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Shoulder Muscle Recruitment Patterns and Related Biomechanics during Upper Extremity Sports

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Contents

Abstract

Understanding when and how much shoulder muscles are active during upper extremity sports is helpful to physicians, therapists, trainers and coaches in providing appropriate treatment, training and rehabilitation protocols to these athletes. This review focuses on shoulder muscle activity (rotator cuff, deltoids, pectoralis major, latissimus dorsi, triceps and biceps brachii, and scapular muscles) during the baseball pitch, the American football throw, the windmill softball pitch, the volleyball serve and spike, the tennis serve and volley, baseball hitting, and the golf swing. Because shoulder electromyography (EMG) data are far more extensive for overhead throwing activities compared with non-throwing upper extremity sports, much of this review focuses on shoulder EMG during the overhead throwing motion. Throughout this review shoulder kinematic and kinetic data (when available) are integrated with shoulder EMG data to help better understand why certain muscles are active during different phases of an activity, what type of muscle action (eccentric or concentric) occurs, and to provide insight into the shoulder injury mechanism.

Kinematic, kinetic and EMG data have been reported extensively during overhead throwing, such as baseball pitching and football passing. Because shoulder forces, torques and muscle activity are generally greatest during the arm cocking and arm deceleration phases of overhead throwing, it is believed that most shoulder injuries occur during these phases. During overhead throwing, high rotator cuff muscle activity is generated to help resist the high shoulder distractive forces ≈80–120% bodyweight during the arm cocking and deceleration phases. During arm cocking, peak rotator cuff activity is 49–99% of a maximum voluntary isometric contraction (MVIC) in baseball pitching and 41–67% MVIC in football throwing. During arm deceleration, peak rotator cuff activity is 37–84% MVIC in baseball pitching and 86–95% MVIC in football throwing. Peak rotator cuff activity is also high is the windmill softball pitch (75–93% MVIC), the volleyball serve and spike (54–71% MVIC), the tennis serve and volley (40–113% MVIC), baseball hitting (28–39% MVIC), and the golf swing (28–68% MVIC).

Peak scapular muscle activity is also high during the arm cocking and arm deceleration phases of baseball pitching, with peak serratus anterior activity 69–106% MVIC, peak upper, middle and lower trapezius activity 51–78% MVIC, peak rhomboids activity 41–45% MVIC, and peak levator scapulae activity 33–72% MVIC. Moreover, peak serratus anterior activity was ≈60% MVIC during the windmill softball pitch, ≈75% MVIC during the tennis serve and forehand and backhand volley, ≈30–40% MVIC during baseball hitting, and ≈70% MVIC during the golf swing. In addition, during the golf swing, peak upper, middle and lower trapezius activity was 42–52% MVIC, peak rhomboids activity was ≈60% MVIC, and peak levator scapulae activity was ≈60% MVIC.

Electromyography (EMG) is the science of quantifying muscle activity. Several studies have reported shoulder muscle activity during a variety of upper extremity sports.[1-7] Understanding when and how much specific shoulder muscles are active during upper extremity sports is helpful to physicians, therapists, trainers and coaches in providing appropriate treatment, training and rehabilitation protocols to these athletes, as well as helping health professionals better understand the shoulder injury mechanism. When interpreting EMG data it should be emphasized that while the EMG amplitude does correlate reasonably well with muscle force for isometric contractions, it does not correlate well with muscle force as muscle contraction velocities increase, or during muscular fatigue (both of which occur in sport).[8] Nevertheless, EMG analyses are helpful in determining the timing and quantity of muscle activation throughout a given movement.

This review focuses on shoulder muscle activity in upper extremity sports, specifically: baseball pitching, American football throwing, windmill softball pitching, the volleyball serve and spike, the tennis serve and volley, baseball hitting, and the golf swing. Most of the movements that occur in the aforementioned sports involve overhead throwing type movements. Shoulder EMG data in the literature are far more extensive for overhead throwing activities, such as baseball pitching, compared with other upper extremity sports that do not involve the overhead throwing motion, such as baseball hitting. Therefore, much of this review focuses on shoulder EMG during activities that involve the overhead throwing motion.

To help better interpret the applicability and meaningfulness of shoulder EMG data, EMG data will be integrated with shoulder joint kinematics (linear and angular shoulder displacements, velocities and accelerations) and kinetics (shoulder forces and torques) when these data are available. In the literature, kinematic, kinetic and EMG measurements have been reported extensively in overhead throwing activities,[2,9-12] such as baseball pitching and football throwing, but these data are sparse in other upper extremity activities, such as the volleyball serve and spike, the tennis serve and volley, baseball hitting, and the golf swing. Overhead throwing activities in particular are commonly associated with shoulder injuries.[13,14] When EMG is interpreted with shoulder kinematics and kinetics, it not only provides a better understanding of why certain muscles are active during different phases of an activity, but also provides information as to what type of muscle action (eccentric or concentric) is occurring, and insight into the shoulder injury mechanism. Although shoulder muscle activity is the primary focus of this review, shoulder injuries will be discussed briefly relative to joint loads, joint motions and muscle activity when these data are available.

1. Shoulder Electromyography (EMG) during the Overhead Baseball Pitch

Shoulder muscle activity during baseball pitching has been examined extensively by Jobe and colleagues,[2,15-18] with their initial report published in 1983.[18] Using 56 healthy male college and professional pitchers, DiGiovine and colleagues[2] quantified shoulder muscle activity

Table I. Shoulder activity by muscle and phase during baseball pitching[a] (adapted from DiGiovine et al.,[2] with permission)

Muscles	No. of subjects	Phase					
		wind-up[b] (% MVIC)	stride[c] (% MVIC)	arm cocking[d] (% MVIC)	arm acceleration[e] (% MVIC)	arm deceleration[f] (% MVIC)	follow-through[g] (% MVIC)
Scapular							
Upper trapezius	11	18±16	64±53	37±29	69±31	53±22	14±12
Middle trapezius	11	7±5	43±22	51±24	71±32	35±17	15±14
Lower trapezius	13	13±12	39±30	38±29	76±55	78±33	25±15
Serratus anterior (6th rib)	11	14±13	44±35	69±32	60±53	51±30	32±18
Serratus anterior (4th rib)	10	20±20	40±22	106±56	50±46	34±7	41±24
Rhomboids	11	7±8	35±24	41±26	71±35	45±28	14±20
Levator scapulae	11	6±5	35±14	72±54	76±28	33±16	14±13
Glenohumeral							
Anterior deltoid	16	15±12	40±20	28±30	27±19	47±34	21±16
Middle deltoid	14	9±8	44±19	12±17	36±22	59±19	16±13
Posterior deltoid	18	6±5	42±26	28±27	68±66	60±28	13±11
Supraspinatus	16	13±12	60±31	49±29	51±46	39±43	10±9
Infraspinatus	16	11±9	30±18	74±34	31±28	37±20	20±16
Teres minor	12	5±6	23±15	71±42	54±50	84±52	25±21
Subscapularis (lower 3rd)	11	7±9	26±22	62±19	56±31	41±23	25±18
Subscapularis (upper 3rd)	11	7±8	37±26	99±55	115±82	60±36	16±15
Pectoralis major	14	6±6	11±13	56±27	54±24	29±18	31±21
Latissimus dorsi	13	12±10	33±33	50±37	88±53	59±35	24±18
Triceps brachii	13	4±6	17±17	37±32	89±40	54±23	22±18
Biceps brachii	18	8±9	22±14	26±20	20±16	44±32	16±14

a Data are given as means and standard deviations, and expressed for each muscle as a percentage of an MVIC.

b From initial movement to maximum knee lift of stride leg.

c From maximum knee lift of stride leg to when lead foot of stride leg initially contacts the ground.

d From when lead foot of stride leg initially contacts the ground to maximum shoulder external rotation.

e From maximum shoulder external rotation to ball release.

f From ball release to maximum shoulder internal rotation.

g From maximum shoulder internal rotation to maximum shoulder horizontal adduction.

MVIC = maximum voluntary isometric contraction.

