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Electromyographic Analysis of Trunk Muscle Activation During a Throwing Pattern Following Rotator Cuff Mobilization

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Electromyographic analysis of trunk muscle activation during a throwing pattern following rotator cuff mobilization

A Thesis Presented

by

Aubrey Lynn Doede

To the Joint Science Department

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In partial fulfillment of

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ABSTRACT

Correct muscular activation of the body segments during an overhand throw is achieved when movement originates in the larger and more proximal legs and trunk and moves sequentially to the smaller, distal segments of the shoulder and arm. This sequence permits angular velocity to transfer progressively through the throw as part of an open kinetic chain. The athlete can summate angular velocity and segmental forces only if he is able to create a separation between the body segments during the movement pattern, and this separation is thus essential to effective segmental sequencing for activation of the trunk muscles to occur separately from distal segment motion. Limited mobility of the shoulder and scapula during the kinematic sequence will limit the ability of that segment to receive and contribute to the angular velocity of its proximal neighbors and to apply its own muscle torque to the throwing implement. This may result in compensatory motion of the proximal muscle groups to meet the demands placed on the body.

To establish a link between compensatory activation of the trunk muscles and mobility in the rotator cuff and to apply this relationship to the pattern of the overhand throw, activity in the latissimus dorsi and external oblique/quadratus lumborum muscles was measured using surface electromyography in 40 college-age participants during arm flexion and lateral shoulder rotation. Muscle activation was recorded both before and after mobilization of relevant throwing muscles through targeted functional exercise. Results showed no significant change but suggested a general decrease in the level of peak muscle activation after participants engaged shoulder exercises. This is indicative of a downward trend in compensatory trunk activation during the initiation of shoulder motion. An increase in overall trunk muscle activity was also observed after exercise, which may imply a simultaneous engagement of the proximal throwing muscles in response to shoulder motion.

ACKNOWLEDGEMENTS

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CHAPTER 1: INTRODUCTION

Background

In athletic activities involving an overhand throw or strike, an athlete is able to produce maximum velocity through the use of an open kinetic chain by correctly timing the muscular activation of the body segments associated with the movement pattern. Although this principle applies to all movement patterns involving the release of an implement or the strike of an object, athletic activities involving the overhand throw of an object are among the most commonly studied versions of the pattern, and much is known about these sports and movements as they relate to muscle activation (Kreighbaum and Barthels, 1985; Escamilla and Andrews, 2009; Kibler, 1998).

Therapies based on current research (Escamilla *et al*, 2009) use muscle-strengthening regimens consisting of discrete and repetitive movements and normally with some form of resistance, for rehabilitative and preventative treatments for shoulder injury. These regimens rely on knowledge of the appropriate anatomy and function in order to maximize the effectiveness of the exercise. Strengthening regimens for athletes whose sports require an overhand throw are supported by extensive EMG studies of shoulder activity during the throwing motion so that these muscles may be appropriately targeted and strengthened (Escamilla and Andrews, 2009). However, these methods commonly focus on specific muscles or muscle groups and do not consider a whole-system approach to proper strength and function. In fact, many therapies to date tend to take a more symptom-based approach to pain and injury rather than viewing the body as a series of interconnected parts, where dysfunction in one area may cause a symptom elsewhere in the body.

In this paper, I attempt to establish a stronger link between mobility of the shoulder and the accompanying activation of the trunk muscles. Based on known muscle activation during the overhand throw, my research aims to build upon other studies to establish this relationship as more critical to the movements associated with throwing pattern. This experimental design was based on current knowledge of the interconnectedness between the muscles and muscular fascia as well as the anatomy and biomechanics of the human body when engaged in the throwing pattern. The experiment was also aimed at viewing human anatomy as a full-body system rather than a series of independent parts.

Proximal-to-distal sequencing in an overhand throw

The throwing pattern requires the body to be divided into functional segments, consisting of the proximal pelvis and trunk; and the more distal segments of the shoulder girdle, arm, forearm, and hand. These segments are activated from proximal to distal positions in the body in relationship to the ground as they articulate around the hip, intervertebral, sternoclavicular, shoulder, elbow, radioulnar, and wrist joints, respectively (Kreighbaum and Barthels, 1985). While simplified, this is a basic description of the human body during segmental sequencing of the movement pattern of the overhand throw. A comprehensive explanation of the benefits of segmental separation will be explained later in this section, and a more in-depth view of the structures involved will be covered in a later section.

The trained throwing athlete knows that to create maximal force before the time of release, the body must follow a specific sequence of rotations and accelerations within the body segments. The pattern to be explored here, termed the “throwlike pattern” by

Kreighbaum and Barthels (1985) includes any movement in which a proximal body segment initiates a forward movement, thereby causing the more distal segments to “lag behind” the rest of the body. This creates a pull between the proximal and distal segments, ultimately allowing the distal segment to accelerate forward just before the sequence is complete. This is demonstrated below by an illustration of the javelin throw (Figure 1.1).

The movement description, however, not only refers to activities involving an overhand throw, but also includes the motions seen in the shot put, a tennis serve, and even a soccer kick, as these activities still share the same basic proximal-to-distal sequencing pattern (Kreighbaum and Barthels, 1985). However, this first section will use the javelin as a focus in order to simplify the explanation of relevant biomechanics and associated anatomy and relate it to the present research, and a later section will add aspects of the baseball pitch for the purpose of elaborating upon the associated anatomy of the movement pattern. In addition, these two athletic activities are nearly biomechanically identical, with the major difference residing in the release angles of the implements (Kreighbaum and Barthels, 1985).

