



Electromyographic analysis of shoulder girdle muscle activation while performing a forehand topspin in elite table tennis athletes with and without shoulder impingement syndrome

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Background: Shoulder impingement syndrome is considered to be associated with an altered muscular activity, which is related to strategy changes in the movement plan. The present study aimed to investigate the differences in timing and intensity of activity of shoulder girdle muscles while performing a forehand topspin loop between elite table tennis players with and without shoulder impingement syndrome. The timing and activity amplitude of these shoulder girdle muscles have not been evaluated in other studies in table tennis elite athletes.

Methods: Activation timing and activity levels of the upper trapezius, lower trapezius, and serratus anterior, anterior deltoid, supraspinatus, and biceps brachii muscles were measured in 30 table tennis players (Premier League tournament level or higher) with shoulder impingement syndrome and compared with 30 same-level healthy players while performing the forehand topspin loop.

Results: The results indicated that the activity levels of the serratus anterior ($P = .007$) and supraspinatus ($P = .001$) muscles significantly decreased; however, the activity level of the upper trapezius significantly increased in the impingement compared with the healthy group ($P = .009$). The serratus anterior ($P = .001$) was activated significantly later, but the upper trapezius ($P = .004$) was activated significantly earlier in the impingement group.

Conclusion: Results of the present study support the theory that the activation and sequence of recruiting of the shoulder muscles are altered in people with impingement symptoms, suggesting that impingement syndrome may be associated with disturbed timing and activity level of shoulder girdle muscles.

Level of evidence: Basic Science Study; Electromyography

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Keywords: Shoulder impingement syndrome; electromyography; table tennis; forehand topspin; muscle recruitment timing; muscle activation

This study is based on a part of the information obtained from the PhD thesis of Nazanin Meghdadi, which has been approved by the Ethical Committee of the Physical Education Research Center in Tehran under the license number: IR.SSRI.REC.1396.194.

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Shoulder pain is probably the most common upper extremity problem of overhead athletes.¹ Researchers have indicated that shoulder impingement syndrome is the most common cause of shoulder pain being very common among athletes whose upper extremities frequently work above the shoulder level for long periods like racket sports, volleyball players, swimmers, and throwing athletes.^{1,2,11} These athletes, specifically if they are competitive elite athletes, need full and unlimited upper extremity function to perform optimally in their sport. Numerous researchers reported that impingement in overhead athletes is often related to glenohumeral functional instability that is known as secondary impingement and termed by some as “functional instability.”^{14,25} Therefore, considering the high mobility of the shoulder joint in competitive elite overhead athletes, if the functional stability of the joint is decreased, it may lead to microtrauma and eventually to secondary impingement.^{1,6}

It is well accepted that the scapula plays a key role in natural shoulder kinematics.^{7,29} Many researchers believe that alteration of function in 1 or more shoulder girdle muscles may lead to its abnormal kinematics. Muscular balance in force couples around the shoulder girdle and the correct sequence of recruitment timing (onset and offset) of scapular and rotator cuff muscle activity are important factors in functional stability of the scapulothoracic and glenohumeral joint as well as coordinated movement of the shoulder joint with the elevation of the arm.^{7,31,40}

In table tennis, the shoulder has been reported as the most vulnerable anatomical region, and shoulder injuries are more common in this sport than in other racket sports, such as tennis and badminton.¹ Forehand topspin loop places high demands on the shoulder of high-level table tennis athletes, and it requires large range of motion of the glenohumeral and scapulothoracic joint and produces large forces on the joint.^{16,32} Professional players focus on attack and most players who are participating in international competitions use the forehand topspin loop to create high spin and speeds on the ball. Moreover, because of making the size of the ball bigger for decreasing rate of the game, the force imposed on shoulder girdle muscles of table tennis players has been increased.¹⁹

