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Rotator cuff tendinopathy alters the muscle activity onset and kinematics of scapula

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Abstract

Athletes with rotator cuff (RC) tendinopathy demonstrate an aberrant pattern of scapular motion which might relate to deficits in the scapular muscles. This study aimed to determine whether alteration in scapular kinematics is associated with deficits in the activity onset of scapular muscles. Forty-three male volleyball players (17 asymptomatic and 26 with RC tendinopathy) joined the study. Three-dimensional scapular kinematics was quantified using an acromial marker cluster method. The activity onset of the upper (UT), middle (MT), and lower trapezius (LT), and serratus anterior (SA) during arm abduction was assessed with electromyography. Athletes with RC tendinopathy demonstrated less scapular upward rotation (6.6 ± 2.3 vs. $8.2 \pm 1.1°$, $p = 0.021$) in the early phase of shoulder abduction from 0° to 30° when compared to asymptomatic athletes. The tendinopathy group had delayed activity onset of LT (14.1 ± 31.4 ms vs. 74.4 ± 45.1 ms, $p < 0.001$) and SA (-44.9 ± 26.0 ms vs. 23.0 ± 25.2 ms, $p < 0.001$) relative to UT when compared to the asymptomatic group. In asymptomatic athletes, earlier activity onset of MT and LT relative to UT was associated with more scapular upward rotation during 0–30° of abduction ($r = 0.665$, $p = 0.021$) and 30–60° of abduction ($r = 0.680$, $p = 0.015$), respectively. Our findings showed the control of the scapular upward rotation is related to the activity onset of the scapular muscles in athletes.

Keywords

Scapular kinematics; Activity onset; Scapular muscles; Rotator cuff tendinopathy; Overhead athletes

1. Introduction

Chronic shoulder pain is the most common musculoskeletal complaint in athletes of repetitive overhead movement sports (Seitz et al., 2011), and rotator cuff (RC) tendinopathy is one of the most frequently reported overuse injuries (Hamilton and Braman, 2010, Lewis et al., 2015). RC tendinopathy is commonly referred to as “impingement syndrome”. However, the concept that the acromial irritation is the primary cause of symptoms has been challenged with improved imaging and arthroscopic techniques because the correlations between pain and structural disorders are poor (Dun et al., 2014, Lewis et al., 2015). Therefore, RC tendinopathy is a preferred term to describe pain, weakness and impaired performance related to RC tendons and associated tissues, without specifying the underlying mechanism or tendon pathology (Lewis et al., 2015).

The coordinated movement couple between the scapula and humerus is a critical component for normal shoulder function (Ludewig and Reynolds, 2009, Paine and Voight, 2013). The normal 3-dimensional kinematics pattern of the scapula during active humeral elevation is upward rotation, posterior tilting, and external rotation in relation to the thorax (McClure et al., 2006), which provides a stable base for optimal activation of the scapular and rotator cuff muscles to prevent RC compression (Kibler, 1998, Ludewig and Reynolds, 2009). Abnormal scapular kinematics has been proposed as one of the contributing factors to RC tendinopathy (Laudner et al., 2006, Ludewig and Cook, 2000, Ludewig and Reynolds, 2009), but discrepancies of scapular movements have been reported in athletes with RC tendinopathy (Laudner et al., 2006, Lin et al., 2011, Su et al., 2004). Su et al. (2004) reported that swimmers with RC tendinopathy have decreased scapular upward rotation of 45°, 90°, and 135° after a session of intense swimming practice using a static digital inclinometer. Lin et al. (2011) found a decrease in scapular posterior tilting in athletes with RC tendinopathy when compared with asymptomatic controls. Contrary to Su et al., 2004, Lin et al., 2011, Laudner et al., 2006 reported that baseball players with RC tendinopathy have significant increases in scapular posterior tilting and elevation from 30° to 120° and from 60° to 120° of abduction when compared with asymptomatic controls, and they hypothesized that this is a compensatory or adaptive pattern to avoid the humeral head coming into contact with the postero-superior portion of the glenoid during overhead motion. With only a few studies, the demographic data such as age, gender, upper extremity activity level and types of sports are largely heterogeneous. Thus, there is no consensus on the kinematics pattern of the scapula during shoulder elevation in athletes with RC tendinopathy.

