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Original Article

Prediction of Scapular Dyskinesis Through Electromyographic Indices of Scapulothoracic Muscles in Female Overhead Athletes

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ABSTRACT

Background: Shoulder joint function and the athletic performance of overhead athletes are influenced by scapular dyskinesis (SD) due to its high prevalence among these athletes and the motor interaction between the scapula and the arm. The present study investigated the prediction of SD through the electromyographic indices of scapulothoracic muscles in female overhead athletes.
Methods: The present descriptive-correlational study was carried out on 60 female volleyball, handball, basketball, and badminton athletes. The lateral scapular slide test was used to examine their SD. The required electromyography and electrogoniometry data was recorded simultaneously to measure the activity and onset time of scapulothoracic muscles, including upper trapezius (UT), lower trapezius (LT), and serratus anterior (SA). The collected data was analyzed using Spearman correlation and multiple regression tests.
Results: Significant correlations were found between all electromyographic variables and SD (P<0.01). The regression effects of all predictive variables on SD were significant (P=0.001). In terms of predictive power, UT/SA co-contraction (β=0.765), UT/LT co-contraction (β=0.716), LT onset time (β=0.672), LT activity (β=0.612), and SA onset time (β=0.576) had the highest regression effects on SD, respectively. The analysis of the study model showed that there was a strong correlation (r=0.694) between the predictive variables and SD and that the independent variables predicted 48% of the variance.
Conclusion*:* The presence of imbalance in the scapulothoracic muscles of overhead athletes with SD indicates that athletes should be monitored by coaches, physiotherapists, and physicians for SD screening. It is also necessary to carry out prospective studies to examine and explore other variables related to SD.

Introduction

In overhead sports, such as volleyball, handball, badminton, and swimming, the proper interaction and function of the scapula and shoulder are directly associated with the athletic performance of the individual [1]. Repeating a specific movement pattern causes overhead athletes to undergo major adaptive changes in the musculoskeletal structure and performance of the shoulder girdle [2].

The important role of the scapula in shoulder movements and its position and orientation in the thorax are very important to the performance of arm movements and the prevention of shoulder injuries in the above-mentioned sports [1]. The importance of the position of the scapula on the thorax is due to the fact that changes

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in its normal position leads to a biomechanical disorder in the shoulder joint. In fact, the inability of the scapula to maintain the normal position and movement in most cases can result in injury [3].

Kibler refers to scapular dyskinesis (SD) as abnormal changes in the position and movement of the scapula [4-6] which are associated with various shoulder pathologies such as subacromial impingement syndrome (SIS) [5, 7], multidirectional glenohumeral instability, rotator cuff disease, and labral injury [1, 4, 6]. Some cases that result in scapular dyskinesis include clavicular fracture, paralysis of long thoracic and spinal accessory nerves, stiffness of the pectoralis minor muscle, decreased strength and activation of the serratus anterior muscle (SA), delayed onset of activation in the lower trapezius muscle (LT) and SA, and increased strength of the upper trapezius muscle (UT) compared to the LT and SA [1, 4].

Neuromuscular factors can alter the movement of the scapula [7], and any alteration in periscapular muscle activation will potentially lead to an abnormal position of the scapula, alteration of the scapulohumeral rhythm, and shoulder dysfunction [8]. Among the muscles that attach to the scapula, the SA muscle plays an important role in the stability of the medial border of the scapula on the thorax as well as the dynamic stability of the scapulothoracic movement [4]. The reduced strength and activity of the SA and LT reduce the upward rotation and posterior tilt of the scapula [7], which is an important reason for winging scapula and SD [1, 4].

Moreover, delayed activation of the SA as well as weak stability of the scapula during shoulder abduction, in addition to causing SD, can reduce the space of subacromial and increase the probability of SIS [4]. During shoulder abduction, the UT, LT, and SA result in the upward rotation and posterior tilt of the scapula as force couples [1, 9]. Therefore, delayed activation of the LT and SA causes a change in the upward rotation and posterior tilt of the scapula [9], followed by SD [1] and a disturbance in the scapulohumeral rhythm [10, 11].

