable	Muscle Activity (%MVC)
Upper Trapezius	39.6±5.1
Lower Trapezius	34.1±7.1
Serratus Anterior	47.5±6.7
Upper Trapezius/Lower Trapezius Co-Contraction	56.9±6.4
Upper Trapezius/Serratus Anterior Co-Contraction	68.5±6.8

The mean and standard deviation of the internal rotation ROM was 44.95±5.17 degrees with a range of 35-53 degrees. The results of the Spearman correlation test for the relation of the measured electromyographic indices and the internal rotation ROM of the dominant shoulder with scapular dyskinesis are provided in Table 2.

Table 2. Results of Spearman correlation test for the relation of the measured electromyographic indices and the internal rotation ROM with scapular dyskinesis

Electromyography Index	N	coefficient of correlation	P-value
Upper Trapezius	60	0.766	0.001
Lower Trapezius	60	-0.729	0.003
Serratus Anterior	60	-0.747	0.000
Upper Trapezius/Lower Trapezius Co-Contraction	60	0.805	0.000
Upper Trapezius/Serratus Anterior Co-Contraction	60	0.746	0.000
Internal Rotation ROM	60	-0.73	0.001

As the results of Table 2 show, the coefficients of correlation between all electromyographic indices and the ROM internal rotation and scapular dyskinesis were found to be significant ($p < 0.01$). Therefore, all the considered predictors (independent variables) can be entered the regression model. A summary of statistical indices used to fit the regression model to the data is presented in Table 3.

Table 3. Summary of statistical indices used to fit the regression model

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.891	0.810	0.783	0.20527

Predictive variables: upper trapezius activity, lower trapezius activity, serratus anterior activity, upper trapezius/lower trapezius co-contraction, upper trapezius/serratus anterior co-contraction, and internal rotation ROM Criterion variable: scapular dyskinesis.

As shown in Table 3, the developed model consists of six independent variables and one dependent variable with a multiple correlation coefficient of 0.891, which signifies a strong correlation between the set of independent variables (predictors) and the dependent variable (criterion). The adjusted coefficient of variation computed for the model (0.783) means that 78.3% of all changes in scapular dyskinesis depend on the independent variables included in this regression model.

Table 4 shows the changes in the criterion variable (scapular dyskinesis) due to changes in the independent variables (regression variations) and other factors outside the model (residual variations).

Table 4. Results of analysis of variance for changes in scapular dyskinesis due to the independent variables included in the model and other factors

Model	Sum of squares	DF	Mean square	F	Sig.
Regression	4.647	6	0.775	50.160	0.000
Residual	0.818	53	0.015		
Total	5.465	59			

Predictive variables: upper trapezius activity, lower trapezius activity, serratus anterior activity, upper trapezius/lower trapezius co-contraction, upper trapezius/serratus anterior co-contraction, and internal rotation ROM Criterion variable: scapular dyskinesis.

As shown in Table 4, the obtained F value is (50.160) is statistically significant ($p = 0.000$) and the sum of the squares of residuals is lower than the sum of the squares of regression, which shows the ability of the model to explain the changes of the dependent variable (scapular dyskinesis). Therefore, it can be concluded that the obtained regression model (with six independent variables and one dependent variable) is acceptably accurate and the set of independent variables can very well predict the changes of scapular dyskinesis.

The regression effect of each variable on the model was determined with the help of multivariate linear regression coefficients (Table 5). As this table shows, the regression effect of all predictive variables on scapular dyskinesis was found to be significant ($p = 0.001$).

Table 5. Regression coefficients computed to determine the effect of predictive variables on the criterion variable (scapular dyskinesis)

Predictor Variable	Unstandardized coefficients	Standardized coefficients	T	P	
	B	SE			
Upper Trapezius Activity	0.012	0.005	0.348	4.844	0.013
Lower Trapezius Activity	-0.025	0.005	0.165	2.568	0.000
Serratus Anterior Activity	-0.001	0.003	-0.122	-2.387	0.04
Upper Trapezius/Lower Trapezius Co-Contraction	-0.022	0.004	-0.458	-5.287	0.000
Upper Trapezius/Serratus Anterior Co-Contraction	0.026	0.005	-0.379	-5.645	0.000
Internal Rotation ROM	-0.017	0.005	-0.302	-3.533	0.001

Discussion

Activity and co-contraction of scapulothoracic muscles.