Scapular muscles are important for stabilizing and controlling the scapula for proper position and normal kinematics during shoulder elevation. Synchronized activity onset of the scapular muscles is important for a smooth scapular motion during shoulder abduction in athletes of overhead sports (Cools et al., 2003, Kibler, 1998). In the literature, only one study had investigated the electromyographic (EMG) activity onset of the scapular muscles in athletes that showed delayed activation of the middle and lower trapezius when compared to healthy athletes during a sudden drop arm test (Cools et al., 2003); while other studies showed contrary results in the non-athletes group (Larsen et al., 2013, Moraes et al., 2008, Worsley et al., 2013). Alteration in the activity onset of scapular muscles during arm elevation may affect the normal kinematics in the athletes but no study has investigated the effects of changes in activity onset of scapular muscles on the scapular kinematics during shoulder abduction.

The aims of this study were to: (1) compare the scapular kinematics and EMG activity onset of the scapular muscles in athletes with and without RC tendinopathy, and (2) investigate the relationship between scapular kinematics and the activity onset of scapular muscles during dynamic shoulder abduction in athletes with and without RC tendinopathy. We hypothesized that (1) athletes with RC tendinopathy would have an altered scapular kinematics and delayed activity onset of scapular muscles during shoulder abduction, and (2) there is an association between the scapular kinematics and the activity onset of scapular muscles during shoulder abduction.

2. Methods

2.1. Participants

This study was an observational, case-control study. The dominant shoulders (or the affected side in athletes with rotator cuff tendinopathy) of forty-three male volleyball players between 18 and 35 years of age (mean age = 22.9 ± 3.5 years) were tested in this study. They were recruited from local sports clubs and universities. They had training experience of more than 3 years with at least three training sessions per week. Clinical tests and ultrasound imaging were conducted by an experienced physiotherapist (LHT) who has more than 7 years of experienced in musculoskeletal ultrasound to allocate the participants into the RC tendinopathy group or the asymptomatic group. The inclusion criteria for the RC tendinopathy group were: (1) presence of shoulder pain during training for more than three months, (2) three out of five positive tests: painful arc, pain or weakness with resisted external rotation, Neer test, Kennedy-Hawkins test and Jobe test. The intensity of pain being provoked should be ≥3/10 on a visual analogue scale (VAS), and (3) ultrasound image showed the presence of non-homogeneity in the supraspinatus tendon (Leong et al., 2016). In the asymptomatic group, participants had no shoulder pain during volleyball training, and clinical tests and ultrasound imaging showed no positive results. The exclusion criteria for all participants included frozen shoulder (25% limitation of passive shoulder motion in two or more movements), shoulder dislocation or instability (positive apprehension and relocation tests), history of shoulder fractures, shoulder surgery or clinical treatment for a shoulder injury, symptoms referred from or related to the spine, and a positive general laxity test (>5/9 Beighton Score) (Leong et al., 2016). The study was approved by the Human Subjects Ethics Sub-committee of the administrating institution, and all participants gave their written informed consent before the study. All procedures adhered to the Declaration of Helsinki.

2.2. Equipment

A Vicon v-370 3-D motion analysis system (Vicon Motion Systems, Oxford, UK) with six cameras was used to capture the upper extremity, scapular motion and trunk motion during shoulder movement (Leong et al., 2017). The Vicon system was calibrated with standard procedures, and the motion was captured at 100 Hz. Reflective markers were placed over the suprasternal notch, xiphoid process, C7 vertebra and T8 vertebra to detect the trunk motion (Wu et al., 2005), a three-marker acromion cluster was placed over the postero-lateral part of acromion to detect scapular motion (Van Andel et al., 2009), and the humeral four-marker cluster was fastened to the participant's humerus to determine the abduction angle of the shoulder.