Huang et al. (2015) studied the relationship between three-dimensional scapular movements and the activity of the scapular muscles in people with different types of SD (inferior angle prominence, medial border prominence, and combination of types 1 and 2) and without SD. They found that SD is correlated with changes in the activity of the scapular muscles as well as the kinematics of the scapula; moreover, the movement patterns and activity of the scapulothoracic muscles are different in people with SD and those without it [12]. Coles et al. (2007) assessed overhead athletes and found that the activity of the UT was higher in overhead athletes with SIS than in healthy overhead athletes, while the activity of the middle trapezius (MT) and LT was less than in healthy athletes. The SIS group also had a higher rate of co-contraction of the UT and MT as well as the co-contraction of the UT and LT [13]. These results indicate the presence of an imbalance in the scapulothoracic muscles of athletes with shoulder disorders.

Other studies, however, obtained different results, and a similar recruitment pattern was observed in the electromyographic activity of the scapulothoracic muscles in groups with shoulder pathologies and healthy athletes [14].

Further research is needed to examine the relationship between the activity of scapulothoracic muscles and SD. Because of the importance of preventing shoulder injuries in overhead athletes, it is necessary to investigate and explain the factors associated with SD (as a potential risk factor for shoulder injury). Predictive studies can effectively anticipate the above-mentioned injuries by examining the factors associated with sports injuries. However, few prospective studies have focused on shoulder injuries, and no predictive study focusing on SD was found. Most studies have focused on symptomatic overhead athletes such as SIS, and a few studies have investigated asymptomatic athletes, but with SD. It is expected that the results of the current study can be used to predict SD and prevent shoulder injuries. Therefore, the present study aimed to investigate the correlation between electromyographic activity of the scapulothoracic muscles and SD and determine the contribution of each of these factors to predicting SD in female volleyball, handball, basketball, and badminton athletes.

Methods

The sample of this descriptive-correlational study comprised 60 female athletes (18-25 years old) who played volleyball, handball, basketball, and badminton (age: 22.13±2.45 years, weight: 62.5±6.29 kg; height: 165±5/8 cm; scapular symmetry: 1.76±0.3) in Guilan, Iran in 2018. The sample size was estimated using G Power software and considering $\alpha \geq 0.05$, power=0.8, and effect size $f^2=0.15$. Therefore, the sample size was estimated to be 55 participants. During sampling, 60 subjects were selected using the purposive convenience sampling method.

Inclusion criteria were female gender, having at least three years of regular sports activity in volleyball, handball, basketball, or badminton, and having SD. The exclusion criteria included pain in the shoulder and neck under normal and practice conditions [1], a history of fracture or dislocation in each shoulder bone, complete rupture of the shoulder muscle [4, 15], shoulder girdle disorder such as SIS [16], paralysis of long thoracic and spinal accessory nerves, and a history of surgery in the shoulder girdle [17]. Overall, 186 female athletes were examined and evaluated by an experienced physiotherapist. Based on the inclusion and exclusion criteria, 60 patients with SD were included in the study.

The lateral scapular slide test (LSST) was used to investigate the SD. According to the results obtained by Kibler, the intratester reliability of this test ranges from 0.84 to 0.88, while its intertester reliability ranges from 0.77 to 0.85 at various angles [6]. In this test, the distance from the inferior angle of the scapula to the corresponding spinous process in the three positions of 0, 45, and 90 degrees of shoulder abduction was measured. Each of the measurements was repeated three times in both arms, and then their average was calculated. If there was a difference of 1.5 cm or more between the two scapulae, the test was considered positive [18].

The intratester reliability (remeasurement was carried out one day after the initial measurement) was 0.98 (intraclass correlation coefficient) with a confidence interval of 95% (0.98-1.00) and standard error of measurement (SEM) of 0.85 mm. Moreover, the intertester reliability was 0.81 (ICC) with 95% interval confidence (0.58-0.92). Accordingly, the standard measurement error was 4.7 mm.

The scapulothoracic muscles activity, which included the UT, LT, and SA, was recorded during shoulder abduction in the scapular plane (30° anterior to the frontal plane). The arm abduction test was performed within 2 seconds (concentric phase) and repeated three times with 30-second intervals between repetitions (Figure 1). The movement rhythm was controlled by a metronome with 60 beats per minute. The abduction was performed on a wooden plane in standing position with the elbow extended and the thumb upward [15, 19].