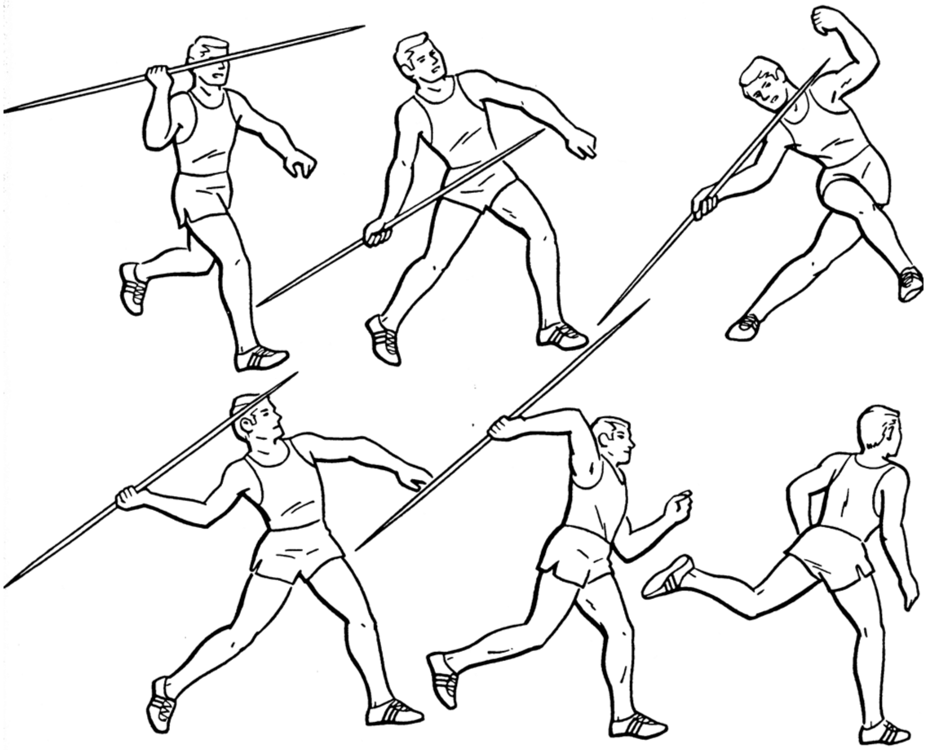


Figure 1.1. Sequential motions of the javelin throw. As with any throwing pattern, the legs and hips must move forward here, leaving the arm and hand behind until later in the throw (from Bunn, 1972).

The sequence of this throwing pattern is initiated by the larger and more proximal segments as part of an open kinetic chain, in which the muscle torques within each segment act on the segments distal to them for movement and energy to transfer progressively toward the smaller and lighter segments. In addition, the most distal segment in an open kinetic chain is not fixed in any one position and may therefore move freely in space, thus allowing the ultimate release of the accumulated kinetic energy in the system. In the case of a throwing pattern, the motion is initiated with a muscle torque from the legs, which provide a stable base, and later transfers to the arm and hand. Notice in Figure 1.1 that the initial step forward in the javelin throw causes the pelvis and torso also to rotate forward under the athlete before the throwing arm becomes an active part of the sequence. As mentioned previously, the distal upper extremity lags behind the body, and, segment-by-segment, the body moves forward to complete the throw (Kreighbaum and Barthels, 1985).

The arm and hand, due to their smaller mass, could only produce this velocity if they were acting as part of a full-body system. However, because the proximal segments are stronger and heavier, they are able to create a large muscle torque and velocity that the smaller and lighter segments can then carry until the end of the throw. In this way, the sum of the forces of each segment will be greater than the magnitude of force that the distal segments could have produced using their weight and momentum alone (Bunn, 1972). As the body of the athlete follows its segmental sequence, it will create the forces necessary to produce a forward projectile of an implement by moving about each segement's respective axis of rotation (Kreighbaum and Barthels, 1985).

In addition to being stronger and heavier than the distal body segments, the size of the legs and trunk with respect to the arm and hand gives them a relatively larger radius about which they must rotate during the throw. Because rotational inertia is defined as the product of the mass of an object (m) times the square of the radius of rotation (r), and because muscle torque (τ) is equal to the product of the moment of inertia (I) and the segment's angular acceleration (α), any initial torque applied to this larger, proximal segment will encounter a greater moment of inertia:

$$I = mr^2 \qquad\qquad \tau = I\alpha$$

Furthermore, because a larger moment of inertia implies that the angular acceleration of this segment will be smaller than one with a smaller radius, the more distal segments of the open kinetic chain will encounter a smaller moment of rotational inertia and, therefore, greater angular acceleration. According to the principle of the conservation of angular momentum, in order to attain the linear velocity that is necessary to achieve a high-speed throw, the angular momentum of the larger base segments must be transferred to the smaller distal segments. This will decrease the system's moment of rotational inertia through a reduction of the radius of rotation, thereby allowing each successive body segment to increase in angular velocity (Kreighbaum and Barthels, 1985).

In addition, it has been shown that in order to produce an energetically efficient open-chain system, the transfer of angular velocity between segments will ideally occur when the more proximal segment reaches its peak angular velocity (Bunn, 1972). For example, it is ideal for the shoulder and arm only to begin their forward segmental motion after the pelvis and trunk have completed their rotation but before the segment begins to decelerate. This concept explains why it is desirable for the arm and hand to lag behind the body for a period of time during the throwing motion, as it will allow enough time for the torso to reach maximum angular velocity.

Figure 1.2 presents a visual model of this process, showing that in addition to a reduction of rotational inertia, the individual muscle torques of each segment also play a role. Due to the decreasing segment sizes, muscle torque at each stage will become smaller with each transfer of angular velocity. This is a general model of an ideal sequencing pattern; however, it may be applied to the throwing pattern and the segments of the pelvis (A), trunk (B), shoulder (C), arm (D), and hand (E) (Kreighbaum and Barthels, 1985).