Surface electromyography with circular Ag/AgCl bipolar electrodes (SX230, Biometrics Limited, Newport, UK) was used to measure the recruitment patterns and latencies of the upper (UT), middle (MT), and lower trapezius (LT), and serratus anterior (SA) (Leong et al., 2017). The diameter of each active electrode was 1 cm, and the center-to-center inter-electrode distance was 2 cm. The sampling rate was 1000 Hz. All raw EMG signals were amplified by a gain factor of 1000 using a single differential amplifier with an input impedance of >10,000,000 M Ohms and a common mode rejection ratio of >96 dB (Biometrics, 2012). The participant's skin surface was prepared by shaving and abrading with sandpaper and cleansed with alcohol to reduce impedance. Conductive gel was applied to the electrode, and active electrodes were attached longitudinally along the belly of the tested muscles following the recommendations of Cram (1998). The ground electrode was attached to the opposite acromial process. Prior to the actual testing, the signal quality of each muscle was verified by asking the participant to contract the muscles against resistance from the operator (Leong et al., 2017). An accelerometer (Analog Devices, ADXL335) was placed on the lateral humeral epicondyle to detect the onset of arm movement. An event-timer switch was used to generate an electrical signal to both EMG and Vicon systems simultaneously.

2.3. Testing procedure

Each participant was asked to sit upright on a stool and relax his forearm on his thigh at 0° of shoulder abduction. The resting EMG activity and kinematic data were recorded for 5 s and these formed the reference value for the determination of activity onset. The participant was then asked to abduct his shoulder from the resting position to maximum achievable range of abduction and then return to the resting position, with elbow flexed at 90° and forearm in pronation. The speed of movement followed the pace of a metronome with 2 s to raise the arm and 2 s to lower the arm back to the resting position (Leong et al., 2017, Ludewig and Cook, 2000). Once the participants familiarized to the speed of motion, the EMG activity and kinematic data were captured for each cycle of shoulder abduction. A total of five measurements were recorded and 1-min rest was allowed between each measurement.

2.4. Data reduction

The humeral and scapular kinematics during shoulder abduction were determined from the humeral cluster and acromial marker cluster with respect to the thorax using the recommended Euler angles of rotation of The International Society of Biomechanics (ISB) (Wu et al., 2005). Customized software within LabView Instrument 8.6 (National Instruments Corporate, Austin, Tx, USA) was used for data reduction (Fig 1). The change in scapular upward/downward rotation, anterior/posterior tilt and internal/external rotation were calculated with respect to shoulder abduction angles from 0° to 30°, 30° to 60° and 60° to 90° (Leong et al., 2017). The change in scapular rotation above 90° of abduction may induce measurement error and was not calculated (Van Andel et al., 2009). The averaged values of the five measurements were calculated for analysis. The test-retest reliability of the scapular kinematics measurements was assessed with 13 healthy individuals in our previous study and has been shown to be good to excellent (Intraclass correlation coefficient (ICC) ranged between 0.71 and 0.90) (Leong et al., 2017). The minimal detectable change (MDC = 1.96 × SEM ×) was calculated for upward/downward rotation during shoulder abduction from 0° to 30° = 1.4°, 30° to 60° = 3.1° and 60° to 90° = 3.7°; anterior/posterior: 0° to 30° = 1.3°, 30° to 60° = 2.8° and 60° to 90° = 3.3°; and internal/external rotation: 0° to 30° = 1.7°, 30° to 60° = 2.1°, 60° to 90° = 2.5° (Leong et al., 2017).