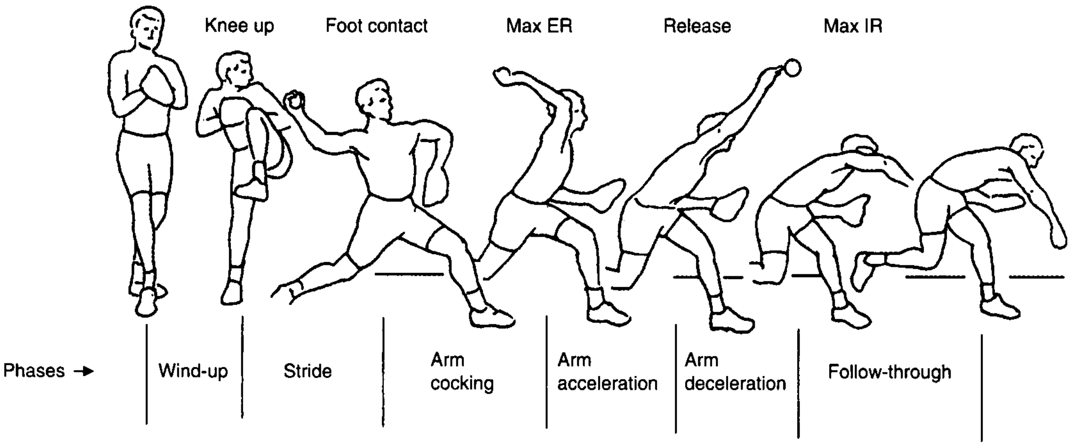

Fig. 1. Pitching phases and key events (adapted from Fleisig et al.,[12] with permission). **ER**=external rotation; **IR**=internal rotation; **max**=maximum.

during baseball pitching (data summarized in table I). To help generalize phase comparisons in muscle activity from table I, 0–20% of a maximum voluntary isometric contraction (MVIC) is considered low muscle activity, 21–40% MVIC is considered moderate muscle activity, 41–60% MVIC is considered high muscle activity and >60% MVIC is considered very high muscle activity.[2] From these initial reports, the baseball pitch was divided into several phases, which later were slightly modified by Escamilla et al.[9] and Fleisig et al.[11] as the wind-up, stride, arm cocking, arm acceleration, arm deceleration and follow-through phases (figure 1).

1.1 Wind-Up Phase

Shoulder activity during the wind-up phase, which is from initial movement to maximum knee lift of stride leg (figure 1), is generally very low due to the slow movements that occur. From table I, it can be seen that the greatest activity is from the upper trapezius, serratus anterior and anterior deltoids. These muscles all contract concentrically to upwardly rotate and elevate the scapula and abduct the shoulder as the arm is initially brought overhead, and then contract eccentrically to control downward scapular rotation and shoulder adduction as the hands are lowered to approximately chest level. The rotator cuff muscles, which have a duel function as glenohumeral joint compressors and rotators, have their lowest activity during this phase. Because shoulder activity is low, it is not surprising that the shoulder forces and torques generated are also low;[9,11] consequently, very few, if any, shoulder injuries occur during this phase.

1.2 Stride Phase

There is a dramatic increase in shoulder activity during the stride phase (table I), which is from the end of the balance phase to when the lead foot of the stride leg initially contacts the ground (figure 1). During the stride the hands separate, the scapula upwardly rotates, elevates and retracts, and the shoulders abduct, externally rotate and horizontally abduct due to concentric activity from several muscles, including the deltoids, supraspinatus, infraspinatus, serratus anterior and upper trapezius. It is not surprising that there are many more muscles activated and to a higher degree during the stride compared with the wind-up phase. Interestingly, the supraspinatus has its highest activity during the stride phase as it works to not only abduct the shoulder but also help compress and stabilize the glenohumeral joint.[2] The deltoids exhibit high activity during this phase in order to initiate and maintain the shoulder in an abducted position.[2] Moreover, the trapezius and serratus anterior have moderate to high activity, as they assist in stabilizing and properly positioning the scapula to minimize the risk of impingement as the arm abducts.[2]

1.3 Arm Cocking Phase

The arm cocking phase begins at lead foot contact and ends at maximum shoulder external rotation. During this phase the kinetic energy that is generated from the larger lower extremity and trunk segments is transferred up the body to the smaller upper extremity segments.[10,19,20] The pitching arm lags behind as the trunk rapidly rotates forward to face the hitter, generating a peak pelvis angular velocity around 600°/sec occurring 0.03–0.05 sec after lead foot contact, followed by a peak upper torso angular velocity of nearly 1200°/sec occurring 0.05–0.07 sec after lead foot contact.[10] Consequently, high to very high shoulder muscle activity is needed during this phase in order to keep the arm moving with the rapidly rotating trunk (table I), as well as control the resulting shoulder external rotation (table I), which peaks near 180°.[10] Moderate activity is needed by the deltoids (table I) to maintain the shoulder at approximately 90° abduction throughout this phase.[10]

Activity from the pectoralis major and anterior deltoid is needed during this phase to horizontally adduct the shoulder with a peak angular velocity of approximately 600°/sec, from a position of approximately 20° of horizontal abduction at lead foot contact to a position of approximately 20° of horizontal adduction at maximum shoulder external rotation.[10] Moreover, a large compressive force of ≈80% bodyweight is generated by the trunk onto the arm at the shoulder to resist the large 'centrifugal' force that is generated as the arm rotates forward with the trunk.[11] The supraspinatus, infraspinatus, teres minor and subscapularis achieve high to very high activity (table I) to resist glenohumeral distraction and enhance glenohumeral stability.

While it is widely accepted that strength and endurance in posterior shoulder musculature is very important during the arm deceleration phase to slow down the arm, posterior shoulder musculature is also important during arm cocking. The posterior cuff muscles (infraspinatus and teres minor) and latissimus dorsi generate a posterior force to the humeral head that helps resist anterior humeral head translation, which may help unload the anterior capsule and anterior band of the inferior glenohumeral ligament.[11,15,21] The posterior cuff muscles (infraspinatus and teres minor) also contribute to the extreme range of shoulder external rotation that occurs during this phase.

A peak shoulder internal rotation torque of 65–70 N • m is generated near the time of maximum shoulder external rotation,[11,22] which implies that shoulder external rotation is progressively slowing down as maximum shoulder external rotation is approached. High to very high activity is generated by the shoulder internal rotators (pectoralis major, latissimus dorsi and subscapularis) [table I], which contract eccentrically during this phase to control the rate of shoulder external rotation.[2]

The multiple functions of muscles are clearly illustrated during arm cocking. For example, the pectoralis major and subscapularis contract concentrically to horizontally adduct the shoulder and eccentrically to control shoulder external rotation. This duel function of these muscles helps maintain an appropriate length-tension relationship by simultaneously shortening and lengthening, which implies that these muscles may be maintaining a near constant length throughout this phase. Therefore, some muscles that have duel functions and simultaneous shortening and lengthening as the shoulder performs duel actions at the same time may in effect be contracting isometrically.

The importance of scapular muscles during arm cocking is demonstrated in table I. High activity from these muscles is needed in order to stabilize the scapula and properly position the scapula in relation to the horizontally adducting and rotating shoulder. The scapular protractors are especially important during this phase in order to resist scapular retraction by contracting eccentrically and isometrically during the early part of this phase and cause scapular protraction by contracting concentrically during the latter part of this phase. The serratus anterior generates maximum activity during this phase. Scapular muscle imbalances may lead to abnormal scapular movement and position relative to the humerus, increasing injury risk.

Because both the triceps brachii (long head) and biceps brachii (both heads) cross the shoulder, they both generate moderate activity during this phase in order to provide additional stabilization to the shoulder. In contrast to the moderate triceps activity reported by DiGiovine et al.[2] during arm cocking, Werner et al.[23] reported the highest triceps activity during arm cocking. Because elbow extensor torque peaks during this phase,[23,24] high eccentric contractions by the triceps brachii are needed to help control the rate of elbow flexion that occurs throughout the initial 80% of this phase.[10] High triceps activity is also needed to initiate and accelerate elbow extension, which occurs during the final 20% of this phase as the shoulder continues externally rotating.[10] Therefore, during arm cocking the triceps initially contract eccentrically to control elbow flexion early in the phase and concentrically to initiate elbow extension later in the phase.