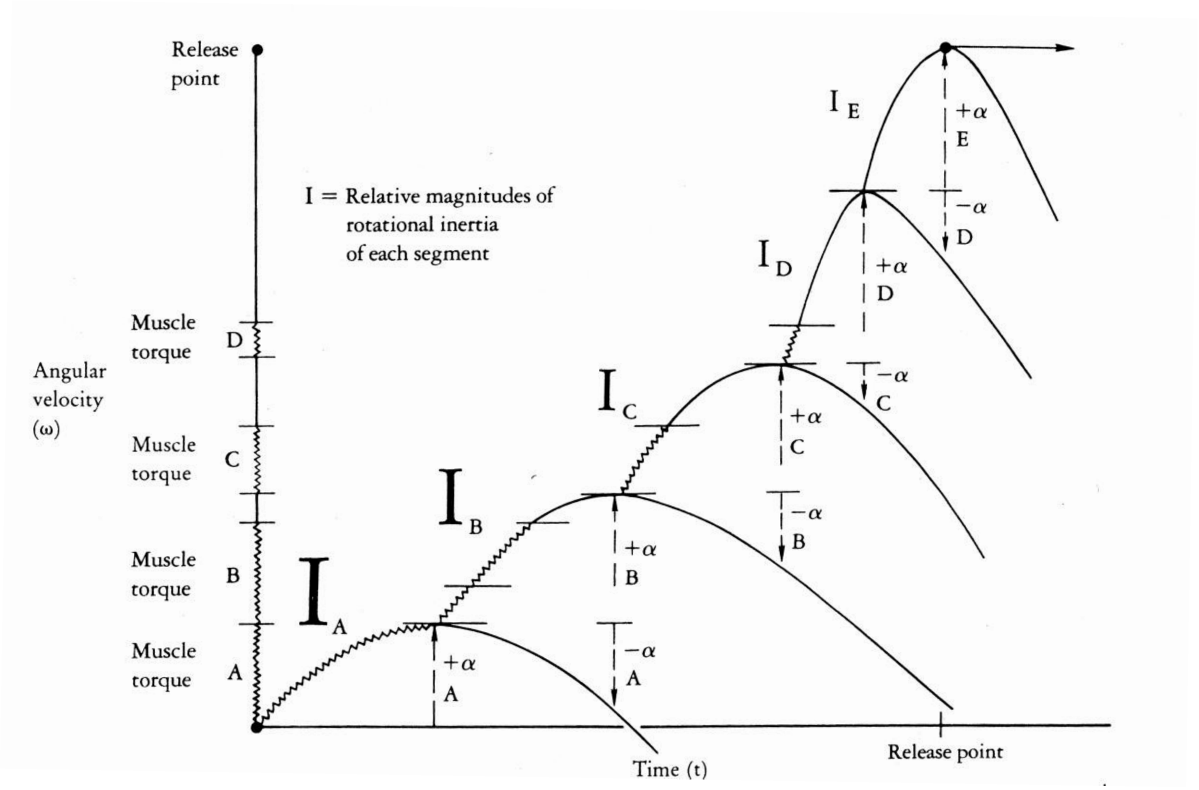


Figure 1.2. A visual representation of the transfer and increase of angular velocity with decreasing rotational inertia. Each segment will transfer angular velocity and incorporate muscle torque at the peak of its own acceleration. Here, each jagged line represents a muscle torque that is added to the system's total angular velocity. Note that torque decreases as acceleration moves up the segmental chain. The magnitudes of rotational inertia also decrease, as represented by the increasingly smaller symbol size (from Kreighbaum and Barthels, 1985).

As a result of this sequential action, the ability of a larger proximal segment to produce a greater force is combined with the ability of the smaller distal segment to more easily overcome the rotational inertia that inhibits the lower body segments from attaining these high velocities (Kreighbaum and Barthels, 1985).

Relevant anatomy of the throwing pattern

Actions within the shoulder and arm segments of the throwing pattern depend largely on the muscle groups that control, move, and support the scapula as it fulfills its role as one segmental portion of the movement. As a general description, the scapula is a thin, flat bone which lies relatively flat along the posterior surface of the thoracic back (Kibler, 1998). The bony attachment sites of the scapula are limited to the glenohumeral joint and the acromioclavicular joint, leaving scapular stabilization dependent on the various muscular attachments associated with this bone. Due to the lack of intrinsic joint stability, the numerous small muscles of the rotator cuff act to stabilize the joint but also allow the scapula to have a great range of motion, as illustrated by Figure 1.4.

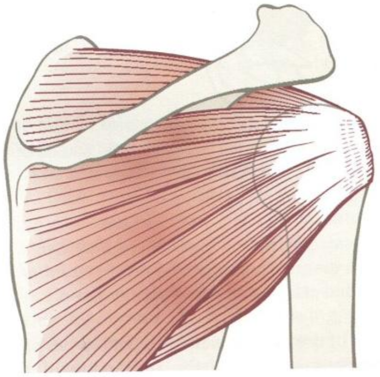


Figure 1.3. The scapula has limited joint articulations and is thus kept stable by the muscular structures that attach to its surface (from Meyers, 2005).

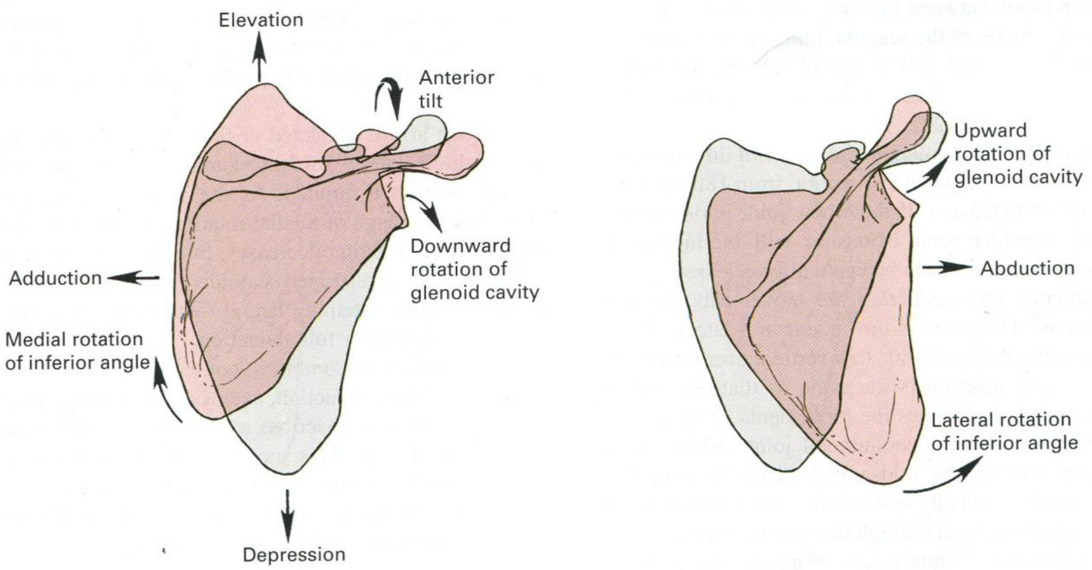


Figure 1.4. Possible directions of movement of the scapula. Scapular movements of adduction and abduction are also referred to as retraction and protraction, respectively, in this paper (from Meyers, 2005).

In order to achieve this range of motion, the scapula relies on the attachments of three major muscle categories. First, scapular stabilization and rotation is achieved by the trapezius, rhomboid group, levator scapulae, and serratus anterior. Second, the deltoid, biceps, and triceps move the humerus and will consequently move the scapula simultaneously. Third, the muscles of the rotator cuff – supraspinatus, infraspinatus, teres minor, and subscapualris – are responsible for moving the scapula alone (Kibler, 1998). Furthermore, it will be shown in the next section that other muscles, such as the latissimus dorsi, teres major, serratus anterior, and pectoralis major, while not directly linked to the scapula, play an influential role in executing the throwing pattern.

In addition to the muscles of the shoulder and rotator cuff, the muscles of the back and torso also play an essential role in the throwing pattern. These muscles include the external and internal obliques and the quadratus lumborum. Lateral flexion and rotation of the trunk, as mentioned previously, contribute largely to the angular acceleration of a throw.

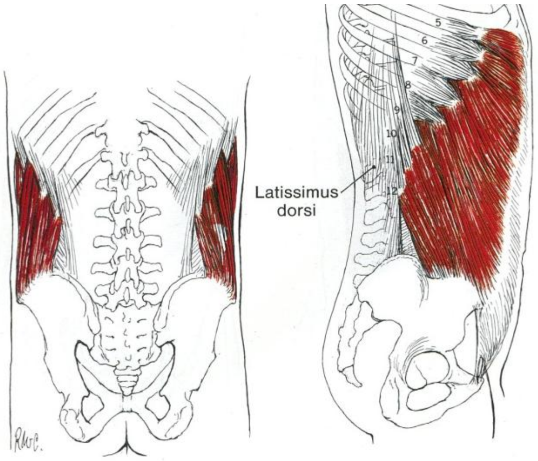


Figure 1.5. The lateral fibers (left) and anterior fibers (right, originating from ribs five through eight) of the external oblique muscles (from Kendall *et al*, 2005).