Electromyographic data processing was performed using LabView Instrument 8.6 (Fig 1). As proposed previously, the EMG signals were digitally full-wave rectified and low-pass filtered (Butterworth 6 Hz, 2nd order). The muscle/movement onset was automatically determined by the onset of muscle activity minus the arm movement onset (the start of tilting of the accelerometer) to provide a value in seconds before (negative value) or after (positive value) the movement onset (Leong et al., 2017). The activity onset of a muscle contraction was denoted as the earliest time that its EMG activity exceeded the mean baseline activity (EMG silence of 5 s) by two standard deviations and remained above this level for 50 ms (Moraes et al., 2008, Leong et al., 2017). Visual inspection was also carried out to verify the detected muscle/movement onset. In our pilot study, the EMG activity exceed a threshold of two standard deviations above baseline activity and remained above this level for 50 ms accurately represents the time of the onset of EMG activity. The test-retest reliability of the activity onset of scapular muscles was assessed with 13 healthy individuals in previous study and was shown to be excellent (ICC ranged between 0.89 and 0.95), and the MDC for UT = 52.1 ms, MT = 30.2 ms, LT = 29.2 ms and SA = 47.8 ms (Leong et al., 2017). In addition, the differences in activity onset of MT, LT and SA relative to UT were calculated (Larsen et al., 2013). A negative value represents initial activity onset in UT before MT, LT or SA activity, whereas a positive value represents the initial activity in MT, LT or SA (Larsen et al., 2013). The test-retest reliability of the activity onset difference was assessed in a pilot study with 13 healthy individuals and was shown to be excellent (ICC ranged between 0.84 and 0.93), and the MDC for MT relative to UT = 38.3 ms, LT relative to UT = 49.7 ms and SA relative to UT = 63.8 ms.

2.5. Statistical analysis

The statistical analyses were performed using SPSS Version 23 for Windows (SPSS Inc., Chicago, IL.). Distributions of the data consistently passed the Shapiro-Wilk normality test (all $p > 0.05$), and all values were reported as mean ± SD. An independent t-test was conducted to compare the demographic data between the two groups (asymptomatic and RC tendinopathy). Repeated measures ANOVAs were used to determine between-group difference for the change in scapular kinematics at different phases of shoulder abduction (within subject factors: phase of shoulder abduction; between-subject factor: group). When significant interaction was found, an independent t-test was used for comparing the means for each dependent measure. To compare the difference in the absolute and relative muscle activity onset between the groups, independent t-tests were conducted. The level of significance for all tests was set at 0.05. Pearson's correlation tests (r) were used to examine the relationships between scapular rotation and relative onset timing at different phases of shoulder abduction in both groups. Bonferroni adjustment was used for correlation analysis in each group, and α was set at 0.025.

3. Results

3.1. Participants

Among the 43 volleyball players, 26 reported to have pain or discomfort in the shoulder during training and clinical tests confirmed the presence of RC tendinopathy in these subjects. Demographic data are presented in Table 1. No between-group differences were found for any of the tested parameters (all $p > 0.080$).

3.2. Scapular kinematics

There was significant interaction between phase of shoulder abduction × group on scapular upward rotation ($p = 0.007$). Post-hoc analysis revealed athletes with RC tendinopathy had significantly less scapular upward rotation (6.6 ± 2.3° vs. 8.2 ± 1.1°, $p = 0.021$) in the early phase of abduction from 0° to 30° when compared to asymptomatic athletes, and the differences were greater than the MDC. No between-group difference and interaction effect was found with regard to the change in scapular posterior tilt ($p = 0.434$ and $p = 0.518$, respectively) and external rotation ($p = 0.851$ and $p = 0.205$, respectively) (Table 2).

3.3. Activity onset of scapular muscles

When comparing the activity onset of scapular muscles between the two groups (Table 2), the LT of the RC tendinopathy group was activated significantly slower compared to the asymptomatic group that was greater than the MDC (−18.5 ± 43.9 ms vs. −72.4 ± 39.0 ms, $p = 0.001$). A significant between-group differences of the activity onset of UT ($p = 0.002$) and SA ($p = 0.003$) were observed that were smaller than the MDC. No significant difference was found in the activity onset of MT between groups ($p = 0.849$). When comparing the activity onset differences of the MT, LT and SA relative to UT (Table 2), the group with RC tendinopathy had a significant delayed activity onset of LT relative to UT (14.1 ± 31.4 ms vs. 74.4 ± 45.1 ms, p <

0.001) and SA relative to UT (−44.9 ± 26.0 ms vs. 23.0 ± 25.2 ms, $p < 0.001$) when compared to asymptomatic athletes that were greater than the MDC. A significant between-group difference was observed in the activity onset of MT relative to UT that was smaller than the MDC ($p = 0.047$).