Gowan and colleagues[16] demonstrated that subscapularis activity is nearly twice as great in professional pitchers compared with amateur pitchers during this phase. In contrast, muscle activity from the pectoralis major, supraspinatus, serratus anterior and biceps brachii was ≈50% greater in amateur pitchers compared with professional pitchers. From these data, professional pitchers may exhibit better throwing efficiency thus requiring less muscular activity compared with amateurs.

Glousman and colleagues[15] compared shoulder muscle activity between healthy pitchers with no shoulder pathologies to pitchers with chronic anterior shoulder instability due to anterior glenoid labral tears. Pitchers diagnosed with chronic anterior instability exhibited greater muscle activity from the biceps brachii and supraspinatus and less muscle activity from the pectoralis major, subscapularis and serratus anterior. Chronic anterior instability results in excessive stretch of the anterior capsular, which may stimulate mechanoreceptors within the capsule resulting in excitation in the biceps brachii and supraspinatus and inhibition in the pectoralis major, subscapularis and serratus anterior.[15] Increased activity from the biceps brachii and supraspinatus helps compensate for anterior shoulder instability, as these muscles enhance glenohumeral stability. Rodosky et al.[25] reported that as the humerus abducts and maximally externally rotates, the biceps long head enhances anterior stability of the glenohumeral joint and also decreases the stress placed on the inferior glenohumeral ligament. Decreased activity from the pectoralis major and subscapularis, which contract eccentrically to decelerate the externally rotating shoulder, may accentuate shoulder external rotation and increase the stress on the anterior capsule.[15] Decreased activity from the serratus anterior may cause the scapula to be abnormally positioned relative to the externally rotating and horizontally adducting humerus, and a deficiency in scapular upward rotation may decrease the subacromial space and increase the risk of impingement and rotator cuff pathology.[26]

Interestingly, infraspinatus activity was lower in pitchers with chronic anterior shoulder instability compared with healthy pitchers.[16] During arm cocking, the infraspinatus not only helps externally rotate and compress the glenohumeral joint, but also may generate a small posterior force on the humeral head due to a slight posterior orientation of its fibres as they run from the inferior facet of the greater tubercle back to the infraspinous fossa. As previously mentioned, this posterior force on the humeral head helps resist anterior humeral head translation and unloads strain on the anterior capsule during arm cocking.[16] It is unclear whether chronic rotator cuff insufficiency results in shoulder instability, or whether chronic shoulder instability results in rotator cuff insufficiency due to excessive activity.

1.4 Arm Acceleration Phase

The arm acceleration phase begins at maximum shoulder external rotation and ends at ball release[10,11,22] (figure 1). Like the arm cocking phase, high to very high activity is generated from the glenohumeral and scapular muscles during this phase in order to accelerate the arm forward (table I).

Moderate activity is generated by the deltoids[2] to help produce a fairly constant shoulder abduction of approximately 90–100°,[10] which is maintained regardless of throwing style (i.e. overhand, sidearm, etc.). The glenohumeral internal rotators (subscapularis, pectoralis major and latissimus dorsi) have their highest activity during this phase[2] (table I) as they contract concentrically to help generate a peak internal rotation angular velocity of approximately 6500°/sec near ball release.[9] This rapid internal rotation, with a range of motion of approximately 80° from maximum external rotation to ball release, occurs in only 30–50 msec.[10,27] The very high activity from the subscapularis (115% MVIC) occurs in part to help generate this rapid motion, but it also functions as a steering muscle to maintain the humeral head in the glenoid. The teres minor, infraspinatus and supraspinatus also demonstrate moderate to high activity during this phase to help properly position the humeral head within the glenoid. With these rapid arm movements that are generated to accelerate the arm forward, it is not surprising that the scapular muscles also generate high activity,[2] which is needed to help maintain proper position of the glenoid relative to the rapidly moving humeral head. Strengthening scapular musculature is very important because poor position and movement of the scapula can increase the risk of impingement and other related injuries,[28] as well as reduce the optimal length-tension relationship of both scapular and glenohumeral musculature.

Although DiGiovine et al.[2] reported that the triceps had their highest activity during this phase,[2] Werner et al.[23] reported relatively little triceps EMG during the arm acceleration phase. In addition, elbow extensor torque is very low during this phase compared with the arm cocking phase.[23,24] It should be re-emphasized that elbow extension initially begins during the arm cocking phase as the shoulder approaches maximum external rotation.[9] Kinetic energy that is transferred from the lower extremities and trunk to the arm is used to help generate a peak elbow extension angular velocity of approximately 2300°/sec during this phase.[9] In fact, a concentric contraction from the triceps brachii alone could not come close to generating this 2300°/sec elbow extension angular velocity. This is supported by findings reported by Roberts,[29] who had found that subjects who threw with paralyzed triceps could obtained ball velocities >80% of the ball velocities obtained prior to the triceps being paralyzed. This is further supported by Toyoshima et al.,[20] who demonstrated normal throwing using the entire body generated almost twice the elbow extension angular velocity compared with extending the elbow by throwing without any lower extremity, trunk and shoulder movements. These authors concluded that during normal throwing the elbow is swung open like a ‘whip’, primarily due to linear and rotary contributions from the lower extremity, trunk and shoulder, and to a lesser extent from a concentric contraction of the triceps. Nevertheless, the triceps do help extend the elbow during this phase, as well as contribute to shoulder stabilization by the triceps long head. These findings illustrate the importance of lower extremity conditioning, because weak or fatigued lower extremity musculature during throwing may result in increased loading of the shoulder structures, such as the rotator cuff, glenoid labrum, and shoulder capsule and ligaments. Further research is needed to substantiate these hypotheses.

Gowan and colleagues[16] demonstrated that rotator cuff and biceps brachii activity was 2–3 times higher in amateur pitchers compared with professional pitchers during this phase. In contrast, subscapularis, serratus anterior and latissimus dorsi activity was much greater in professional pitchers. These results imply that professional pitchers may better coordinate body segment movements to increase throwing efficiency. Enhanced throwing mechanics and efficiency may minimize glenohumeral instability during this phase, which may help explain why professional pitchers generate less rotator cuff and biceps activity, which are muscles that help resist glenohumeral joint distraction and enhance stability.

Compared with healthy pitchers, pitchers with chronic anterior shoulder instability due to anterior labral injuries exhibit greater muscle activity from the biceps brachii, supraspinatus and infraspinatus, and less muscle activity from the latissimus dorsi, subscapularis and serratus anterior.[15] The increased activity from rotator cuff and biceps musculature in pitchers with chronic anterior instability is needed in order to provide additional glenohumeral instability that is lacking in these pitchers due to a compromised anterior labrum.

With shoulder internal rotation, the long biceps tendon is repositioned anteriorly at the shoulder, providing compressive and posterior forces to the humeral head, both of which enhance anterior stability. Therefore, throwers with chronic anterior instability activate their biceps to a greater extent (32% vs 12% MVIC), as well as their supraspinatus and infraspinatus (37% vs 13% MVIC), compared with asymptomatic throwers.[15] However, increased and excessive biceps activity due to anterior instability results in increased stress to the long biceps anchor at the superior labrum, which over time may result in superior labral pathology that is anterior to posterior in direction (SLAP lesions). In addition, chronic anterior shoulder instability inhibits normal contributions from the internal rotators and serratus anterior,[15] which may adversely affect throwing mechanics and efficiency, as well as increase shoulder injury risk.