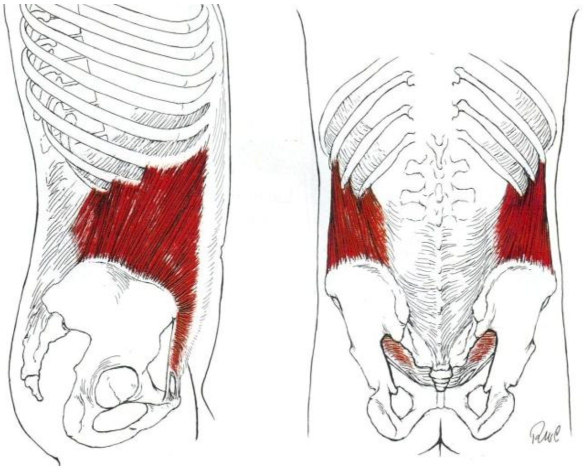


Figure 1.6. The upper anterior fibers (left) and lateral fibers (right) of the internal oblique muscles (from Kendall *et al*, 2005).

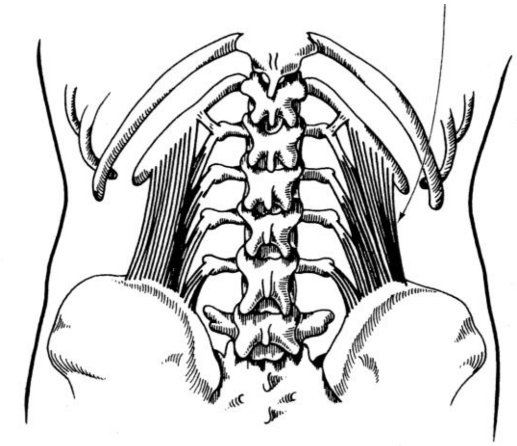


Figure 1.7. The quadratus lumborum laterally flexes the vertebral column (from Kelley, 1971).

The anterior fibers of the external oblique muscles work with the anterior fibers of the contralateral internal oblique to rotate the vertebral column. The lateral fibers of the external oblique, in conjunction with the lateral fibers of the contralateral internal oblique, also rotate the vertebral column, and the lateral fibers of the internal oblique alone may act to laterally flex the trunk, as does the quadratus lumborum (Kendall *et al*, 2005). In addition, it is notable that the lateral fibers of the external oblique (shown originating from ribs ten through twelve in Figure 1.5) also interdigitate with the latissimus dorsi, which is partially responsible for the internal rotation, adduction, and extension of the shoulder joint as well as hyperextension of the spine (Kendall *et al*, 2005).

Segmental sequencing during the overhand throw

To initiate the overhand throw, the athlete steps forward with a simultaneous backward push with the hind foot, creating an oppositional force between the back foot and the ground. This force initiates and contributes to the sequential activation and rotation of the legs and trunk (Knudson and Morrison, 2002), as illustrated in Figure 1.8.

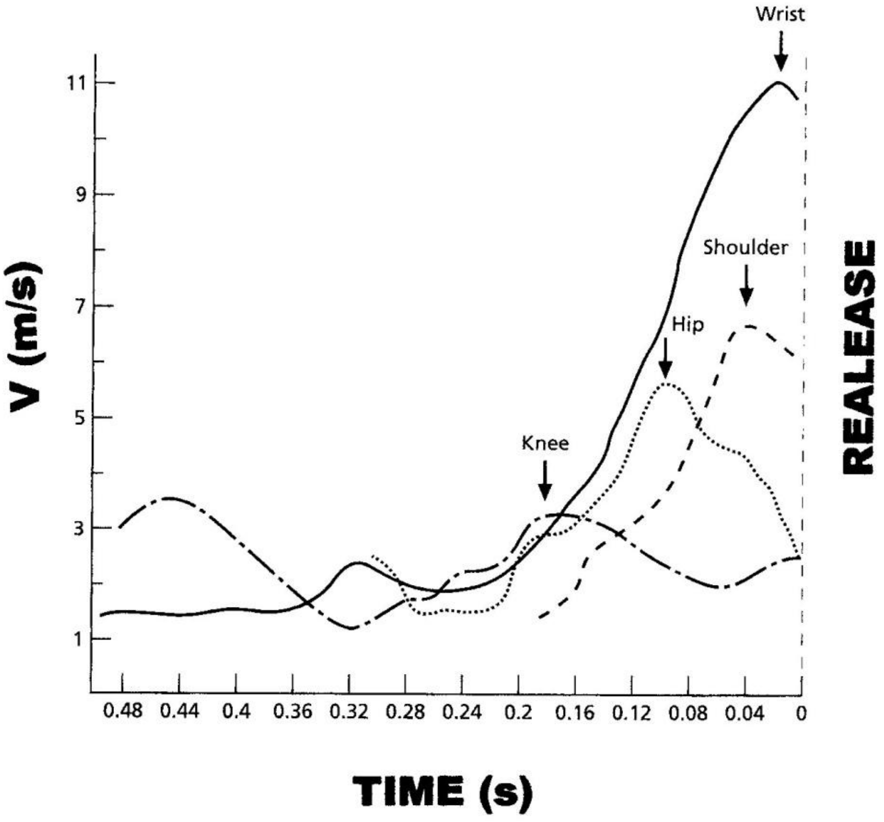


Figure 1.8. Sequential activation of the knee, hip, shoulder, and wrist during a shot put throw (from Lanka, 2000).

At this time, medial pelvic rotation, along with transverse rotation and lateral flexion around the vertebral column, are the sources of angular momentum and rotational inertia described in the previous section. The resultant angular velocity will ultimately lead to the linear acceleration of the arm and hand at the end of the throw (Kreighbaum and Barthels, 1985). Trunk rotation, caused in part by the internal and external oblique muscles, has been found to produce a peak angular velocity of approximately 600 degrees per second in the pelvis and close to 1,200 degrees per second in the torso shortly following contact of the foot with the ground (Escamilla and Andrews, 2009), and it has been shown that during a tennis serve, 51% of total kinetic energy and 54% of total force is generated by the lower segments (Kibler, 1998). Thus, it is essential to the effectiveness of this movement pattern and kinetic sequence that trunk activation occur before and almost separately from muscular activation in the rotator cuff in order to produce an effective kinetic sequence (Milton, 2010).