In most studies, the activity patterns of the shoulder girdle muscles have been studied in controlled clinical tasks under no load conditions, which, at most, include 25% to 30% of the maximum voluntary contraction of the muscles.^{10,11,26,35,40} Such values are small to the extent that they can be affected by the difference of intergroup power.³¹ It has been suggested to use special functional and practical field tests and tasks that are able to appropriately assess the athletic performance.⁸ As a result, it may be helpful to use an effective functional method for assessment of the upper extremity in considering preventive measures and planning conditioning and rehabilitation programs of shoulder girdle injuries.³⁴

The present study was designed to investigate the differences in muscle activation patterns, intensity and strength of muscle contraction, and timing of activation and deactivation of shoulder girdle muscles while performing a forehand topspin loop between professional table tennis athletes with and without shoulder impingement syndrome. The research hypothesis was that muscle activation timing and the intensity of activation would be different in table tennis athletes with and without shoulder impingement syndrome.

Materials and methods

Subjects

This is a prospective study of 60 male national-level table tennis players who participated in this study. All of them were assigned in top 100 list of Iran Table Tennis Federation, including all of the national team players. All subjects were professionally active in Iran Premier League, aged 20 to 28 years and with a right dominant hand. We assigned 30 players who had impingement on the dominant side of the upper extremity to the impingement syndrome group (group 1) and 30 players who were homogeneous with respect to age, height, and weight to the healthy group (group 2) (Table I). We conducted this study in compliance with the Declaration of Helsinki. The athletes voluntarily participated in the study, and each player signed an informed consent form.

All participants completed a questionnaire about their history of shoulder pain as well as their training and athletic performance history. We excluded the participants if they had a history of shoulder dislocation, shoulder surgery, occult or overt instability, current symptoms related to the cervical spine, rotator cuff tendinitis or documented structural injuries to the shoulder complex, or other current shoulder pathology. We assessed their functional ability with the modified Rowe score,⁴¹ which ranges from 0 to 100, with lower scores indicating worse function. The Rowe scores of impingement group and demographic characteristics of both groups are presented in Table I. A medical consultant referred the participants; furthermore, one of the senior authors who is also a physiotherapist evaluated them and determined the symptoms of shoulder impingement by the participant's history and a physical examination to check for signs of impingement (Neer sign, Hawkins sign, Jobe test, apprehension test, and relocation test). We included patients in the impingement group if they had at least 2 of the following 5 criteria: (1) a positive Neer sign with the reproduction of pain when the examiner passively flexed the humerus to the end range with overpressure; (2) a positive Hawkins sign with a reproduction of pain when the shoulder was passively placed in 90° of forward flexion and internally rotated to the end range; (3) a positive Jobe's sign with a reproduction of pain and a lack of force production with isometric elevation in the scapular plane in internal rotation (the empty can test); (4) pain without apprehension with a reproduction of pain when an anteriorly directed force was applied to the proximal humerus in the position of 90° of abduction and 90° of external rotation; and (5) a positive relocation with a reduction of pain after a positive apprehension test when a posteriorly directed force was applied to the proximal humerus in the position of 90° of abduction and 90°

Table I Descriptive statistics (means and standard deviation) of the demographic data

	Healthy (n = 30)	Impingement (n = 30)	P value
Age (yr)	24 (2.59)	25 (2.29)	.333
Height (cm)	176 (7.81)	174 (7.06)	.484
Weight (kg)	74 (5.82)	75 (5.50)	.329
Experience (yr)	5 (2.11)	6 (1.97)	.173
Duration of shoulder pain (mo)	–	12 (5.54)	–
Rowe score	–	73.66 (12.86)	–

of external rotation. It was thought that patients with minor instability and secondary impingement would experience pain but not apprehension during these tests.