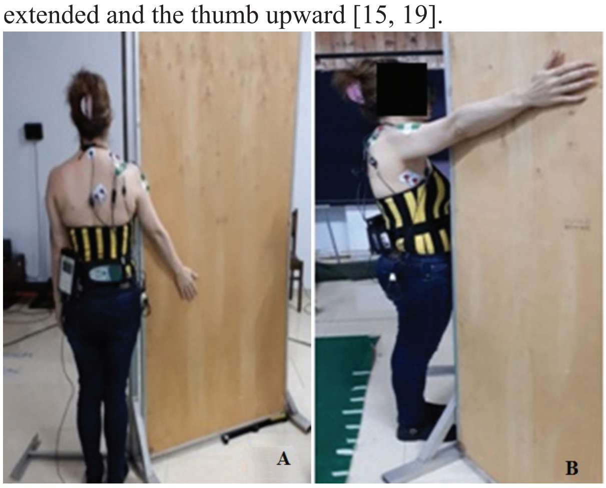

Figure 1: Abduction task procedure. A) The participant is standing next to the wooden plane; B) Abduction task around the scapular plane

Electromyographic activity was measured using an 8-channel electromyographic device ME6000 made by Megawin Co., Finland, with a sampling frequency of 1000 Hz and a digital band-pass filter of 10-450 Hz. Electromyographic signals were recorded using electrode surfaces made of silver/silver chloride alloy manufactured by the Austrian SkinTact Company. The distance between the centers of the two surface electrodes located on each muscle was 2 cm. The trapezius-related electrodes were set according to SENIAM instruction [16], while SA-related electrodes were set according to valid papers [15] (Figure 2). The root mean square (RMS) value of each muscle was recorded during the abduction task. The maximal voluntary isometric contraction test was used to normalize the electromyographic data [13].

A British-made biometrics electrogoniometer was used to determine the onset time of the selected muscle activity. Electromyographic and electrogoniometric data were recorded simultaneously during each abduction task. The fixed arm of the electrogoniometer was set on the scapular spine, and its moving arm was fixed on the posterolateral surface of the arm. To record the onset time of the selected muscle, the resting state and the activity of that muscle were measured at 500 milliseconds before the start of movement (abduction task) [20]. This baseline activity was regarded as a reference for determining the onset time of muscle activity. The onset time was considered to be the fastest time in which the electromyographic activity of the muscle exceeded the average resting level up to 2 standard deviation units and remained at this level for 50 milliseconds [17].

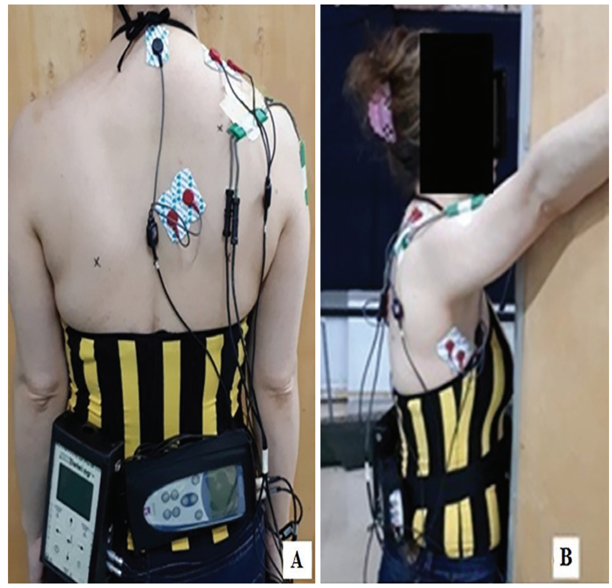

Figure 2: Installing the electrodes of the selected muscles and establishing the electromyographic system and electrogoniometer. A) Posterior view; B) lateral view

The delay in the start of muscle activity was measured through observation and compared to the start of the movement. In other words, the time interval between the start of the signal in each muscle and the start of movement determined by the electrogoniometer was considered as the onset of muscle activity [20]. The co-contraction of UT/LT and UT/SA was calculated using the following co-contraction ratio formula presented by Radolf et al. [5, 21]:

$$\frac{EMG_{Low}}{EMG_{High}} \times (EMG_{Low} + EMG_{High})$$

Where, EMG_{Low} represents normalized electromyographic data with a lower RMS, and EMG_{High} represents a muscle with a higher RMS.