Not only do these trunk movements contribute force and speed to the throw, but they will also help to correctly position the upper extremity in preparation for the remainder of the movement (Kreighbaum and Barthels, 1985). As explained by Kibler (1998), the athlete's body may be seen as analogous to an inverted funnel, which summates and transfers forces from the larger proximal segments to the much smaller and distal ones. Thus, proper positioning and control of the segments are as important to the production of a high velocity throw as the actual generation of muscle forces that move through these segments. As movement is transferred through the shoulder and to the humerus, for example, the throw is most effective if the

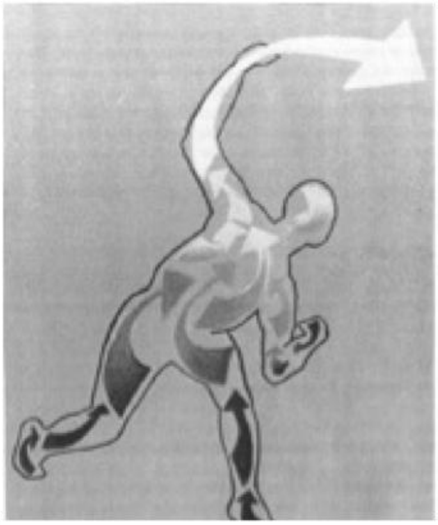


Figure 1.9. During a throw, the athlete's body should act as a funnel for muscle forces as they travel through the body segments (from Kibler, 1998).

humerus is rotating about an axis that travels through the exact center of the joint and segment. To accomplish this proper position during the early phases of the throw, the rotation of the trunk in the transverse plane leads to arm abduction and elbow flexion so that both segments are at 90 degrees relative to their respective proximal segments (Kreighbaum and Barthels, 1985). While still in this position, the anterior deltoid and pectoralis major muscles work to hold the shoulder in abduction (Escamilla and Andrews, 2009). This phase of the throw in a baseball pitch is known as arm cocking (phase b of Figure 1.10). At this time, the scapula of the throwing arm is retracted, placing demand on the rhomboid group to achieve this position.

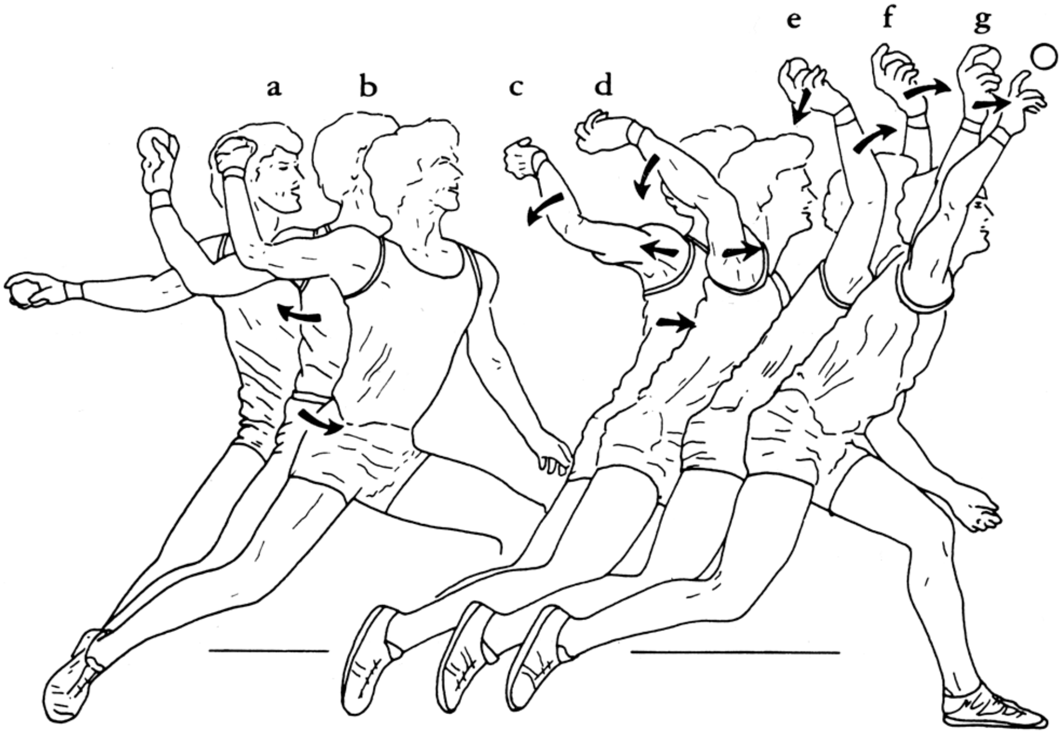


Figure 1.10. Sequence of a baseball throw. As the legs and the trunk begin to move forward, the shoulder, arm, and hand consequently lag farther behind the rest of the body, provided that the athlete possesses the necessary shoulder mobility (from Kreighbaum and Barthels, 1985).

Scapular retraction at this time allows the aforementioned anterior muscles to maintain the proper amount of tension before arm acceleration (Kibler, 1998).

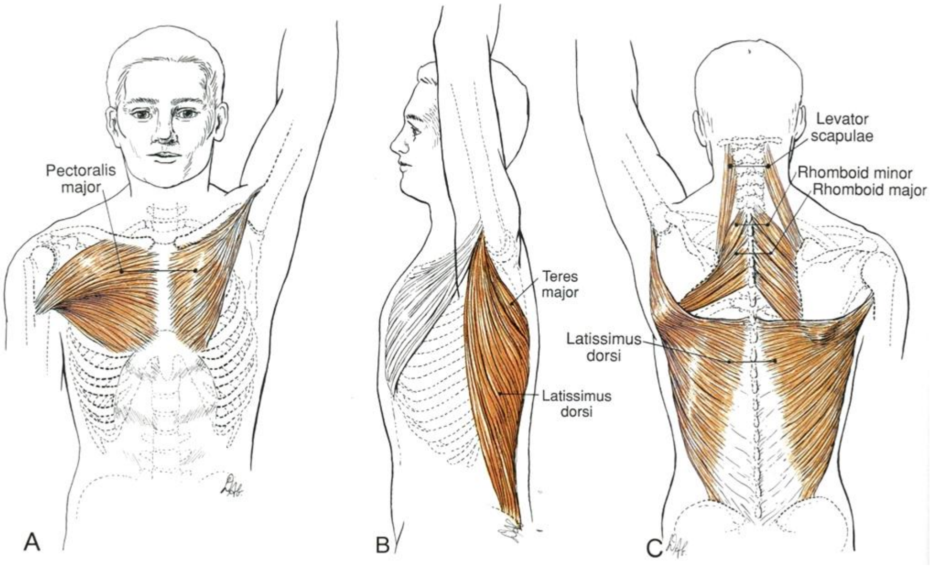


Figure 1.11. The pectoralis major (A), teres major (B), and rhomboid group (C) act to stabilize the scapula and hold the humerus in the proper position during the arm cocking phase (from Kendall *et al*, 2005).