1.5 Arm Deceleration Phase

The arm deceleration phase begins at ball release and ends at maximum shoulder internal rotation (figure 1).[10,11,22] Large loads are generated at the shoulders to slow down the forward acceleration of the arm. The purpose of this phase is to provide safety to the shoulder by dissipating the excess kinetic energy not transferred to the ball, thereby minimizing the risk of shoulder injury. Posterior shoulder musculature, such as the infraspinatus, teres minor and major, posterior deltoid and latissimus dorsi, contract eccentrically not only to decelerate horizontal adduction and internal rotation of the arm, but also help resist shoulder distraction and anterior subluxation forces. A shoulder compressive force slightly greater than bodyweight is generated to resist shoulder distraction, while a posterior shear force of 40–50% bodyweight is generated to resist shoulder anterior subluxation.[9,11] Consequently, high activity is generated by posterior shoulder musculature,[2] in particular the rotator cuff muscles. For example, the teres minor, which is a frequent source of isolated tenderness in pitchers, exhibits its maximum activity (84% MVIC) during this phase (table I). In addition, scapular muscles also exhibit high activity to control scapular elevation, protraction and rotation during this phase. For example, the lower trapezius – which generate a force on the scapula in the direction of depression, retraction and upward rotation – generated their highest activity during this phase (table I). High EMG activity from glenohumeral and scapular musculature illustrate the importance of strength and endurance training of the posterior musculature in the overhead throwing athlete. Weak or fatigued posterior musculature can lead to multiple injuries, such as tensile overload undersurface cuff tears, labral/biceps pathology, capsule injuries and internal impingement of the infraspinatus/supraspinatus tendons on the posterosuperior glenoid labrum.[14]

Compared with healthy pitchers, pitchers with chronic anterior shoulder instability exhibited less muscle activity from the pectoralis major, latissimus dorsi, subscapularis and serratus anterior, which is similar to what occurred in the arm cocking and acceleration phases.[15] However, muscle activities from the rotator cuff and biceps brachii are similar between healthy pitchers and pitchers with chronic anterior shoulder instability during this phase, which is in contrast to the greater rotator cuff and biceps brachii activity demonstrated in pitchers with chronic anterior shoulder instability during the arm cocking and acceleration phases.[15] This difference in muscle activity may partially be explained by the very high compressive forces that are needed during arm deceleration to resist shoulder distraction, which is a primary function of both the rotator cuff and biceps brachii.

The biceps brachii generate their highest activity (44% MVIC) during arm deceleration (table I). The function of this muscle during this phase to 2-fold. Firstly, it must contract eccentrically along with other elbow flexors to help decelerate the rapid elbow extension that peaks near 2300°/sec during arm acceleration.[9] This is an important function because weakness or fatigue in the elbow flexors may result in elbow extension being decelerated by impingement of the olecranon in the olecranon fossa, which may lead to bone spurs and subsequent loose bodies within the elbow. Secondly, the biceps brachii works synergistically with the rotator cuff muscles to resist distraction and anterior subluxation at the glenohumeral joint. Interestingly, during arm deceleration biceps brachii activity is greater in amateur pitchers compared with professional pitchers,[16] which may imply that amateur pitchers employ a less efficient throwing pattern compared with professional pitchers. As previously mentioned, excessive activity from the long head of the biceps brachii may lead to superior labral pathology.

2. Shoulder EMG during the Overhead American Football Throw

There is only one known study that has quantified muscle activity during the football throw.[3] Using 14 male recreational and college athletes, Kelly et al.[3] quantified activity from nine glenohumeral muscles throughout throwing phases specific for football; their results are summarized in table II. The defined phases for football throwing (table II) are similar but slightly different to the defined phases for baseball pitching (table I). Early arm cocking in the football throw was similar to the stride phase in baseball, while late cocking in the football throw was the same as arm cocking in baseball. The acceleration phase was the same for both the football throw and the baseball pitch. The arm deceleration and follow-through phases in the baseball pitch were combined into a single arm deceleration/follow-through phase in the football throw.

From table II, rotator cuff activity progressively increased in each phase of the football throwing, being least in the early cocking phase and peaking in the arm deceleration/follow-through phase. This is a slightly different pattern than the baseball pitch, where rotator cuff activity was generally greatest during either the arm cocking phase or the arm deceleration phase (table I). For both baseball pitching and football throwing, deltoid and biceps brachii activity were generally greatest during the arm deceleration

Table II. Shoulder activity by muscle and phase during the overhead football throw[a] (adapted from Kelly et al.,[3] with permission)

Muscles	No. of subjects	Phase				
		early cocking[b] (% MVIC)	late cocking[c] (% MVIC)	arm acceleration[d] (% MVIC)	arm deceleration and follow-through[e] (% MVIC)	total throw[f] (% MVIC)
Supraspinatus	14	45±19	62±20	65±30	87±43	65±22
Infraspinatus	14	46±17	67±19	69±29	86±33	67±21
Subscapularis	14	24±15	41±21	81±34	95±65	60±28
Anterior deltoid	14	13±9	40±14	49±14	43±26	36±9
Middle deltoid	14	21±12	14±14	24±14	48±19	27±9
Posterior deltoid	14	11±6	11±15	32±22	53±25	27±11
Pectoralis major	14	12±14	51±38	86±33	79±54	57±27
Latissimus dorsi	14	7±3	18±9	65±30	72±42	40±12
Biceps brachii	14	12±7	12±10	11±9	20±18	14±9

[a] Data are given as means and standard deviations, and expressed for each muscle as a percentage of a MVIC.

[b] From rear foot plant to maximum shoulder abduction and internal rotation.

[c] From maximum shoulder abduction and internal rotation to maximum shoulder external rotation.

[d] From maximum shoulder external rotation to ball release.

[e] From ball release to maximum shoulder horizontal adduction.

[f] Mean activity throughout the four defined phases.

MVIC = maximum voluntary isometric contraction.

phase (tables I and II). The greatest activity of the pectoralis major, latissimus dorsi and subscapularis was during arm cocking and arm acceleration in baseball pitching (table I), while peak activity occurred in these muscles during arm acceleration and arm deceleration in football throwing (table II). The pectoralis major, latissimus dorsi and subscapularis are powerful internal rotators. These muscles contract eccentrically and help generate a shoulder internal rotation torque of ≈50 N • m during arm cocking to slow down the externally rotating shoulder, and they contract concentrically during arm acceleration to help generate a peak shoulder internal rotation angular velocity of approximately 5000°/sec.[19] The pectoralis major and subscapularis also help horizontally adduct the shoulder during arm cocking and arm acceleration, but in a different kinematic pattern compared with the baseball pitch. In football passing, the quarterback tends to 'lead with the elbow' as the elbow moves anterior to the trunk in achieving approximately 30° of horizontal adduction during arm cocking and arm acceleration, generating a peak horizontal adduction torque of ≈75 N • m.[19] In contrast, in the baseball pitch the elbow remains slightly in the back of the trunk during arm cocking (≈15°) and slightly in front of the trunk (≈5°) during arm acceleration.[19]

The greatest activity in the rotator cuff muscles and latissimus dorsi occurred during the arm deceleration/follow-through phase of the football throw. These muscles work to generate a peak shoulder compressive force ≈80% bodyweight during arm deceleration/follow-through to resist shoulder distraction, which is 20–25% less than the shoulder compressive force that is generated during baseball pitching during this phase.[19] The latissimus dorsi, posterior deltoid and infraspinatus also contract eccentrically to slow down the rapid horizontal adducting arm. Fleisig and co-authors[19] reported a shoulder horizontal abduction torque ≈80 N • m, which is needed to help control the rate of horizontal adduction that occurs during arm deceleration/follow-through. Moreover, the peak activity that occurred in the latissimus dorsi, posterior deltoid and infraspinatus during arm deceleration/follow-through helps resist anterior translation of the humeral head within the glenoid by, in part, generating a peak shoulder posterior force ≈240 N.[19]

The aforementioned kinematic and kinetic differences between football passing and baseball pitching help explain the differences in muscle activity between these two activities, and they occur in part because a football weighs three times more than a baseball. Therefore, a football cannot be thrown with the same shoulder range of motion and movement speeds compared with throwing a baseball. This results in smaller loads (i.e. less shoulder forces and torques) overall applied to the shoulder in football passing compared with baseball pitching,[19] which may in part account for the greater number of shoulder injuries in baseball pitching compared with football passing.