3.4. Correlation

In the asymptomatic athletes, significant positive correlations were found between the relative activity onset of scapular muscles and scapular rotations (Table 3). Earlier activity onset of MT relative to UT was associated with more scapular upward rotation during 0–30° of abduction ($r = 0.665$, $p = 0.021$), and earlier activity onset of the LT relative to the UT was associated with more scapular upward rotation from 30° to 60° of abduction ($r = 0.680$, $p = 0.015$). However, such relationships could not be detected in athletes with RC tendinopathy (Table 3).

4. Discussions

Our findings revealed less upward scapular rotation in athletes with RC tendinopathy during early abduction from 0° to 30°. Athletes in overhead sports events with RC tendinopathy demonstrated delayed activity onset of LT and SA relative to UT when compared with the asymptomatic athletes. Earlier activity onset of the MT and LT relative to the UT were associated with more scapular upward rotation during early abduction from 0° to 30° and 30° to 60°.

When comparing the change in scapular rotation at different phases of shoulder abduction, athletes with RC tendinopathy demonstrated less scapular upward rotation during early shoulder abduction from 0° to 30° than their asymptomatic counterparts (by 2°). These small changes in the scapular upward rotation between the two groups may be attributed to the differences in the sensorimotor processing or proprioceptive changes (Uri et al., 2015), and may signify some deficits in the dynamic control of the scapula in athletes with RC tendinopathy during early shoulder abduction. Our finding was similar to the study reported by Su et al. (2004) in which swimmers with RC tendinopathy were found to have a decrease in upward scapular rotation during early shoulder elevation at 45° after a session of intense swimming practice. Several studies reported the presence of a setting phase in which the scapula has little contribution in the early phase of shoulder elevation (Inman et al., 1944, Fung et al., 2001, McClure et al., 2001). However, other studies rejected such a notion (Ludewig et al., 2009, Struyf et al., 2011). Nevertheless, Myers et al. (2005) have demonstrated that athletes of overhead sports undergo adaptive changes in the scapular kinematics in their throwing shoulders to generate forces during overhead movements. They found an increase in scapular upward rotation in the throwing shoulders during arm at rest and up to 120° of arm elevation, and proposed a chronic adaptation to be present in the athletes which helps to preserve the subacromial space and prevent RC compression during the throwing motion. In our present study, athletes with RC tendinopathy demonstrated less scapular upward rotation during early shoulder abduction from 0° to 30° than the asymptomatic athletes. Decreased upward rotation was believed to result in an inability to elevate the lateral acromion to preserve the subacromial space during arm elevation (Ludewig and Reynolds, 2009). Our recent findings also showed athletes with RC tendinopathy demonstrated more reduction of the subacromial space during early shoulder abduction from 0°

to 30° (Leong et al., 2016). Based on this notion, any factors that control the early phase of shoulder abduction would be essential in providing adequate scapular rotation to prevent RC compression in the athletes.