As the trunk continues to rotate in the transverse plane, muscular force and angular momentum are transferred successfully to the distal segments, and the muscles of the rotator cuff help to bring the body through the throw until its completion. In addition to motion through the conservation of angular momentum, there is also a sequential activation of muscles that contribute to the total force and velocity throughout the motion (Kibler, 1998). This is the source of the additional muscle torques shown in Figure 1.2 in the first section.

The shoulder and arm will laterally rotate with the activation of the infraspinatus and teres minor (Escamilla and Andrews, 2009), a motion that is associated with a "lagging back" of the distal segment in preparation for arm acceleration (Kreighbaum and Barthels, 1985). As a general description, the portion of the throw involving the distal segements requires the scapula to remain stable as the humerus rotates about the shoulder joint (phases c and d of

Figure 1.10). In some activities involving the throwing pattern, the athlete's feet are no longer or only minimally in contact with the ground by the time any force is transferred to the shoulder and arm, leaving stability of the segments almost entirely reliant on the scapular muscles (Kibler, 1998). At this point during the throwing pattern, the infraspinatus and teres minor also aid in stabilizing the glenohumeral joint against dislocation. These muscles work with the assistance of the other lateral rotators of the shoulder – the supraspinatus and subscapularis – and the medial shoulder rotators, the pectoralis major and latissimus dorsi (Escamilla and Andrews, 2009).

Nearing the end of trunk rotation, the scapula then protracts and upwardly rotates, placing the arm in partial medial rotation as the elbow continues to extend past 90 degrees (Bunn, 1972). This scapular position is also important because it allows the scapula to continue its motion while preventing shoulder impingement at the acromion process (Kibler, 1998). Scapular protraction is accompanied by forearm pronation and wrist flexion in order to position the wrist and hand for the throw. As described earlier, the arm and forearm will begin to accelerate at the peak angular velocity of the trunk, thus drawing on the previous segment's angular velocity while reducing rotational inertia and adding muscle torques to the system. In the throwing athlete, the proximal segment's peak angular velocity will occur when that segment's associated muscles are maximally flexed or extended (Bunn, 1972). In the case of the overhand throw, elbow extension occurs during the final stages of trunk rotation, and as a result of the stretched arm position, the distal segment will begin its forward acceleration. In addition, and especially in the case of the javelin throw, forceful extension of the elbow may activate the muscular stretch reflex and further accelerate the arm motion through forceful involuntary muscle contraction (Kreighbaum and Barthels, 1985).

Goal and experimental design

The concepts mentioned in the previous sections regarding the transfer of angular velocity and the summation of segmental muscular forces can only be accomplished if the athlete is capable of adequately creating a separation between motion in the body segments during the overhand throw. This is because the mechanical and elastic properties of the muscle groups will only be effective when they are positioned correctly relative to other body segments. As a result, any tightness or inflexibility that exists within or around the muscles of the rotator cuff or shoulder girdle will limit the mobility of the arm and scapula during the kinematic sequence of the throwing pattern. Consequently, the shoulder and other distal segments will also have a limited ability to receive and contribute to the angular velocity from their proximal neighbors and to apply their own muscle torques to the implement. Furthermore, if the muscle forces do not transfer completely to the distal segments, muscle activity and angular momentum will remain in the proximal segments of the back and torso, and as a result, these muscle groups will engage in compensatory activation in order to meet the demands placed on the body.

It has been recently postulated (Myers, 2009) that a large factor contributing to muscle tightness and joint immobility are the networks of fascia that join muscle groups. It is already known that this thin layer of tissue surrounds all tissue groups of the body, including the internal organs and the skeletal muscles. The novel theory about fascia resides in the possible connections that the tissue may make between seemingly separate muscle groups and how these connections affect human movement on a global, rather than muscle-specific, scale.

The muscles of the torso investigated in the current research were the latissimus dorsi muscle and the quadratus lumborum and oblique muscle pair. According to Meyers (2009), both the internal and external obliques have close fascial connections with the rhomboid muscle group via the serrratus anterior. In addition, the external obliques are explicitly linked to the latissimus dorsi through close muscular origins and insertions at the ribs (Kendall *et al*, 2005).

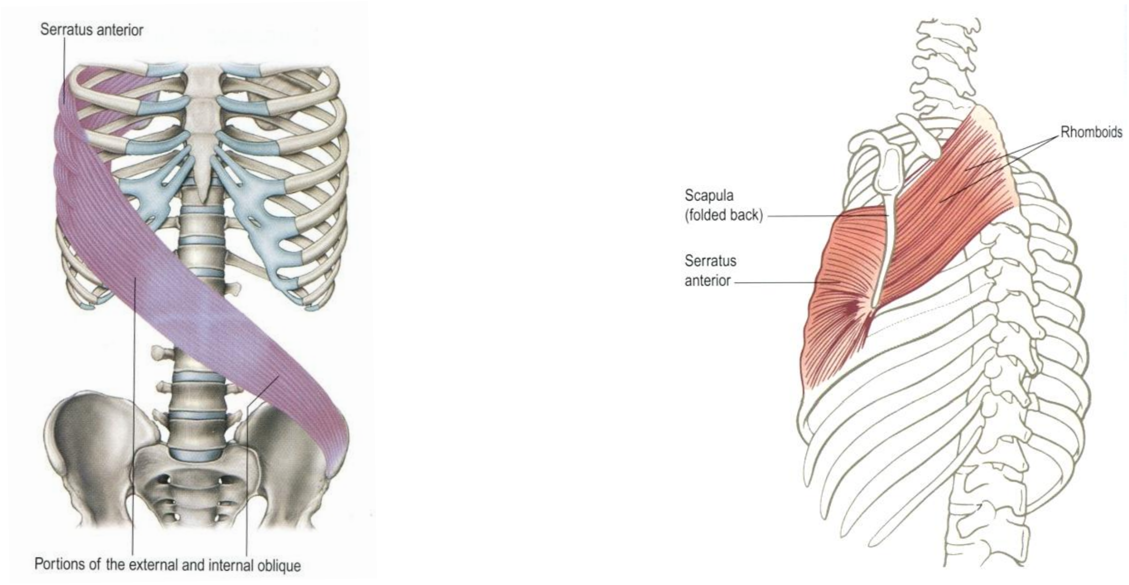


Figure 1.12. Suggested fascial connections. **Left:** between the oblique muscles and the serratus anterior, and **Right:** between the serratus anterior and rhomboid group (from Meyers, 2009).