The results of our study showed that scapular dyskinesis has a positive relationship with the activity of upper trapezius muscle and a negative relationship with the activity of lower trapezius and serratus anterior muscles. In other words, people with higher activity in the upper trapezius and lower activity in lower trapezius and serratus anterior are more likely to have scapular dyskinesis. Scapular dyskinesis was also found to have a positive relationship with the co-contraction of the upper trapezius and lower trapezius and the co-contraction of the upper trapezius and serratus anterior, which shows that people with higher co-contraction of these muscles are more likely to have scapular dyskinesis.

Scapular dyskinesis can be the cause or the effect of alteration in the activity of scapulothoracic muscles [29]. Since arm abduction involves upper and lower trapezius and serratus anterior muscles creating a force-couple that result in upward rotation of the scapula, they play an important role in maintaining the neutral scapular position and the scapulohumeral rhythm [30]. Therefore, the increased upper trapezius activity, which may be caused by the effort to control movement impairment and assist arm elevation and the decreased activity in lower trapezius and serratus anterior can cause muscle imbalance (an increase in upper trapezius/lower trapezius and upper trapezius/serratus anterior co-contraction ratios), and consequently an imbalance in the created force-couple, which result in scapular dyskinesis [9,16,30,31]. Also, since the serratus anterior muscle plays a key role in the stabilization of the inner edge of the scapula on the rib cage and the dynamic stabilization of scapulothoracic movements, any disturbance in the activity of this muscle can also cause abnormal positioning and movement of the scapula [1,32].

The upper trapezius muscle is known to be the prime mover in arm abduction. The increased upper trapezius activity takes place during the clavicle lifting and anterior scapular tilt and is considered a compensatory strategy for lifting the arm in people with shoulder disorders [33]. The increased upper trapezius activity has been reported in many studies, including Lopes et al. (2015), Cools et al [29]. (2007),(2003) Chester et al. (2010) [16,31,32]. According to the study of Lopes et al. (2015) on the relationship between changes in the electrical activity of muscles and changes in scapular kinematics, people with scapular dyskinesis had a significantly higher upper trapezius activity (12%) than those without this condition. They also had 2.1 degrees more external scapular rotation in the concentric phase and 2.5 degrees more shoulder flexion in the eccentric phase than the control group. Based on these results, Lopes et al. concluded that in patients with shoulder impingement syndrome and scapular dyskinesis, muscle activity and kinematics of the scapula undergo some changes, which are related to scapular dyskinesis [29].

The observed relationship between increased upper trapezius activity and decreased lower trapezoidal and serratus anterior activity and scapular dyskinesis can also be explained according to tonic and phasic muscle systems. Janda has classified the upper trapezius as a tonic muscle but has placed the lower trapezius and serratus anterior in the class of phasic muscles. Considering that tonic muscles tend to have increased activity, more intense stiffening and shortening, and faster responses and phasic muscles tend to be weaker and less active, get inhibited more easily, and have slower elongation and delayed responses, these features could be the cause of the observed increase in upper trapezius activity and the decrease in the activity of lower trapezius and serratus anterior [19]. Also, because of the reciprocal inhibition mechanism, an increase in the activity of upper trapezius muscle inhibits its antagonist muscles, which are lower trapezius and serratus anterior. Furthermore, since lower trapezius and serratus anterior are susceptible to inhibition, it is reasonable to expect them to get weak and less active when upper trapezius experiences increased activity. According to Janda, an overactive muscle reflexively inhibits its antagonist muscle, which then leads to muscle imbalance [19]. This muscle imbalance, in turn, results in the generation of unbalanced forces, which changes the kinematics of the scapula and causes scapular dyskinesis [33].