The normal distribution of data was examined using the Kolmogorov-Smirnov Test. Then, given the fact that the data was not normally distributed, the Spearman correlation test was used to investigate the relationship between variables and SD. Finally, the relationships between the variables and SD were examined using the multiple regression test through SPSS 22.0. The level of statistical significance was set at $\alpha<0.05$.

Results

The normalized electromyographic activity in the abduction task is described in Table 1.

The onset of muscle activity (as compared to the start

Table 1: Normalized electromyographic activity of muscles in the concentric phase of shoulder abduction task

Variable	Muscle Activity (%MVC)
UT	39.6±5.1
LT	34.1±7.1
SA	47.5±6.7
UT/LT Co-contraction	56.9±6.4
UT/SA Co-contraction	68.5±6.8

of the electrogoniometer movement) is described in Table 2.

The results of the Spearman correlation test for selected electromyographic indices and SD are presented in Table 3.

As shown in Table 4, the correlation coefficients between all selected electromyographic indices and SD were significant ($P<0.01$). Therefore, all (independent) predictive variables of the study could be included in the regression model. A summary of the variables which represent the fit of the regression model is presented in Table 4.

According to Table 4, in the present research model which consists of 8 independent and one dependent variable, the value of the multiple correlation coefficient is 0.694, which indicates that there is a strong correlation between the set of independent variables (predictors) and the dependent variable (criterion). Additionally, the value of the adjusted correction coefficient was 0.479, suggesting that 47.9% of total changes in SD depend on the independent variables mentioned in this regression model. In other words, the set of independent variables in this study predicts nearly half of the cases of SD.

Changes in SD caused by the independent variables of the model (regression changes) and other factors originating from outside the model (residual changes) are shown in Table 5.

Table 2: Onset time of muscle as compared to the start of the electrogoniometer movement

Calculation Method	Muscle	Time (ms)
Interval between the electrogoniometer movement and muscle onset time	UT	-152.8±21.4
	LT	94.4±16.5
	SA	47.0±7.1

*Negative values represent the time muscle activity started earlier than the start of the electrogoniometer, while positive values represent the time muscle activity started later than the start of the electrogoniometer.

Table 3: Results of the Spearman correlation test for electromyographic indices and SD

Electromyographic Index	N	Coefficient of Correlation	P value
UT	60	0.766	0.001
LT	60	-0.729	0.003
SA	60	-0.747	0.001
UT/LT Co-contraction	60	0.805	0.001
UT/SA Co-contraction	60	0.746	0.001
UT Onset time	60	-0.843	0.002
LT Onset time	60	0.850	0.002
SA Onset time	60	0.835	0.001

Table 4: Summary of variables which represent the fit of the regression model

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	0.694	0.481	0.479	3.21473

Predictor Variable: UT/SA Co-contraction, UT/LT Co-contraction, LT Onset Time, LT Activity, SA Onset Time, UT Activity, UT Onset Time, SA Activity; Criterion Variable: Scapular Dyskinesis

Table 5: Results of ANOVA analysis for changes in SD due to independent variables and other factors

Model	Sum of squares	DF	Mean square	F	Sig.
Regression	39482.907	8	4935.3633	4.392	0.001
Residual	30294.318	51	594.0062		
Total	69777.225	59			

Predictor Variable: UT/SA Co-contraction, UT/LT Co-contraction, LT Onset Time, LT Activity, SA Onset Time, UT Activity, UT Onset Time, SA Activity; Criterion Variable: Scapular Dyskinesis

Table 6: Regression coefficients to determine the effect of predictive variables on criterion variables (SD)