3. Shoulder EMG during Windmill Softball Pitching

Maffet et al.[4] conducted the only known study that quantified shoulder muscle firing patterns during the softball pitch. These authors used ten female collegiate softball pitchers who all threw the 'fast pitch' and quantified activity in the anterior and posterior deltoid, supraspinatus, infraspinatus, teres minor, subscapularis, pectoralis major and serratus anterior. The 'fast-pitch' motion starts with the throwing shoulder extended and then as the pitcher strides forward the arm fully flexes, abducts and externally rotates and then continues in a circular (windmill) motion all the way around until the ball is released near 0° shoulder flexion and adduction. The six phases that define the pitch[4] are as follows: (i) wind-up, from first ball motion to 6 o'clock position (shoulder flexed and abducted approximately 0°); (ii) from 6 o'clock to 3 o'clock position (shoulder flexed approximately 90°); (iii) from 3 o'clock to 12 o'clock position (shoulder flexed and abducted approximately 180°); (iv) from 12 o'clock to 9 o'clock position (shoulder abducted approximately 90°); (v) from 9 o'clock position to ball release; and (vi) from ball release to completion of the pitch.

The total circumduction of the arm about the shoulder from the wind-up to the follow-through is approximately 450–500°.[30] Moreover, this circumduction occurs while holding a 6.25–7 oz (177–198 g) ball with the elbow near full extension, which accentuates the 'centrifugal' distractive force acting at the shoulder.

EMG results by muscle and phase during the softball pitch are shown in table III. Muscle activity was generally lowest during the wind-up and increased during the 6–3 o'clock phase as the arm began accelerating upwards. Both the supraspinatus and infraspinatus generated their highest activity during this phase. During the 6–3 o'clock phase the arm accelerates in a circular motion and achieves a peak shoulder flexion angular velocity of approximately 5000°/sec.[30] The anterior deltoid was moderately active to help generate this rapid shoulder flexion angular velocity, and the serratus anterior was moderately active in helping to upwardly rotate and protract the scapula. The arm rapidly rotating upwards in a circular pattern results in a distractive force of ≈20–40% bodyweight, which is resisted in part by the shoulder compressive action of the supraspinatus and infraspinatus.

As the arm continues its upward acceleration during the 3–12 o'clock phase, the posterior deltoids, teres minor and infraspinatus all reach their peak activity. These muscles not only help externally rotate the shoulder during this phase but also help resist the progressively increasing shoulder distractive forces, which are ≈50% bodyweight during this phase.[30] These muscles are also in good position to resist shoulder lateral forces, which peak during this phase.[30]

The arm begins accelerating downward during the 12–9 o'clock phase. It is during this phase that the shoulder begins to rapidly internally rotate 2000–3000°/sec.[30] It is not surprising that the internal rotators (subscapularis and pectoralis major) exhibit high activity during this phase. High activity from the pectoralis major also helps adduct the shoulder. The subscapularis helps stabilize the humeral head and may help unload anterior capsule stress caused by the overhead and backward position of the arm as it begins accelerating forward. The serratus anterior exhibited a marked increase in activity to help stabilize the scapula and properly position the glenoid with the rapidly moving humerus.

The subscapularis, pectoralis major and serratus anterior collectively generated their highest activity during the 9 o'clock to ball release phase. The serratus anterior continues to work to stabilize the scapula and properly position it in relation to the rapidly moving humerus. High subscapularis and pectoralis major activity is needed during this phase to resist distraction at the shoulder, which peaks during this phase with a magnitude of approximately bodyweight.[30,31] These muscles also help generate a peak shoulder internal rotation of approximately 4600°/sec[30] and help adduct and flex the arm until the arm contacts the lateral thigh. However, not all softball pitchers exhibit the same pattern of motion

Table III. Shoulder activity by muscle and phase during the windmill softball pitch[a] (adapted from Maffet et al.,[4] with permission)

Muscles	No. of subjects	Phase					
		wind-up (% MVIC)	6–3 o'clock position (% MVIC)	3–12 o'clock position (% MVIC)	12–9 o'clock position (% MVIC)	10 o'clock to ball release (% MVIC)	follow-through (% MVIC)
Anterior deltoid	10	25±11	38±29	17±23	22±24	43±38	28±21
Supraspinatus	10	34±17	78±36	43±32	22±19	37±27	19±12
Infraspinatus	10	24±13	93±52	92±38	35±22	29±17	30±15
Posterior deltoid	10	10±5	37±27	102±42	52±25	62±29	34±29
Teres minor	10	8±7	24±25	87±21	57±21	41±23	44±11
Pectoralis major	10	18±11	17±12	24±18	63±23	76±24	33±20
Subscapularis	10	17±4	34±23	41±33	81±52	75±36	26±22
Serratus anterior	10	23±9	38±19	19±9	45±39	61±19	40±14

a Data are given as means and standard deviations, and expressed for each muscle as a percentage of an MVIC.

MVIC = maximum voluntary isometric contraction.

during this phase, as none of the 53 youth softball pitchers studies by Werner et al.[31] adopted the release strategy of contacting the lateral thigh at ball release. This may partially explain why the collegiate pitchers in the Maffet et al.[4] study generated relatively low posterior cuff activity and relatively low activity in general during the follow-through. With contact of the arm with the lateral thigh near ball release, the deceleration forces and torques generated by muscles to slow down the arm are much less compared with no contact of the arm with the lateral thigh. With no arm contact with the lateral thigh, shoulder compressive and related forces and torques may be higher during follow-through, as relatively high shoulder forces and torques have been reported.[30,31] However, these forces and torques are less during follow-through compared with the 9 o'clock to ball release acceleration phase. This is one major difference between overhand throwing and the 'windmill' type motion. In overhead throwing the deceleration phase after ball release generates greater shoulder forces and torques compared with the acceleration phase up to ball release. In softball pitching the greatest forces and torques occur during the acceleration phase of the delivery.

The rapid shoulder movements and high shoulder forces that are generated during the 'windmill fast pitch' makes the shoulder susceptible to injury. There is also a higher risk of subacromial impingement due to the extreme shoulder flexion and abduction that occurs during the pitch. A significant number of shoulder injuries have been reported in softball pitchers, including bicipital and rotator cuff tendonitis, strain and impingement.[32]

4. Shoulder EMG during the Volleyball Serve and Spike

Both the volleyball serve and spike involve an overhead throwing motion that is similar to baseball pitching and football throwing. Unlike baseball pitching and football passing, there are no known studies that have quantified the shoulder forces and torques that are generated during the volleyball serve and spike. Nevertheless, because the motion is overhead and extremely rapid, similar to baseball pitching, it is hypothesized that high shoulder forces and torques are generated, especially during the volleyball spike. To support this hypothesis, numerous injuries occur each year in volleyball, primarily involving muscle, tendon and ligament injuries during blocking and spiking.[33] It has been reported that approximately one-quarter of all volleyball injuries involve the shoulder.[33-36] Moreover, in athletes who engage in vigorous upper arm activities, shoulder pain ranks highest in volleyball players, which is largely due to the repetitive nature of the hitting motion.[33-36] Therefore, understanding muscle firing patterns of the shoulder complex is helpful in developing muscle-specific treatment and training protocols, which may both minimize injury and enhance performance.

There are no known studies that have quantified muscle activity from the scapular muscles during the volley serve or spike. This is surprising given the importance of the scapular muscles in maintaining proper position of the scapula relative to the humerus. Volleyball players with shoulder pain often have muscle imbalances of the scapula muscles.[37] Therefore, the firing pattern of the scapular muscles during the volleyball serve and spike should be the focus of future research studies.

Rokito et al.[6] conducted the only known study that quantified muscle firing patterns of glenohumeral muscles during the volleyball serve and spike. These authors studied 15 female college and professional volleyball players who performed both the volleyball serve and spike. The shoulder muscles quantified included the anterior deltoid, supraspinatus, infraspinatus, teres minor, subscapularis, teres major, latissimus dorsi and pectoralis major. The serve and spike motions were divided into five phases, which collectively are 1.95 sec in duration for the serve[6] and 1.11 sec for the spike:[6] (i) wind-up (comprises 39% of total serve time and 33% of total spike time) begins with shoulder abducted and extended and ends with the initiation of shoulder external rotation; (ii) cocking (comprises 20% of total serve time and 23% of total spike time) – initiation of shoulder external rotation to maximum shoulder external rotation; (iii) acceleration (comprises 6% of total serve time and 8% of total spike time) – maximum shoulder external rotation to ball impact; (iv) deceleration (comprises 8% of total serve time and 9% of total spike time) – ball impact to when upper arm is perpendicular to trunk; and (v) follow-through (comprises 28% of total serve time and 27% of total spike time) – upper arm perpendicular to trunk to end of arm motion.