Besides the change in scapular movement patterns, we examined the EMG activity onset of the scapular muscles in athletes with and without RC tendinopathy. Synchronized activity onset of the scapular muscles is important for a smooth scapular motion during shoulder abduction in athletes of overhead sports (Cools et al., 2003, Kibler, 1998). In asymptomatic athletes, our findings showed the MT (−19.2 ± 52.7 ms), LT (−72.4 ± 39.0 ms), and SA (−12.8 ± 16.7 ms) were activated before the onset of arm movement, and the UT (21.4 ± 38.1 ms) was activated after the onset of arm movement. In contrary to our findings, previous studies demonstrated that the UT was activated first, followed by SA, MT, and LT (Cools et al., 2003, Moraes et al., 2008). Such conflicting results may due to the different measurement methods and subject group. In the study of Cools et al. (2003), the EMG activity onset of the scapular muscles in overhead athletes were measured during sudden drop arm tests; while the study of Moraes et al. (2008) examined the EMG activity onset of the scapular muscles in the non-athletes group during arm elevation (Moraes et al., 2008). In our present study, the MT, LT and SA were activated before the UT in the asymptomatic athletes during shoulder abduction. One possible reason for the early activation of the MT, LT and SA during shoulder abduction in the athletes of upper limb sports is that the muscles stabilize the scapula and provide a stable base for the scapulohumeral muscles to generate force during arm movements. This early activation of the scapular muscles may be essential in overhead athletes that require forceful and quick actions needed in sport. When comparing the activity onset of scapular muscles between the asymptomatic group and RC tendinopathy group, our findings revealed deficits in the activity onset of scapular muscles in athletes with RC tendinopathy compared to the asymptomatic athletes. The LT was activated significantly slower in athletes with RC tendinopathy than in the asymptomatic athletes. We calculated the activity onset differences of MT, LT and SA relative to UT and found a significantly delayed activation of the LT and SA relative to UT in athletes with RC tendinopathy compared to their asymptomatic counterparts. Cools et al. (2003) also showed a delay in the MT and LT relative to the UT in athletes with RC tendinopathy when compared to asymptomatic athletes during sudden drop arm tests. In this way, when the LT and SA were activated too slowly relative to an early onset of the UT, this may lead to relative supremacy of the UT muscle (Cools et al., 2003). The consequence of this alteration may ultimately lead to abnormal coordination of scapular rotation during arm movement, and may render the athletes more vulnerable to RC tendinopathy.

Furthermore, patients with RC tendinopathy seems to behave a tight EMG activation in time, i.e. all muscles become activated at unison to stabilize the scapula (particularly UT (-19.5 ± 36.1 ms), MT (-15.9 ± 56.4 ms) and LT (-18.5 ± 43.9 ms)), which would not happen in the asymptomatic athletes group. In healthy shoulders, it is expected to see more variance in the activity onset of the scapular muscles for more adaptability during shoulder movement. In this way, patients with RC tendinopathy may implement a rather stereotype activation pattern of the scapular muscles during shoulder elevation, which has been suggested in other studies that showed patients with recurrent anterior shoulder instability may implement a preplanned stereotypical movement for the arm kinematics when compared to the healthy controls (Arzi et al., 2014, Uri et al., 2015). The idea of this activation adaptability in those with RC tendinopathy warrants further investigations.

Indeed, we found a relationship between the activity onset of scapular muscles and scapular upward rotation during early shoulder abduction in the asymptomatic athletes. Earlier activity onset of the MT and LT relative to UT was associated with more scapular upward rotation during 0–30° and 30–60° of shoulder abduction, respectively. These findings indicate that the activation of MT and LT may contribute to the control of scapular motions during early arm movement. Scapular muscles deficits have been identified in athletes with RC tendinopathy (Leong et al., 2016, Seitz et al., 2015), and was associated with alterations in scapular kinematics (Seitz et al., 2015). Seitz et al. (2015) reported LT strength deficits to be moderately associated with a lack of scapular upward rotation in athletes involved in overhead sports; and Leong et al. (2016) also showed weaker MT and LT were associated with more reduction in the SAS during early abduction from 0° to 30° and 0° to 60°. Our findings further confirm the role of MT and LT in the control of scapular motions in these athletes in the early phase of arm abduction. Whether deficits in the activity onset of scapular muscles is a causal factor in terms of the development of abnormal scapular kinematics and shoulder pain in athletes with RC tendinopathy or the other way round warrants further investigation in the form of a longitudinal study.