Study protocol

This study evaluated muscle activation using surface electromyographic (EMG) electrodes during the entire forehand topspin loop and determined onset and offset of the activations relative to the ball impact (T_0). Activations before T_0 are negative numbers, whereas those after T_0 are positive numbers. Before the electrode application, we prepared the skin with alcohol to reduce skin impedance (typically $<10\text{ k}\Omega$) and then placed the surface electrodes (Ag/AgCl; Skintact, Austria) with a 2-cm interelectrode distance over the upper and lower portions of the trapezius, the anterior section of the deltoid, serratus anterior, biceps brachii, and supraspinatus muscles.⁵ Electrodes for the upper trapezius were placed midway between the spinous process of the seventh cervical vertebra and the posterior tip of the acromion process along the line of the trapezius muscle. The lower trapezius muscle electrodes were placed obliquely upward and laterally along a line between the intersection of the spine of the scapula with the vertebral border of the scapula and the seventh thoracic spinous process. The biceps brachii electrodes were placed over the belly of the muscle approximately midway between the axillary fold and the midpoint of the cubital fossa. For the anterior deltoid, the electrodes were placed approximately 4 cm below the clavicle parallel to the muscle fibers on the anterior aspect of the arm. The serratus anterior electrodes were placed parallel to the muscle fibers, below the axilla, anterior to the latissimus dorsi, and posterior to the pectoralis major. The supraspinatus electrodes were placed above the spine of the scapula and over the supraspinatus fossa.

We collected surface EMG signals on each participant using the Muscle Tester ME6000 (Mega Electronics Ltd., Kuopio, Finland). This is an 8-channel portable microcomputer with an 8-channel A/D conversion (14-bit resolution), a Common Mode Rejection Ratio of 110 dB, and a band-pass filter of 20-500 Hz. The sampling frequency was programmed at 1000 Hz. We transferred the EMG signals online to a compatible computer and monitored them by the Megawin 3 program (Mega Electronics Ltd., Kuopio, Finland), and then registered the measured data using state-of-the-art amplification technology in which the amplifier was connected directly to the grounding electrode. This effectively eliminated any disturbances, such as those caused by movements.

In this study, to record the time of contact of the ball with the racket as a frame of reference for the assessment of the timing of



Figure 1 Special racket: a specially designed table tennis racket that was synchronized with the electromyography device.

muscle activity, we designed a special table tennis racket that was synchronized with the electromyography device. The body of the racket was exactly the same as table tennis racket wood, with the surface being sensitive to the contact of the ball with the surface of the racket (Fig. 1). The signal and EMG data from the muscles were stored in Megawin software.

To perform the test, we first determined the electrode locations in the shoulder area of the right side. We marked the electrode locations on the upper trapezius, lower trapezius, supraspinatus, serratus anterior, anterior deltoid, and biceps brachii muscles. Then we placed the electrodes over the belly of the muscles parallel to the muscle fibers and confirmed the appropriate placements of the electrodes using isolated isometric contractions of the muscles. After confirmation of these procedures, we recorded EMG activities of the muscles while performing the table tennis forehand topspin loop diagonally on the table (Figs. 2 and 3). To make the test conditions more similar to real table tennis conditions and make sure that the conditions were similar for all subjects, we installed a ball launcher device (TTmatic 505 Table Tennis Robot, Germany) on the table tennis table and adjusted the speed, spin, and launch angle of the ball similarly for all participants. The participant's distance from the table was all the same, but the position of the legs and type of guard were adjusted by considering the participant's preference and habits. Furthermore, to perform the technique, we asked the participant to hit with his typical technique. After warming up for 4 to 5 minutes by performing active movements as well as 10 to 15 strokes to get acquainted with the test and rate of ball launch, each participant completed 5 phases of the test with the EMG activity being simultaneously recorded by the Megawin software. Each



Figure 2 Performing the table tennis forehand topspin loop diagonally on the table: starting point.

participant rested for 1 minute before the next phase. To prevent the displacement of the electrodes and movement of the cables on the skin due to the movement performed, we secured the cables on the skin by antiallergic paper tape (Fig. 4). Ultimately, for each participant, we used the 3 best of 5 recorded attempts for further analysis.²⁰

Signal processing and statistical analysis

To analyze the EMG data, we used MATLAB software (MATLAB R2012a; TheMathWorks Inc., Natick, MA, USA). Quiet files were collected for each muscle in an interval of 200 milliseconds before the onset of movement when the muscles were relaxed, to establish the baseline from which muscle activity was determined. To determine the onset and offset of the muscles, each muscle was considered “on” when its amplitude was 3 standard deviation (SD) points above the baseline signal for a 25-millisecond window. Each muscle was considered to be “off” when the amplitude dropped below 3 SD points above the baseline signal.