Predictor Variable	Unstandardized coefficients	Standardized coefficients	T	P
UT activity	0.478	0.395	12.586	0.003
LT activity	0.612	0.604	16.902	0.002
SA activity	0.237	0.203	10.341	0.002
UT/LT Co-contraction	0.716	0.593	13.719	0.001
UT/SA Co-contraction	0.765	0.706	11.207	0.001
UT Onset time	0.318	0.298	17.165	0.002
LT Onset time	0.672	0.670	14.493	0.001
SA Onset time	0.576	0.364	10.811	0.003

According to Table 5, the F value (4.392) is significant (P=0.001), and the sum of the remaining squares is less than the sum of the regression squares. This result indicates the high explanatory power of the model in explaining the dependent variable changes (SD); therefore, it can be concluded that the regression model consists of 8 independent and one dependent variable and can be considered as an appropriate model. Accordingly, a set of independent variables can predict the changes in SD.

The multivariate linear regression coefficients (See Table 6) were used to determine the regression effect of each variable in the model. According to this table, the effect of all predictive variables on SD is statistically significant (P=0.001).

Discussion

Activity and Co-contraction of the Scapulothoracic Muscles

According to the results, UT activity is positively associated with SD, while LT and SA activities are negatively associated with SD. In other words, the rate of SD was greater in patients with higher UT activity and lower SA activity. Furthermore, there was a positive correlation between UT/LT co-contraction and UT/SA co-contraction and SD, which indicates that those with higher UT/LT and UT/SA co-contractions had a higher rate of SD.

The dominant shoulder in overhead athletes is exposed to large loads due to repetitive throwing tasks at angles greater than 90 degrees, and this can lead to changes in the electromyographic activation of the muscles as well as scapular kinematic changes [22].

The UT is known as the prime mover. Increased activation of the UT occurs during elevation of the clavicle and anterior scapular tilting. This is a compensatory strategy in people with SD attempting to elevate the arm [16]. The increased activation of the UT has been confirmed in many studies, including Lopes et al. (2015) [22], Cools et al. (2007) [13] and (2003) [20], Chester et al. (2010) [23], and Ludewig et al. (2000) [7]. According to Lopes et al. (2015), who investigated the relationship between the scapular muscle activity and kinematics, UT muscle activity was significantly greater (12%) in subjects with SD than in people without SD. Additionally, in people with SD, the external rotation of the scapula during concentric and eccentric phases was respectively 1.2 and 2.5 degrees, while shoulder flexion was less than that of the control group. The authors concluded that in SIS patients with SD, the muscle activity and kinematics of the scapula undergo alterations, and these alterations are associated with SD [22].

Janda categorized the UT as tonic muscles and the SA and LT as phasic muscles. The characteristics of the tonic muscle system emphasize the tendency to increased activity, tightness, shortness and the characteristics of the phasic muscle system represent weakness, decreased activity, inhibition, latency in activation [24]; thus, the increased activity of the UT and decreased activity of the SA and LT can be explained. Moreover, with regard to the reciprocal inhibition mechanism, it should be pointed out that the increased activity of the UT inhibits the antagonistic muscle, i.e. LT and SA. On the other hand, the LT and SA are susceptible to inhibition. Therefore, it can be predicted that the increased activity of the UT will result in weakness and decrease the activity of the LT and SA. Janda believed that the hyperactive muscle inhibits its antagonistic muscle in a reflexive way. This leads to muscular imbalance [24]. By applying unbalanced forces, muscular imbalance changes the scapular kinematics and leads to SD [16].

As regards the UT with the LT or SA causing a couple force in the scapular upward rotation during the shoulder abduction, both play significant roles in maintaining the normal scapular position as well as the scapulohumeral rhythm [10]. Therefore, the increased activity of the UT may result from an attempt to control the movement and help the arm elevation [7, 13, 23]. Moreover, the decreased activity and strength of the LT and SA cause muscular imbalance and subsequently lead to an imbalance of the couple forces, consequently leading to the occurrence of SD [10]. The SA plays a key role in the stability of the medial border of the scapula on the thorax and provides the dynamic stability of the scapulothoracic muscles; thus, disturbances in the activity of this muscle can cause abnormal positioning and movement of the scapula [20].