Shoulder EMG results by muscle and phase during the volleyball serve and spike are shown in table IV. Similar to other overhead throwing activities, muscle activity during the serve was relatively low during the wind-up and follow-through phases. However, during the wind-up phase of the spike, peak activity was recorded in the anterior deltoid, infraspinatus and supraspinatus. These muscles are important to help rapidly elevate the arm overhead (anterior deltoid and supraspinatus) and initiate external rotation (infraspinatus). The rotator cuff muscles are also active to help stabilize the humeral head in the glenoid fossa.

During the cocking phase the shoulder rapidly externally rotates, which helps explain the high activity in the infraspinatus and teres minor during both the serve and spike. As mentioned during the section on baseball pitching, these muscles also produce a posterior force on the humerus that may help unload the anterior capsule due to the humeral head attempting to translate

Table IV. Shoulder activity by muscle and phase during the volleyball serve and spike[a] (adapted from Rokito et al.,[6] with permission)

Muscles	No. of subjects	Phase				
		wind-up (% MVIC)	cocking (% MVIC)	acceleration (% MVIC)	deceleration (% MVIC)	follow-through (% MVIC)
Anterior deltoid	15					
Serve		21 ± 11	31 ± 13	27 ± 22	42 ± 17	16 ± 16
Spike		58 ± 26	49 ± 19	23 ± 17	27 ± 10	15 ± 7
Supraspinatus	15					
Serve		25 ± 10	32 ± 18	37 ± 25	45 ± 13	24 ± 16
Spike		71 ± 31	40 ± 17	21 ± 27	37 ± 23	27 ± 15
Infraspinatus	15					
Serve		17 ± 10	36 ± 16	32 ± 22	39 ± 21	13 ± 11
Spike		60 ± 17	49 ± 16	27 ± 18	38 ± 19	22 ± 11
Teres minor	15					
Serve		7 ± 8	44 ± 20	54 ± 26	30 ± 23	8 ± 9
Spike		39 ± 20	51 ± 17	51 ± 24	34 ± 13	17 ± 7
Subscapularis	15					
Serve		8 ± 8	27 ± 25	56 ± 18	27 ± 15	13 ± 11
Spike		46 ± 16	38 ± 21	65 ± 25	23 ± 11	16 ± 15
Teres major	15					
Serve		1 ± 1	11 ± 7	47 ± 24	7 ± 8	3 ± 3
Spike		28 ± 14	20 ± 11	65 ± 31	21 ± 18	15 ± 16
Latissimus dorsi	15					
Serve		1 ± 2	9 ± 18	37 ± 39	6 ± 9	3 ± 3
Spike		20 ± 13	16 ± 17	59 ± 28	20 ± 21	15 ± 10
Pectoralis major	15					
Serve		3 ± 6	31 ± 14	36 ± 14	7 ± 11	7 ± 6
Spike		35 ± 17	46 ± 17	59 ± 24	20 ± 16	21 ± 12

a Data are given as means and standard deviations, and expressed for each muscle as a percentage of an MVIC.

MVIC = maximum voluntary isometric contraction.

anteriorly as the shoulder externally rotates. Also, the rotator cuff muscles have high activity to generate glenohumeral compression and resist distraction. The relatively high activity from the subscapularis and pectoralis major (both internal rotators) help provide support to the anterior shoulder (without such support anterior instability may ensue), as these muscles also contract eccentrically to slow down and control the rate of the rapid shoulder external rotation.

An important distinction between the serve and spike occurs during the acceleration phase. During the serve the objective is not to impart maximum velocity to the ball but rather hit the ball so it 'floats' over the net with a parabolic trajectory in an area that would be most difficult for the opponent to return. In contrast, during the spike the primary objective is to hit the ball as hard as possible so as to convey maximum velocity to the ball. Consequently, muscle activity was higher in the powerful acceleratory muscles during the spike compared with during the serve. Because overhead throwing motions such as baseball pitching, football passing and the tennis serve achieve shoulder internal rotation angular velocities between 4000 and 7000°/sec,[9,19,38] it is reasonable to assume that similar internal rotation angular velocities occur during the volleyball spike. The shoulder internal rotators (teres major, subscapularis, pectoralis major and latissimus dorsi) all generated their highest activity for both the serve and the spike in order to both internally rotate the shoulder and accelerate the arm forward.

During the acceleration phase, teres minor activity peaked to provide a stabilizing posterior restraint to anterior translation. In contrast, infraspinatus activity was relatively low. The differing amounts of EMG activity between the teres minor and infraspinatus throughout the different phases of the serve and spike is interesting, especially since both the teres minor and infraspinatus provide similar glenohumeral functions and they are both located adjacent to each other anatomically. However, the spatial orientations of these two muscles are different, with the teres minor in a better mechanical position to extend the shoulder in a sagittal plane and the infraspinatus in a better mechanical position to extend the shoulder in a transverse plane. There are also clinical differences between these two muscles, as they are typically not injured together but rather an isolated injury occurs to either the teres minor or infraspinatus.[2,6] These different clinical observations between the teres minor and infraspinatus are consistent with the different muscle firing patterns that occur within any given phase of overhead throwing, such as baseball pitching (table I).[2]

During the deceleration phase, infraspinatus and supraspinatus activity was greatest during the serve, but not during the spike. In fact, rotator cuff activity was generally lower in the spike compared with the serve, which may be counterintuitive. For example, because a primary function of the rotator cuff is to generate shoulder compressive force to resist shoulder distraction, and since shoulder compressive forces from similar overhead throwing motions (such as baseball pitching and football passing) generate large shoulder compressive forces during this phase,[9,19] it is plausible to assume large compressive forces are also needed during the spike. The relatively low activity from the rotator cuff muscles during the spike is a different pattern compared with the moderate to high rotator cuff activity generated during the baseball pitch and football pass (tables I and II). The higher rotator cuff activity during baseball pitching and football passing is needed during this phase to resist the large distractive forces that occur at the shoulder, which are near or in excess of bodyweight. These EMG differences between varying overhead throwing motions may be due to mechanical differences between these different activities. For example, in both baseball pitching and football passing a weighted ball (5 oz [142 g] baseball and 15 oz [425 g] football) is carried in the hands throughout throwing phases but is released just prior to the beginning of the deceleration phase. With these weighted balls no longer in hand, the arm may travel faster just after ball release (beginning of deceleration phase) and thus more posterior shoulder forces and torques may be generated by the posterior musculature to slow down the rapidly moving arm. In the volleyball spike there is no weighted implement in the hand throughout the entire motion. Moreover, when the hand contacts the ball, the ball generates an equal and opposite force on the hand, which acts to slow down the forward moving hand. Therefore, a slower moving arm may result in smaller forces and torques at the shoulder to decelerate the arm and less muscle activity. This explanation may partially explain the lower rotator cuff activity in the volleyball spike compared with baseball pitching and football passing, especially from the posterior musculature (table IV). However, a biomechanical analysis of the volleyball spike is needed to quantify shoulder forces and torques to help confirm this hypothesis.

5. Shoulder EMG during the Tennis Serve and Volley

There is a scarcity of shoulder EMG data during the tennis serve and volley. Ryu and colleagues[39] conducted the only known study that extensively quantified shoulder EMG during the tennis serve. EMG data were collected during the serve from eight shoulder muscles using six male collegiate tennis players. One of the limitations of this study is there were no standard deviations reported and only a few subjects were used. The serve was divided into four phases: (i) wind-up start of service motion to ball release; (ii) cocking-ball release to maximum shoulder external rotation; (iii) acceleration-maximum shoulder external rotation to racquet-ball contact; and (iv) deceleration and follow-through-racquet-ball contact to completion of serve. Shoulder EMG results during the serve are shown in table V.