To study the activity intensity of the muscles, after applying a low-pass digital filter with a cutoff frequency of 0.1 on the signal, we normalized the data by root mean square analysis in the subsequent 25-millisecond segments of the movement cycle. To compare the results of various muscles and participants, we normalized root mean square signals proportionate to the maximum activity observed while attempting the maneuver.⁴ Then, to study the pattern of activation of the muscles,



Figure 3 Performing the table tennis forehand topspin loop diagonally on the table: ending point.

we observed the time of contact of the ball with the racket and then calculated the timing and sequence of activation and deactivation of the muscles with respect to the time of ball contact.

To examine normally distributed data, we used Shapiro-Wilk tests. We performed intergroup comparisons using independent *t*-tests with the significance level at $\alpha < 0.05$, performing statistical analysis using SPSS, version 20 (IBM, Armonk, NY, USA).

Results

Demographic data of the participants, the activation and deactivation times, and the levels of activity of the selected shoulder girdle muscles from the 2 groups for table tennis forehand topspin tests are presented in Tables I, II, and III, respectively. The results indicated that the levels of activity of the serratus anterior ($P = .007$) and supraspinatus ($P = .001$) muscles significantly decreased in the impingement group compared with the healthy group, and the level of activity of the upper trapezius significantly increased in the impingement group compared with the healthy group ($P = .009$). There were no significant differences in the activity levels of the lower trapezius ($P = .301$), anterior deltoid ($P = .314$), and biceps brachii ($P = .291$) between the 2 groups. Furthermore, the independent *t*-test results indicated that there was a significant difference in time of activation of the serratus anterior ($P = .001$) and upper



Figure 4 Placement of the electrodes and preventing the movement of the cables on the skin due to the movement performed by anti-allergic paper tape.

trapezius ($P = .004$) muscles between the 2 groups. The serratus anterior muscle was activated significantly later, but the upper trapezius was activated significantly earlier in the experimental group compared with the healthy group. There was no significant difference in time of activation of the lower trapezius ($P = .807$), anterior deltoid ($P = .713$), supraspinatus ($P = .146$), and biceps brachii ($P = .269$) muscles between the 2 groups. Also, there was no significant difference in the deactivation time of all muscles.

Discussion

The present study was designed to investigate the differences in patterns and levels of activity and activation and deactivation timing of shoulder girdle muscles while performing a forehand topspin task between elite table tennis players with shoulder impingement syndrome and healthy players. Our findings indicated that there were significant differences in the activity levels of the serratus anterior, upper trapezius, and supraspinatus muscles between the healthy and impingement groups. The activity levels of the serratus anterior and supraspinatus muscles significantly decreased in the impingement group compared with the healthy group, and the activity level of the upper trapezius muscle significantly increased in the impingement group compared with the healthy group. Furthermore, no significant differences were found in the

activity levels of the lower trapezius, anterior deltoid, and biceps brachii muscles between the 2 groups. Consistent with these findings, Lin et al²² studied the activity level of shoulder girdle muscles with an elevation of the upper extremity in the scapular plane and its relationship with the kinematics of the scapula in baseball players with shoulder impingement syndrome and healthy controls with exercise comprising overhead activities. They reported an increased activity level in the upper trapezius and a significant decrease in the activity level of the serratus anterior muscle, consistent with the present study. In contrast, 3 studies conducted by de Moraes Faria et al,¹² Bandholm et al,³ and Larsen et al²¹ found no differences in muscular activity levels between healthy and experimental subjects, findings that are not consistent with the results of the present study.