Incidentally, all of these muscles are active during at least one phase of the throwing pattern, implying that inactivity in the rhomboids, serratus anterior, or other scapular movers will have direct consequences for the oblique muscle group or the latissimus dorsi. Furthermore, the rhomboid group has strong fascial connections with three of the scapular muscles – supraspinatus, infraspinatus, and teres minor – thus further supporting the relationship between the low back and shoulder muscle groups. Finally, the latissimus dorsi may be linked to the anterior humerus and pectoralis major through a mutual fascial connection with the teres major muscle (Meyers, 2009).

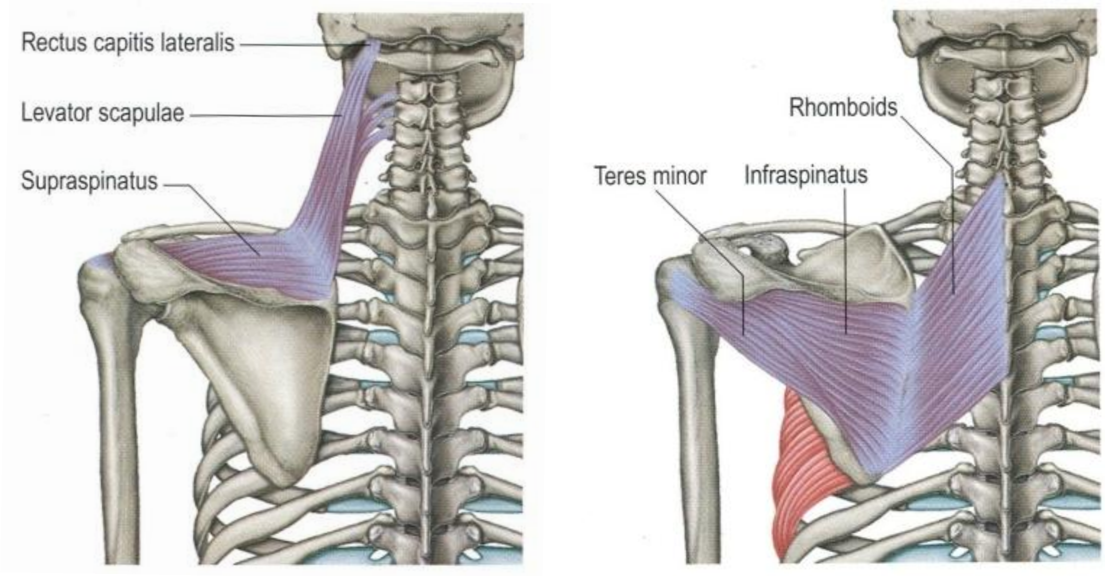


Figure 1.13. In addition to connections with the serratus anterior, the rhomboids are thought to connect to muscles of the rotator cuff (subscapularis excluded) via connecting muscular fascia (from Meyers, 2009).

The hypothesis of this study is that a subject's decreased ability to engage the muscles of the rotator cuff (as a result of posture, inactivity, or other reasons) will result in compensatory activation of the low back muscles during two tests for muscular activity. This is represented by a sudden increase in the electromyographic reading during the initial trial. It is also predicted that after participants performed exercises designed to increase rotator cuff engagement and glenohumeral joint mobility, the reading of muscle activity in the back and torso would consequently be reduced during a second measurement because the shoulder's increased ability to complete the movement tests on its own will relieve the trunk muscles from some or all of their compensatory activation.

This prediction was thought to have one possible exception for a test in which participants began the movement with arms held in 90 degrees flexion and raised the arms overhead (described more fully in the next chapter). Because of the initial position of the hands in front of the torso, the change in the center of mass to farther in front of the body would increase static lumbar muscle activity in the body's effort to maintain stability in this position. As the arms were moved overhead and in line with the original center of mass, the lumbar muscles would have less need to engage, regardless of the level of shoulder mobility. However, if this were the case and muscle activity decreased rather than spiked after a repositioning of the arms, it was still hypothesized that the overall muscle activity in the lumbar area would be reduced during the second test of muscle activation.

CHAPTER 2: MATERIALS AND METHODS

Participant group

25 male and 15 female volunteers between the ages of 18 and 23 were recruited from the campuses of the Claremont Colleges in Claremont, California. Of the 40 total subjects, 37 claimed that they regularly participated in an athletic activity. Six participants had some history of rotator cuff injury, but no subjects reported any shoulder pain at the time of the experiment. Volunteers provided informed consent to participate and entered the study with knowledge of the risks involved. However, they were not given details regarding the research objectives in order to maintain a single-blind nature for the study.

Measurement of muscle activity

Instrumentation and electrode placement

Activity in the latissimus dorsi and of the external oblique and quadratus lumborum muscles were measured using surface electromyography (sEMG). Pre-gelled BioPac EL 503 general-purpose electrodes were used, measuring 1 cm in diameter with a 35 mm contact point. The sEMG data were gathered using two inputs of a data acquisition system (Powerlab 16/30). Signals were collected at a sampling rate of 10 k/s and a frequency band pass of 2-10 kHz with a range of 20 mV.

Following specifications by Kram and Casman (1998), activity in both muscle groups was detected by the surface electrodes on each participant’s dominant side. Additionally, one reference electrode was placed at the top of the lateral side of the ipsilateral ankle. To record activity of the latissimus dorsi, one electrode was positioned approximately 2 cm from the midline of the spine at the level of the L3 vertebral process, over the muscle mass. The second electrode was placed approximately 2 cm above the first, oriented longitudinally along the muscle mass so that the electrodes were parallel to the spine. sEMG activity of the quadratus lumborum and external obliques was detected by placing one electrode halfway between the iliac crest and twelfth rib on the subject's dominant side and the second electrode approximately 3 cm anterior to the first, at an oblique angle.

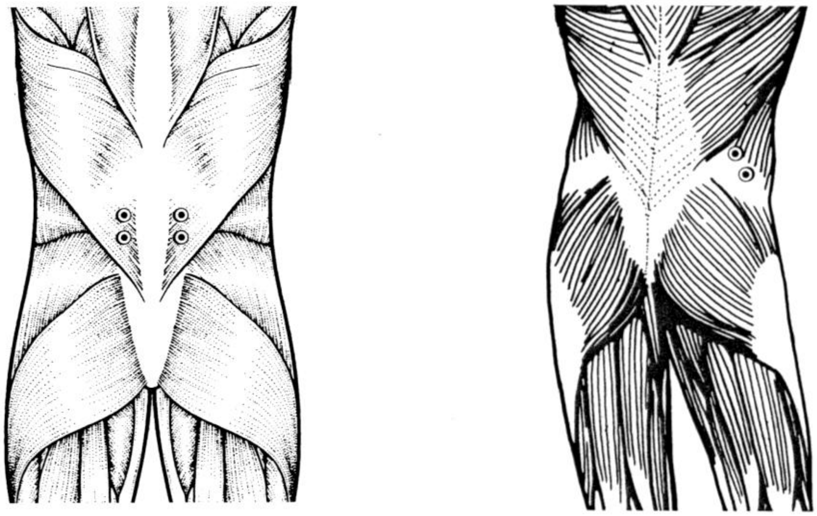


Figure 2.1. Surface electrode placement. **Left:** placement for the latissimus dorsi. **Right:** placement for the quadratus lumborum and external obliques (from Kram and Casman, 1998).