The results of our study are consistent with the results of studies that have investigated the relationship of scapular kinematics with muscle activity in people with shoulder impingement syndrome [1, 3, 9, 14, 16, 25, 30]. Although most of the past studies have been conducted on athletes with shoulder impingement syndrome, since scapular dyskinesis can be considered a potential risk factor for future injuries, our results are comparable to the results of these studies [5]. The studies of Cools et al. (2007) and Oliveira et al. (2013) overhead athletes showed that athletes with impingement syndrome and scapular dyskinesis have greater upper trapezius activity and higher upper trapezius/lower trapezius and upper trapezius/serratus anterior co-contraction ratios [16, 33]. In this regard, Huang et al. (2017) have reported that scapular muscular activity and scapular kinematics depend on the type of scapular dyskinesis. After studying overhead athletes, who were divided in three groups in terms of pattern and type of scapular dyskinesis (1-protrusion in the inferior angle of the scapula, 2- protrusion in the inner edge of the scapula, and 3- combination of both conditions), these researchers found that the first pattern of movement impairment predicts 41% and the second pattern predicts 42.6% of all changes in scapular mobility. In this study, the main predictive variable for the first pattern was the co-contraction of the upper trapezius and lower trapezius and for the second pattern, it was the co-contraction of the upper trapezius, medial trapezius, and serratus anterior [34]. These studies point to the existence of a relationship between the electrical activity of scapulothoracic muscles, the positioning of the scapula, and the static and dynamic scapular stability.

Internal rotation ROM

To explain the observed relationship between the internal rotation ROM and scapular dyskinesis, it can be argued that the scapula contributes to the release of energy during the follow-through of throwing motion by moving away from the rib cage [35, 36]. In the absence of enough internal rotation ROM, this motion of scapulae intensifies to compensate for ROM deficit and to maintain the acceleration of overhead motion. This constant pressure causes soft tissue adaptation and weakens the scapular stabilizers [18, 35, 36]. As a result, the scapula fails to provide a stable surface for supporting the rotator cuff muscles. This reduces the performance of the scapula and puts extra pressure on the static structures of the dominant shoulder [17]. Therefore, rather than exerting pressure on the brachium in the glenoid cavity, the rotator cuff pushes the scapula outward and causes extra protraction and external rotation in this bone, which alters the scapulohumeral rhythm and causes scapular dyskinesis [2]. A study by Thomas et al. (2010) on overhead athletes with internal rotation ROM deficit showed that scapular protraction is associated with scapular dyskinesis, and that scapular dyskinesis intensifies with the increase of internal rotation ROM deficit [36]. The strength-oriented and repetitive nature of overhead throwing motions when combined with poor muscle control (scapular dyskinesis) can alter the shoulder rotation ROM by increasing external rotation and decreasing internal rotation [37]. The special needs of overhead throwing exercises induce some changes in shoulder joint mobility and stability [38]. In overhead sports, repetitive and high intensity throwing motions apply small but sustained pressure on the shoulder joint capsule, which leads to the stiffening of the posterior part of this capsule and therefore a change in the ROMs of the internal and external shoulder rotators [20]. More specifically, this results in a decrease in the internal rotation ROM and an increase in the external rotation ROM [20, 25,38]. A study by Borich et al.(2006) on the rotation ROM and the three-dimensional scapular position in professional baseball players also found a positive relationship between abnormal scapular position and rotation ROM deficit [39].

Overall, our findings showed a strong correlation (0.891) between the predictor variables and the criterion variable of this study (scapular dyskinesis). It was also found that 78.3% of all changes in scapular dyskinesis were dependent on the predictor variables included in the developed regression model. The variables with the strongest predictive power for scapular dyskinesis were found to be upper trapezius/lower trapezius co-contraction, upper trapezius/serratus anterior co-contraction, upper trapezius activity, internal rotation ROM, lower trapezius activity, and serratus anterior activity, in that order. The analysis of the developed regression model demonstrated the good power of this model in explaining changes in scapular dyskinesis. From these results, it can be concluded that electromyographic indices of scapulothoracic muscles and the internal shoulder rotation ROM are well capable of predicting changes in scapular dyskinesis.

Conclusion

Considering the results of this study and the observed miscoordination in the electrical activity of scapulothoracic muscles and the internal rotation ROM deficit of female overhead athletes with scapular dyskinesis, periodic screening of these athletes for the diagnosis of scapular dyskinesis should be recommended to coaches, physiotherapists, and team physicians. Also, prospective studies are needed to investigate the relationship of scapular dyskinesis with other possibly related factors such as three-dimensional scapular motion, shoulder rotator strength, and length of pectoralis minor.

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Conflicts of interest

None.

Author's contribution

All participants completed the consent form, participated in the study willingly, and could leave the study at any stage.

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