To study the activity levels of muscles, different methodologies and tasks have been used. For example, in a study conducted by Bandholm et al, the subject was in a sitting position, with the trunk totally fixed by a strap and the arm placed on the lever of an isokinetic device, which significantly decreases the proximal to distal muscular activity.³ In addition, in most studies, controlled clinical tasks, such as elevation at the scapular plane or abduction and adduction, were used to assess the activity level of the muscles.^{3,12,21,22} However, a specific functional athletic task customized with the conditions of table tennis was used in the current study. For this purpose, the authors believe that the EMG range of the muscles depends on the length, force, and rate of contraction of the muscles.³⁶ Therefore, the task used for assessing the activity level of the shoulder girdle muscles may account for the differences between the results of the present study and those of other studies.

Scapulothoracic muscles maintain the scapula in a stabilized position for the attachment of muscles to enable the head of the humerus to begin elevation of the extremity,⁷ and activity of the muscles stabilizing the scapula is vital for the promotion of the mechanical efficiency of the joint.¹³ A change in activity of the muscles attached to the scapula has been confirmed as a factor causing pain in the subacromial area of the shoulder.²³ Hence, the decreased activity of the serratus anterior muscle potentially results in an abnormal movement of the scapula, thereby being a key element in impingement syndrome.²³ On the other hand, impingement syndrome often involves the supraspinatus tendon, which results in a disturbance of the natural function of the supraspinatus muscle in its force couple with the deltoid muscle, leading to an abnormal movement of the head of the humerus while performing arm movements.³⁹ According to the results of the present study, a significant difference was also found in the activity levels of both the serratus anterior and supraspinatus muscles in the impingement group in the forehand topspin task, which can affect the kinematics

Table II Muscle onset and offset

	Group	Mean (SD) onset (ms)	<i>P</i> value	<i>t</i>	Mean (SD) offset (ms)	<i>P</i> value	<i>t</i>
Supraspinatus	Healthy	-348.70 (37.53)	.146	1.49	447.06 (49.36)	.354	-0.94
	Impingement	-370.48 (42.18)			466.88 (64.85)		
Upper trapezius	Healthy	-402.81 (32.35)	.004	3.15	419.55 (62.27)	.331	-0.99
	Impingement	-448.58 (45.78)			444.17 (73.53)		
Lower trapezius	Healthy	-384.12 (31.09)	.807	0.24	433.13 (54.34)	.360	-0.93
	Impingement	-386.93 (31.02)			454.70 (71.55)		
Serratus anterior	Healthy	-466.99 (36.73)	.001	-3.92	402.44 (54.66)	.323	1.01
	Impingement	-413.84 (37.39)			385.99 (31.20)		
Biceps brachii	Healthy	-361.75 (33.11)	.269	1.27	377.90 (38.96)	.444	0.77
	Impingement	-379.35 (50.58)			367.99 (30.40)		
Anterior deltoid	Healthy	-461.08 (42.21)	.713	-0.37	387.48 (44.88)	.700	0.38
	Impingement	-455.75 (36.17)			382.22 (27.04)		

SD, standard deviation.

Table III Muscle level of activity

	Group	Mean (SD) muscular activity	<i>P</i> value	<i>t</i>
Supraspinatus	Healthy	41.9 (6.9)	.001	4.042
	Impingement	32.4 (5.9)		
Upper trapezius	Healthy	31.7 (7.7)	.009	-2.829
	Impingement	40.7 (9.5)		
Lower trapezius	Healthy	39.2 (6.3)	.301	1.053
	Impingement	37 (5.0)		
Serratus anterior	Healthy	42.1 (8.9)	.007	2.929
	Impingement	34.4 (4.9)		
Biceps brachii	Healthy	35.4 (3.2)	.291	-1.077
	Impingement	37.4 (6.4)		
Anterior deltoid	Healthy	38.1 (1.8)	.314	-1.026
	Impingement	38.9 (2.1)		

SD, standard deviation.

of the scapula while performing this task and disturb shoulder girdle functions, leading to increased symptoms.