There are a few limitations of this study. First, we identified athletes with and without RC tendinopathy by clinical tests and ultrasound imaging. However, the clinical tests used in the diagnosis of RC tendinopathy have poor specificity, and there is a lack of correlation between symptoms and contemporary methods of imaging. Thus, athletes with RC tendinopathy were included if they had experienced shoulder pain during training for more than three months, and presented with 3 out of 5 positive clinical tests that has been shown to have acceptable diagnostic accuracy (sensitivity & specificity ≥ 0.74, positive likelihood ratio = 3–5) (Michener et al., 2009) and ultrasound imaging to confirm the presence of pathological changes in the tendon. Second, the acromial marker cluster method in the measurement of scapular kinematics is prone to error (less than 6°, Van Andel et al., 2009) due to skin movement artefact although an attempt was made to reduce the error by placing the markers on the flat part of the acromion when compared to surface motion sensors or skin markers. Third, the study was carried out in a sitting position to standardize all the measurements. Future studies may investigate the standing position in order to reproduce a more realistic situation in these athletes.

5. Conclusion

Athletes of overhead sports with RC tendinopathy demonstrated less upward scapular rotation during early abduction from 0° to 30°. They also demonstrated delayed activity onset of LT and SA relative to UT when compared with the asymptomatic athletes. Delayed activity onset of MT and LT relative to UT were associated with less scapular upward rotation during early abduction. In this context, the role of improving the neuromotor control of the scapular muscle in the rehabilitation and prevention of shoulder disorders in athletes of overhead sports merits further research.

Conflict of interest

The authors have no conflict of interest to declare.

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Table 1 Demographic data of participants.

Variables	**Asymptomatic athletes (n = 17)**	**Athletes with RC tendinopathy (n = 26)**
Age (years)	21.7 ± 3.5	23.6 ± 3.3
Weight (kg)	69.6 ± 5.1	70.0 ± 9.0
Height (cm)	179.4 ± 6.0	178.6 ± 6.9
BMI (kg/m^2)	21.7 ± 1.9	21.9 ± 2.1
Years of sports training	8.7 ± 3.7	10.3 ± 3.3
Training hours per week	6.9 ± 2.2	7.1 ± 2.9
Duration of shoulder pain (months)	–	21.9 ± 17.1

Values are mean ± SD.

Abbreviations: BMI, Body mass index; RC: rotator cuff.

Table 2. Mean ± SD of the change in scapular kinematics and the EMG activity onset and the activity onset differences of scapular muscles between asymptomatic athletes and athletes with rotator cuff (RC) tendinopathy.

	Asymptomatic athletes (n = 17)	**Athletes with RC tendinopathy (n = 26)**
Scapular kinematics		
Upward rotation (°)		
0–30°	8.2 ± 1.1	6.6 ± 2.3*,†
30–60°	13.7 ± 3.4	14.8 ± 3.1
60–90°	14.7 ± 3.6	17.0 ± 4.5
Posterior tilt (°)		
0–30°	4.2 ± 1.5	3.2 ± 1.1
30–60°	5.4 ± 2.1	4.1 ± 2.1
60–90°	11.3 ± 5.7	12.5 ± 5.7
External rotation (°)		
0–30°	4.1 ± 1.9	2.7 ± 1.0
30–60°	3.5 ± 1.2	3.9 ± 2.0
60–90°	8.1 ± 4.3	8.7 ± 2.9
EMG activity		
Activity onset (ms)		
UT	21.4 ± 38.1	−19.5 ± 36.1*
MT	−19.2 ± 52.7	−15.9 ± 56.4
LT	−72.4 ± 39.0	−18.5 ± 43.9*,†
SA	−12.8 ± 16.7	29.2 ± 48.4*
Activity onset difference (ms)		
MT relative to UT	43.5 ± 50.2	10.2 ± 46.2*
LT relative to UT	74.4 ± 45.1	14.1 ± 31.4*,†
SA relative to UT	23.0 ± 25.2	−44.9 ± 26.0*,†

Abbreviations: EMG: electromyography; UT: upper trapezius; MT: middle trapezius; LT: lower trapezius; SA: serratus anterior.