The results of the present study are in good agreement with those of studies that investigated the relationship between kinematic alteration of the scapula and muscle activity in people with SIS [1, 7, 9, 10, 13]. By studying a group of healthy overhead athletes and a group with SIS and SD, Cools et al. and Oliveira et al. found that UT activity as well as UT/LT and UT/SA co-contraction are higher in the group with SIS and SD [13, 16]. Huang et al. (2017) declared that the activity of the muscles and the scapular kinematics are dependent on the type of SD. The results of studies focusing on overhead athletes who were divided into three groups in terms of pattern and type of SD (inferior angle prominence, medial border prominence, and the combination of both) detected that the first and second patterns of SD account for 41.4% and 42.6% of the total changes in SD, respectively. The main characteristic of the first pattern was contraction of the MT and LT, while the contraction of the UT, MT, and SA was seen in the second pattern [25]. These studies confirm the results of the present study and emphasize the relationship between scapulothoracic muscle activity and the position of the scapula.

Onset time of Scapulothoracic Muscles

The results indicated a significant latency in the activation of the SA and LT, which was positively associated with SD. In other words, the rate of SD was greater in patients in whom the SA and LT activated later than the movement (abduction task).The results also indicated that the delayed activity of the UT was negatively correlated with SD; in other words, the rate of SD was greater in patients with earlier-activated UT.

Based on the results, it can be concluded that the special order of the activation of the SA, UT, and LT in a coordinated and proportional manner leads to the upward rotation of the scapula, maintaining the position and normal movement of the scapula as well as the scapulohumeral rhythm, which requires the proper and timely activation of the muscles involved in the upward rotation of the scapula [10, 11]. Changes in the scapular muscle recruitment pattern and coordination of the scapulothoracic muscles lead to SD [9] and shoulder injuries [4]. This altered scapular muscle recruitment pattern is common in patients with SD [1].

The early UT onset time (before the beginning of movement) may be the result of an attempt to control the abnormal scapular abduction. Whereas the SA plays a role in providing dynamic stability to the scapula [4], the delayed activation of the SA can lead to SD and disturb the scapulohumeral rhythm [10].

It should be noted that few studies have considered the delayed activation of scapulothoracic muscles in asymptomatic athletes with SD. The results of the current study are in good agreement with those of Cools et al. The researchers found that there was a significant difference between overhead athletes with SIS and healthy overhead athletes regarding the delayed onset of muscle activity. It was observed that the activation of the MT and LT muscles was more delayed in athletes with SIS, and the athletes with SIS also had an abnormal timing pattern in their trapezius muscles. This result confirms the relationship between SIS and the delayed activity of the MT and LT muscles [20].

The results of the current study agree with those of studies that investigated the relationship between SD and the onset of muscle activation in people with SIS. In a review study, Chester et al. (2010) found that the delayed onset of the LT activation and an increase in the UT activation in people with SIS is highly prevalent [23]. Moraes et al. reported similar scapular muscle recruitment patterns for people with SIS and the control group. However, in the group of patients, the delay in scapular muscle activation was reported to be higher in patients than in those with healthy scapular muscles [14].

The early onset of UT activation seems to play an important role in the abnormal scapular position and movement on the thorax [1]. In addition, the delayed onset time of the SA [11] and LT [10] leads to a decrease in the upward rotation of the scapula and abnormal scapular kinematics [1].

The results also indicated a strong correlation between the set of predictive variables and the dependent variable (SD) (0.694). In addition, according to the results, almost half of the total changes in SD (47.9%) depended on the predictive variables mentioned in this regression model. In terms of predictive power, the variables of UT/SA co-contraction, UT/LT co-contraction, LT onset time, LT activity, SA onset time, UT activity, UT onset time, and SA activity had the highest regression effects on SD, successively. The analysis of the present research model demonstrated the high explanatory power of the model, which was able to explain the changes in SD; therefore, it can be concluded that the electromyographic indices of the scapulothoracic muscles can predict changes in SD.

Conclusion

According to the results and the presence of an imbalance in the scapulothoracic muscles of athletes with SD, overhead athletes should be monitored and periodically screened by coaches, physiotherapists, and physicians for SD. Prospective studies are needed to examine the relationship between the prediction of other relevant variables, including three-dimensional scapular movement, strength and glenohumeral rotation range of motion, and the length of the pectoralis minor muscle, and SD.

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