Previous authors have indicated that subacromial swelling is associated with a defect in the sensorimotor system. The changes seen in electrical activity of the shoulder muscles of experimental subjects, as compared with healthy subjects, may result from decreased proprioception of the joint pursuant to pain. The authors believe that increased afferent signals sent by pain receptors around the shoulder decrease proprioceptive efferent signals. Likewise, Michener et al²⁷ reported decreased kinesthesia in patients with shoulder impingement syndrome. Neural proprioceptive feedbacks are transferred to the central nervous system and interact with the somatosensory, vestibular, and visual systems, which finally control dynamic components around the shoulder joint (neuromuscular control). The sense of force (ie, the sense of perception and interpretation of the

forces produced and/or applied to the joint) is one component of proprioception.³³ Because of damage to this sense, patients may face problems in accommodating the force required for performing functional activities and activate muscles more and/or less than the required force. Increased activity of the upper trapezius has been accepted by most authors as the outcome of general shoulder pain.^{17,23,30,42} In the present study, the activity level of this muscle increased in the experimental group. Previous studies also indicate that patients with shoulder pain have more upward rotation of the scapula than in healthy groups. It seems that the activity of the upper trapezius increases for the same reason (ie, excessive upward rotation of the scapula).⁴² Furthermore, the findings of the present study indicated that there was a significant difference in the time of activation of the serratus anterior and upper trapezius muscles between the healthy and experimental groups. The serratus anterior and upper trapezius muscles were activated significantly

later and sooner, respectively, in the experimental group compared with the healthy group. Furthermore, no significant differences were found in the activation times of the lower trapezius, anterior deltoid, supraspinatus, and biceps brachii muscles, or in the time of deactivation of all selected muscles between the 2 groups. For this purpose, Wadsworth and Bullock-Saxton assessed the delay in activation of muscles in healthy and injured swimmers. In injured swimmers, the upper trapezius was activated before movement, and there was a significant difference in the time of activation of this muscle between healthy and injured subjects.⁴⁰ In contrast, 2 studies conducted by Cools et al.¹¹ and Moraes et al.²⁸ found no significant difference in the time of activation of the upper trapezius muscle between healthy and patient groups.

To calculate the recruitment time of the muscles, different methods have been used. For example, Wadsworth and Bullock-Saxton considered the time of activation of the muscle as the point where the EMG signal reached above 5% of the maximum range,⁴⁰ whereas Cools suggested 10% of the maximum range as the threshold.¹¹ In fact, in these 2 studies, the time of activation of the muscle was expressed in comparison with the maximum range of the signal. Unlike these studies, Moraes et al.²⁸ defined the time of activation of the muscle as a point where the EMG signal exceeds the baseline by 2 SD. In the present study, the time of activation of the muscle was defined as a point where the EMG signal exceeds the mean baseline by 3 SD. Thus, part of the differences in the time of activation of muscle in various studies may be attributed to the different methodologies used.

The pattern of activation of muscles in the healthy group while performing a forehand topspin was as follows: serratus anterior, anterior deltoid, upper trapezius, lower trapezius, biceps brachii, and supraspinatus, which was the expected sequence when the specific functions of these muscles were considered. Numerous researchers have indicated that the serratus anterior is one of the most important stabilizers of the scapula in flexion of the arm.^{17,27,37,40} The upper fibers of the trapezius then create a force couple to initially stabilize the scapula and elevate the acromion.²⁴ The activity of the lower fibers of the trapezius occurs later to complete the stabilization of the scapula and elevation of the acromion. The concentric activity of the lower fibers of the trapezius is necessary to provide a stable surface for the activity of the rotator cuff muscles.¹⁵

In contrast to the healthy group, the pattern of activation of the selected muscles in the impingement group exhibited changes. The pattern was as follows: anterior deltoid, upper trapezius, serratus anterior, lower trapezius, biceps brachii, and supraspinatus, with the upper fibers of the trapezius being activated significantly sooner than in the healthy group. This early activation of the upper trapezius is consistent with the results of recent studies,

indicating a higher activity range in the upper fibers of the trapezius.²³ People with impingement syndrome are likely to use a different movement strategy, which is related to the upper fibers of the trapezius for elevation of the acromion while elevating the arm.^{30,31} Consistently, Phadke and Ludewig³¹ reported a change in the pattern of activity in the experimental group, but Moraes et al.²⁸ and Santos et al.³⁵ found no change in the pattern of activity of shoulder girdle muscles in the experimental group.