Mean EMG peaked for the infraspinatus and supraspinatus during the cocking phase. During this phase the shoulder externally rotates approximately 170° with a peak shoulder internal rotator torque of ≈65 N • m.[38] These kinematic and kinetic data help explain the high activity from the infraspinatus, which is active to initiate shoulder external rotation during the first half of the cocking phase. The infraspinatus and supraspinatus also contract to resist shoulder distractive forces during the cocking phase. Although not quantified during the tennis serve, the shoulder compressive force needed to resist distraction is ≈80% bodyweight during the cocking phase in baseball pitching, which is a similar motion to the tennis serve.[11] The biceps brachii may also help generate shoulder compressive force during the cocking phase,[15] which may help explain the relatively high activity from this muscle. Pectoralis major, latissimus dorsi and subscapularis activity was greatest during the acceleration phase, as they contract to help generate a peak shoulder internal rotation angular velocity ≈2500°/sec,[38] as well as accelerate the arm forward. Serratus anterior activity also peaked during the acceleration phase to properly

Table V. Shoulder activity by muscle and phase during the tennis serve[a] (adapted from Ryu et al.,[39] with permission)

Muscles	No. of subjects	Phase			
		wind-up (% MVIC)	cocking (% MVIC)	acceleration (% MVIC)	deceleration and follow-through (% MVIC)
Biceps brachii	6	6	39	10	34
Middle deltoid	6	18	23	14	36
Supraspinatus	6	15	53	26	35
Infraspinatus	6	7	41	31	30
Subscapularis	6	5	25	113	63
Pectoralis major	6	5	21	115	39
Serratus anterior	6	24	70	74	53
Latissimus dorsi	6	16	32	57	48

a Data are given as means (standard deviations not reported), and expressed for each muscle as a percentage of an MVIC.

MVIC = maximum voluntary isometric contraction.

position the scapula relative to the rapidly moving humerus. These EMG findings during the tennis serve are similar to EMG findings during baseball pitching, which is not surprising considering there are numerous kinematic and kinetic similarities between the tennis serve and baseball pitch.[9-11,38]

EMG activity during arm deceleration and follow-through demonstrated moderate to high activity, but less than the EMG observed during baseball pitching and football passing. One reason for this, as previously explained for the volleyball spike, is that the force the ball exerts against the racquet acts to slow down the arm, which may result in less posterior force and torque needed from muscle contractions. The relatively high activity from the biceps brachii helps stabilize the shoulder, resist distraction and decelerate the rapid elbow extension angular velocity, which peaks at ≈1500°/sec.[38] The moderate to high activity from the rotator cuff muscles generate compressive force to help resist shoulder distractive forces, with peak forces ≈75% bodyweight during the serve.[38]

A few studies have examined shoulder activity during the tennis backhand and forehand.[1,39,40] Ryu and colleagues[39] collected EMG data from eight shoulder muscles using six male collegiate tennis players. This study is weakened by the low number of subjects, no standard deviations are reported and there are no statistical analyses between the forehand and backhand volleys. The

Table VI. Shoulder activity by muscle and phase during the tennis forehand and backhand volley[a] (adapted from Ryu et al.,[39] with permission)

Muscles	No. of subjects	Phase		
		racquet preparation (% MVIC)	acceleration (% MVIC)	deceleration and follow-through (% MVIC)
Biceps brachii	6			
Forehand		17	86	53
Backhand		11	45	41
Middle deltoid	6			
Forehand		27	17	20
Backhand		22	118	48
Supraspinatus	6			
Forehand		22	25	14
Backhand		10	73	41
Infraspinatus	6			
Forehand		29	23	40
Backhand		7	78	48
Subscapularis	6			
Forehand		28	102	49
Backhand		8	29	25
Pectoralis major	6			
Forehand		10	85	30
Backhand		15	29	14
Serratus anterior	6			
Forehand		14	76	60
Backhand		12	45	31
Latissimus dorsi	6			
Forehand		6	24	23
Backhand		4	45	10

a Data are given as means (standard deviations not reported), and expressed for each muscle as a percentage of an MVIC.

MVIC = maximum voluntary isometric contraction.

forehand and backhand volleys have been divided into three phases:[39] (i) racquet preparation – shoulder turn to initiation of weight transfer to front foot; (ii) acceleration-initiation of weight transfer to front foot to racquet-ball contact; and (iii) deceleration and follow-through-racquet-ball contact to completion of stroke. Shoulder EMG results from this study are shown in table VI.

Muscle activity was relatively low during the racquet preparation phase, which is consistent with forehand and backhand shoulder EMG data from Chow et al.[1] Relatively large differences in muscle activity have been reported between the forehand and backhand during the acceleration phase.[1,39] High activity has been reported in the biceps brachii, anterior deltoid, pectoralis major and subscapularis during the forehand volley, but these same muscles exhibited low activity during the backhand volley.[1,39,40] The high activity during the forehand volley from the pectoralis major, anterior deltoid and subscapularis is not surprising given their role as horizontal flexors and internal rotators. However, the high activity from the biceps brachii is somewhat surprising. Morris et al.[41] also reported high biceps activity during the forehand in the acceleration phase. The biceps are in a mechanically advantageous position to horizontally flex the shoulder during the forehand motion, and they also may work to stabilize both the shoulder and elbow. Moreover, they may also help cause the slight amount of elbow flexion that occurs, or at least stabilize the elbow and keep it from extending (due to inertial forces and torques the arm applies to the forearm at the elbow as the arm rapidly horizontally flexes). The serratus anterior is also more active during the forehand compared with the backhand to help protract the scapula during the acceleration phase and help properly position the scapula relative to the rapidly moving humerus.

Posterior deltoids, middle deltoids, supraspinatus, infraspinatus, latissimus dorsi and triceps brachii exhibit high activity during the backhand volley, but relatively low activity during the forehand volley.[1,39] These muscles all work synergistically during the backhand to horizontally extend and externally rotate the shoulder. The triceps are also active to extend the elbow and help stabilize both the shoulder and elbow. The high activity from the supraspinatus and infraspinatus help provide shoulder compressive forces to resist shoulder distraction. The supraspinatus and deltoids also help maintain the shoulder in abduction.

6. Shoulder EMG during Baseball Batting

There is only one known study that has quantified muscle activity of the shoulder during baseball hitting.[7] Using the swings of 18 professional male baseball players during batting practice, these investigators quantified posterior deltoid, triceps brachii, supraspinatus and serratus anterior activity during the following swing phases: (i) wind-up – lead heel off to lead forefoot contract; (ii) pre-swing – lead forefoot contact to beginning of swing; (iii) early swing – beginning of swing to when bat was perpendicular to ground; (iv) middle swing – when bat was perpendicular to ground to when bat was parallel with ground; (v) late swing – when bat was parallel with ground to bat-ball contact; and (vi) follow-through-bat-ball contact to maximum abduction and external rotation of lead shoulder.

Muscle activity was relatively low during the wind-up and follow-through phases, with EMG magnitudes generally <25% MVIC. The posterior deltoid peaked at 101% MVIC during pre-swing and then progressively decreased throughout early swing (88% MVIC), middle swing (82% MVIC) and late swing (76% MVIC). Triceps brachii activity was 46% MVIC during pre-swing, peaked at 92% MVIC during early swing, and then progressively decreased to 73% MVIC during middle swing and 38% MVIC during late swing. Both the supraspinatus and serratus anterior generated relatively moderate and constant activity from pre-swing to late swing in the range 28–39% MVIC throughout these four phases.

Compared with overhand throwing, EMG data for hitting are relatively sparse, and thus it is hard to make definite conclusions. There are EMG data for only a few shoulder muscles with which to compare. Nevertheless, it does appear that both glenohumeral and scapular muscles generate high activity during the swing, as both concentric and eccentric muscle actions are needed throughout the swing. To make it even more difficult to develop summaries of muscle firing patterns in hitting, there are currently no shoulder kinetic data in the hitting literature. The focus of future hitting studies should be on quantifying shoulder forces and torques throughout the swing, and shoulder EMG data for additional shoulder muscles, such as the infraspinatus, teres minor, pectoralis major, latissimus dorsi, biceps brachii and trapezius.