Table 3. Results of Pearson's correlations (r) between scapular rotations at different phases of shoulder abduction with relative activity onset differences of scapular muscles.

	Asymptomatic athletes			**Athletes with RC tendinopathy**		
	MT relative to UT	**LT relative to UT**	**SA relative to UT**	**MT relative to UT**	**LT relative to UT**	**SA relative to UT**
Upward rotation						
0–30°	0.655*	0.613	−0.219	0.032	−0.021	−0.068
30–60°	0.269	0.680*	−0.060	0.122	0.051	0.068
60–90°	−0.112	0.564	0.410	0.125	0.006	0.230
Posterior tilt						
0–30°	0.216	−0.158	−0.312	−0.209	−0.190	−0.330
30–60°	0.477	0.143	−0.242	0.208	0.165	−0.302
60–90°	0.501	0.274	0.098	−0.209	0.208	0.115
External rotation						
0–30°	0.344	−0.058	−0.231	0.320	0.042	0.230
30–60°	0.533	0.261	−0.099	0.005	0.346	−0.148
60–90°	0.457	0.612	0.440	0.024	0.106	−0.248

*p < 0.025 (Bonferroni adjusted)

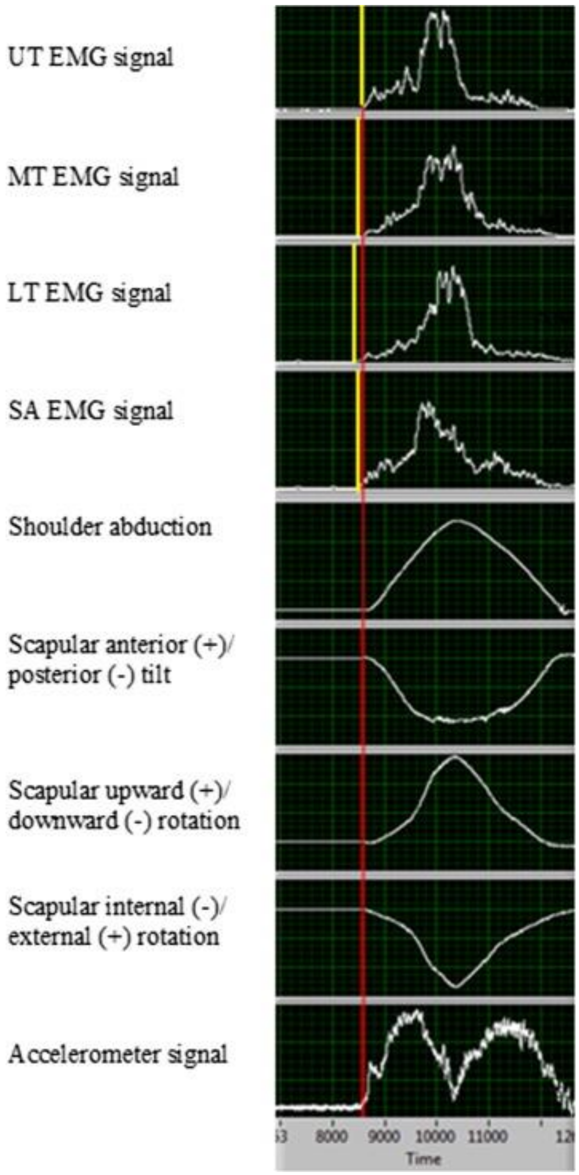

Figure 1 Synchronized raw data of the electromyography (EMG) onset of the scapular muscles (upper trapezius (UT), middle trapezius (MT), lower trapezius (LT), and serratus anterior (SA)), scapular kinematics and accelerometer signal during shoulder abduction using LabView Instrument 8.6 (National Instruments Corporate, Austin, Tx, USA). The red line indicates the arm movement onset detected by the start of tilting of the accelerometer. The yellow lines indicate the EMG activity onset of the scapular muscles. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)