Although no significant difference was found in the deactivation of the muscles between the 2 groups, the results of the present study indicated an early deactivation of the serratus anterior muscle in the experimental group, which is consistent with the findings of recent clinical studies. This disorder is known to be related to scapular dyskinesia in people with shoulder impingement syndrome in the arm lowering phase.³¹ The serratus anterior is one of the most important muscles moving and controlling the scapula,^{7,30} and its early deactivation while lowering the arm results in a disturbance in scapulothoracic movement and rhythm. The lack of a normal posterior tilt and upward rotation of the scapula by the serratus anterior may cause a change in kinematics of the scapula and, consequently, more impingement of the rotator cuff tendons.³¹

The relationship between problems of the shoulder and scapulothoracic joints has been studied by many authors who have suggested that an inappropriate position of the scapula and an abnormal function of shoulder girdle muscles are present in patients with subacromial swelling and/or other shoulder problems.^{13,17,18,23,30,38} Some authors have suggested that either an inappropriate position of the scapula or a muscular malfunction increases the risk of developing subacromial swelling.^{17,30} Therefore, a malfunction of the shoulder muscles is considered the initial factor of an injury, but other authors have suggested that, because of painful situations, the functions of the shoulder muscles are disturbed and, consequently, they consider it as a subsequent factor.⁹ One possible reason for the difference between the results of the present study and those of former studies is the difference in movement tasks. In addition, different muscles under different conditions, loads, and rates have been studied in various studies, all of which can affect the results.

Limitations

Exact measurement of muscle onset, offset, and intensity of activation can be technically difficult due to muscle “cross-talk,” impure “EMG” signal. Moreover, differences in arm position and speed of the movement could be one of the reasons of intrasubject variation. Despite the highly skillful level of players, nobody performs the same technique exactly the same as others.

Future research suggestion

In this study, all of the subjects were males. There can be a different activation pattern and intensity in females. It is suggested that this case gets further investigated.

Conclusion

Considering the results of this study, it can be concluded that a recruitment timing of movement control and the extent of activity of the shoulder girdle muscles are altered in people with shoulder impingement syndrome. On the other hand, considering the differences between the results of this study and previous studies that used controlled tasks with no extra load, changes in movement patterns may depend on the type of activity and the extent and rate of the task performed.^{31,36} In general, the results of the present study support the theory that shoulder muscles experience dysfunction in people with impingement symptoms, suggesting that impingement syndrome may be related to the alterations in muscular activity and temporal recruitment of the scapulothoracic and glenohumeral muscles and may have implications for the preventive, conditioning, and rehabilitation programs designed by experts for table tennis athletes.

Acknowledgments

Thanks to the officials of the Islamic Republic of Iran Table Tennis Federation, especially the President (Mr. Mehrdad Ali Ghardashi) and the General Secretary (Mr. Mahmood Nazari); National Olympic and Paralympic Academy of the Islamic Republic of Iran (all the procedures of data collection took place at the laboratory of this academy); the National Table Tennis Players who collaborated in this study; and a very special thanks to the Captain of the team (Mr. Afshin Noroozi) whose assistance and cooperation helped the researchers to a great extent, and a group of the students of the University of Tehran and Bu-Ali Sina who also assisted and cooperated in this team work.

Disclaimer

The authors, their immediate families, and any research foundations with which they are affiliated have not received any financial payments or other benefits from any commercial entity related to the subject of this article.

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