7. Shoulder EMG during the Golf Swing

Several studies have examined shoulder muscle activity during the golf swing.[5,42-45] Jobe et al.[43,44] and Pink et al.[5] used male and female professional golfers to study shoulder activity. These authors quantified both shoulder[43,44] and scapular[45] muscles of both the lead arm (left arm for a right-handed golfer) and trail arm (right arm for a right-handed golfer) and also reported no significant differences during the swing in shoulder EMG between male and female professional golfers.[44] The golf swing has been divided into five different phases:[43-45] (i) take-away – from ball address to the end of backswing; (ii) forward swing – end of backswing to when club is horizontal; (iii) acceleration – when club is horizontal to club-ball impact; (iv) deceleration – club-ball impact to when club is horizontal; and (v) follow-through – when club is horizontal to end of motion.

Table VII. Shoulder activity by muscle and phase during the golf swing^a (adapted from Pink et al.,[5] with permission)

Muscles	No. of subjects	Phase take-away (% MVIC)	 forward swing (% MVIC)	 acceleration (% MVIC)	 deceleration (% MVIC)	 follow-through (% MVIC)
Supraspinatus	13					
Trail arm		25±20	14±14	12±14	7±5	7±5
Lead arm		21±12	21±15	18±11	28±20	28±14
Infraspinatus	13					
Trail arm		27±24	13±16	7±8	12±13	9±10
Lead arm		14±12	16±13	27±25	61±32	40±24
Subscapularis	13					
Trail arm		16±12	49±31	68±67	64±67	56±44
Lead arm		33±23	29±24	41±34	23±27	35±27
Anterior deltoid	13					
Trail arm		5±6	21±23	10±10	11±15	8±8
Lead arm		13±13	9±9	10±10	21±25	28±30
Middle deltoid	13					
Trail arm		3±3	2±3	2±5	8±10	8±8
Lead arm		3±3	4±6	2±2	7±8	5±3
Posterior deltoid	13					
Trail arm		17±25	10±15	9±13	17±16	11±12
Lead arm		5±8	24±20	11±9	9±9	8±14
Latissimus dorsi	13					
Trail arm		9±7	50±38	47±44	39±39	28±19
Lead arm		17±13	48±25	31±28	32±33	18±15
Pectoralis major	13					
Trail arm		12±9	64±30	83±55	74±55	37±35
Lead arm		21±32	18±14	83±75	74±74	38±23

a Data are given as means and standard deviations, and expressed for each muscle as a percentage of an MVIC.

MVIC = maximum voluntary isometric contraction.

Table VIII. Scapular activity by muscle and phase during the golf swing[a] (adapted from Kao et al.,[45] with permission)

Muscles	No. of subjects	Phase				
		take-away (% MVIC)	forward swing (% MVIC)	acceleration (% MVIC)	deceleration (% MVIC)	follow-through (% MVIC)
Levator scapulae	15					
Trail arm		29±19	38±39	34±41	12±12	4±4
Lead arm		5±3	42±20	62±46	39±26	29±24
Rhomboids	15					
Trail arm		30±18	46±27	32±24	21±12	5±4
Lead arm		7±13	68±27	57±46	26±26	30±33
Upper trapezius	15					
Trail arm		24±14	4±4	13±20	23±19	5±6
Lead arm		5±4	29±26	42±50	34±29	27±18
Middle trapezius	15					
Trail arm		37±12	18±24	19±26	26±21	12±15
Lead arm		3±3	51±26	36±21	21±18	28±20
Lower trapezius	15					
Trail arm		52±28	17±12	16±28	22±22	10±15
Lead arm		7±10	49±27	37±28	20±16	35±18
Upper serratus anterior	15					
Trail arm		6±4	58±39	69±29	52±18	40±14
Lead arm		30±15	20±29	31±31	31±18	21±13
Lower serratus anterior	15					
Trail arm		9±5	29±17	51±33	47±25	40±18
Lead arm		27±11	20±21	21±24	29±20	29±21

a Data are given as means and standard deviations, and expressed for each muscle as a percentage of an MVIC.

MVIC = maximum voluntary isometric contraction.

Shoulder muscle activity during the golf swing is shown in table VII[5] and scapular muscle activity is shown in table VIII.[45] During the take-away phase, muscle activity was relatively low to moderate, suggesting that lifting the arms and club up during the backswing is not a strenuous activity. The levator scapulae and lower/middle trapezius of the trail arm exhibit moderate activity during this phase to elevate and upwardly rotate the scapula, while moderate activity from the serratus anterior of the lead arm helps protract and upwardly rotate the scapula. Upper, lower and middle trapezius activities were highest during this phase compared with the other four phases. Interestingly, infraspinatus and supraspinatus activities of the trail arm were also highest during this phase but only firing ≈25% MVIC, which implies relatively low activity from these rotator cuff muscles throughout the golf swing. This is surprising in part because most shoulder injuries are overuse injuries that typically involve the supraspinatus or infraspinatus.[46-49] However, these rotator cuff EMG data are only for the trail arm, which may exhibit less overall rotator cuff activity throughout the swing compared with the lead arm. These data imply that rotator cuff injury risk may be higher in the lead arm, but this conclusion may not be valid because it only takes relative muscle activity into account and not other factors (such as impingement risk between shoulders). Another interesting finding is that anterior, middle and posterior deltoid activities were all relatively low throughout all phases, implying that these muscles are not used much throughout the swing.

During the forward swing phase, muscle activity was also relatively low to moderate, except for relatively high activity from the subscapularis, pectoralis major, latissimus dorsi and serratus anterior of the trail arm to adduct and internally rotate the trail arm and protract the scapula. There was also relatively high activity from the rhomboids and middle/lower trapezius of the lead arm to help retract and stabilize the scapula.

Muscle activity during the acceleration phase was higher overall compared with the forward swing phase. The subscapularis, pectoralis major, latissimus dorsi and serratus anterior of the trail arm demonstrated high activity during the acceleration phase to continue adducting and internally rotating the trail arm. These muscles may be the most important 'power' muscles of the upper extremity to help accelerate the arm during the acceleration phase of the downswing. In addition, using a short or long backswing may affect shoulder activity during the acceleration phase. Slightly greater pectoralis major and latissimus dorsi activity has been reported during the acceleration phase when a short backswing was used compared with a long backswing, pointing to the conclusion that shoulder injury risk may increase over time.[42]

During the deceleration phase the subscapularis, pectoralis major, latissimus dorsi and serratus anterior of the trail arm continued to demonstrated high activity, although now the muscle action was more eccentric and slightly smaller in magnitude compared with the acceleration phase. Low to moderate activity occurred from the scapular muscles of the lead arm, while high pectoralis major and infraspinatus activity occurred in the lead arm. Muscle activity generally decreased from the deceleration phase to the follow-through phase.

8. Conclusions

This review reports shoulder muscle activity, and when available shoulder kinematics and kinetics, during a variety of upper extremity sports. During overhead throwing, high rotator cuff muscle activity was generated to help resist the high shoulder distractive forces of ≈80–120% bodyweight during the arm cocking and deceleration phases. During arm cocking, peak rotator cuff activity is 49–99% MVIC in baseball pitching and 41–67% MVIC in football throwing. During arm deceleration, peak rotator cuff activity is 37–84% MVIC in baseball pitching and 86–95% MVIC in football throwing. Peak rotator cuff activity is also high in the windmill softball pitch (75–93% MVIC), the volleyball serve and spike (54–71% MVIC), the tennis serve and volley (40–113% MVIC), baseball hitting (28–39% MVIC) and the golf swing (28–68% MVIC).

Peak scapular muscle activity is also high during the arm cocking and arm deceleration phases of baseball pitching, with peak serratus anterior activity 69–106% MVIC, peak upper, middle and lower trapezius activity 51–78% MVIC, peak rhomboids activity 41–45% MVIC and peak levator scapulae activity 33–72% MVIC. Moreover, peak serratus anterior activity was ≈60% MVIC during the windmill softball pitch, ≈75% MVIC during the tennis serve and forehand and backhand volley, ≈30–40% MVIC during baseball hitting, and ≈70% MVIC during the golf swing. In addition, during the golf swing, peak upper, middle and lower trapezius activity was 42–52% MVIC, peak rhomboids activity was ≈60% MVIC, and peak levator scapulae activity was ≈60% MVIC. Understanding when and how much the shoulder muscles are active during upper extremity sports is helpful to physicians, therapists, trainers and coaches in providing appropriate treatment, training and rehabilitation protocols to these athletes, as well as help better understand the injury mechanism.

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