Initial sEMG measurements

Two initial movement tests were performed in order to measure muscle activity of the low back during motion in the rotator cuff. Each subject was asked to stand at a wall with the heels and upper back touching and with the feet hip-width apart, pointed straight forward. This position was intended to help ensure consistency of posture across participants, as any variation in alignment has the potential to alter an individual's scapular position (Kreighbaum and Barthels, 1985). A seated or supine position for these functional tests would have been better suited for testing the available range of motion of these shoulder muscles alone by disengaging the muscles of the trunk and preventing them from substituting for a lack of mobility elsewhere (Kendall *et al*, 2005). However, this research was focused on the level of compensatory action of the trunk muscles, and the participants were therefore asked to stand, thus allowing this substitution to occur if applicable.

Furthermore, subjects were not asked to mimic a throwing pattern to further limit the amount of variability in motion between participants because an individual's throwing technique and skill play a major role in the muscles used and the extent of muscular activity in different segments. Instead, participants were asked to perform two discrete movement tasks involving the rotator cuff. These tasks were chosen because they were likely to engage the same shoulder muscles that are active during an overhand throw.

In the first test of muscular activity, participants began with arms laterally abducted and with both elbows touching the wall. All segments (torso, humerus, and forearm) were positioned at right angles to each other with palms facing downward, elbows flexed at 90 degrees, and hands parallel to the ground. Once a stable baseline of sEMG activity was established over a 10 second time period, the participant was asked to bring the backs of the hands to the wall while keeping the elbows in the same position throughout the motion. The participant then held this second position for an additional 10 seconds in order to establish an overall level of muscular activity after the muscle reached a maximum level.

Figure 2.2. Movement test of lateral rotation. **Left:** Initial position. **Right:** Final position.

It has been well established that after a certain degree of humeral motion, the scapula will simultaneously protract at half the rate of lateral arm abduction or forward flexion at the glenohumeral joint (Kibler, 1998; Hay and Reid, 1982). This applies to forward flexion after 60 degrees or to lateral abduction after 30 degrees (Hay and Reid, 1982). Thus, in this movement test, when the arms were laterally abducted at 90 degrees, the scapulae in this position were protracted at 30 degrees before the hand movement occurred. The muscles at work in the initial position include the deltoid and supraspinatus to abduct the arm and the upper trapezius and serratus anterior to help protract the scapula. Once participants began the transition to the second position, the motion began to engage the lateral rotators of the shoulder – the infraspinatus, posterior deltoid, and teres minor (Kendall *et al*, 2005).

Participants began the second movement test with arms medially rotated and held in 90 degrees forward flexion and with elbows locked and palms facing downward, parallel to the ground. After a baseline level of EMG activity was established, participants were asked to bring both arms over the head.

Figure 2.3. Movement test of arm flexion. **Left:** initial position. **Right:** final position.

Here, as before, 90 degrees forward flexion will cause the scapula to be at 30 degrees of protraction in the initial position, thereby involving the serratus anterior and deltoid group here as well. In order to raise the arms overhead, participants must make use of the pectoralis major, latissimus dorsi, teres major, subscapularis, and rhomboid group (Kendall *et al*, 2005).

Rotator cuff mobilization

Participants were asked to complete a series of five shoulder exercises with the intention of mobilizing the scapulae through engagement of the scapular muscles. With the exception of the last exercise, subjects were asked to perform the exercises in a seated position with feet placed flat on the floor and with a small arch in the lower back. Again, the purpose of this seated position was to maintain as much between-subject consistency as possible throughout the exercises. A seated position as opposed to a standing position aimed to relieve the lower back and trunk muscles from continual activity. This was intended to allow the muscles of the shoulder and rotator cuff to activate and move the upper extremity almost independently of the trunk.

The motions performed during these exercises were intended to engage the same muscles and create some of the same motions apparent in a throwing pattern. These motions included humeral abduction, internal and external medial rotation withing the glenohumeral joint, and scapular protraction and retraction. Targeted muscles here included the latissimus dorsi, pectoralis major, rhomboids, and serratus anterior, among other secondary muscle groups that act to move and stabilize the shoulder.

In addition, from a point of view involving the muscular fascia, these exercises promote engagement of the extensor muscles of the body by placing the torso in an upright posture for the first four exercises and in a partially loaded and fully extended position for the last. Proper positioning of all joint segments here could also theoretically cause a release of muscular fascia.

After participants were taken through rotator cuff mobilization exercises described below, sEMG activity in the latissimus dorsi and the area over the obliques and quadratus lumborumduring these two movements was measured a second time in order to compare muscular activity within each participant.

Seated overhead extension

In this exercise, participants were asked to interlace the fingers and bring the arms straight overhead with the palms facing upward. Participants were also asked to lock the elbows, look up toward the hands, and to relax the trapezius muscles as much as possible. This exercise was held for one minute.

Figure 2.4. Overhead extension (adapted from Egoscue Inc., 2009).

The purpose of this exercise was to induce abduction and internal rotation of the humerus. Thus, this motion engages all four muscles of the rotator cuff. In addition, the latissimus dorsi and pectoralis major muscles assist in medial rotation of the humerus (Kelley, 1971), a motion which allows the arm to fully flex and reach a position above the head (Hay and Reid, 1982). A conscious effort to disengage the trapezius, especially the upper fibers, allowed for depression of the scapula (Kendall *et al*, 2005). As mentioned previously, the scapula will protract with arm abduction at a ratio of two degrees of arm abduction to every one degree of scapular protraction. Thus, scapular protraction will also require activation of the rhomboid group and serratus anterior to stabilize the scapula in this position. Instructing the participant to look up toward the hands also contributes to the extended spinal position, as it will enhance the extension of the cervical spine and contribute to increased thoracic extension.

Seated arm circles

Participants were asked to perform arm circles while keeping the scapula retracted and the trapezius muscles relaxed as much as possible, again for the purposes of scapular depression. Throughout the exercise, the participants were also expected to maintain a hand grip in which the fingers were curled toward the palms with the thumbs pointed straight. This hand position was intended to stiffen the wrist joint and transfer more of the work to the shoulder girdle.

Arm circles were expected to be approximately 6 inches in diameter. This exercise was repeated for a total of 100 repetitions: 50 times forward with palms facing downward and thumbs pointed straight ahead, and 50 times backward with palms facing upward and thumbs pointed straight back.

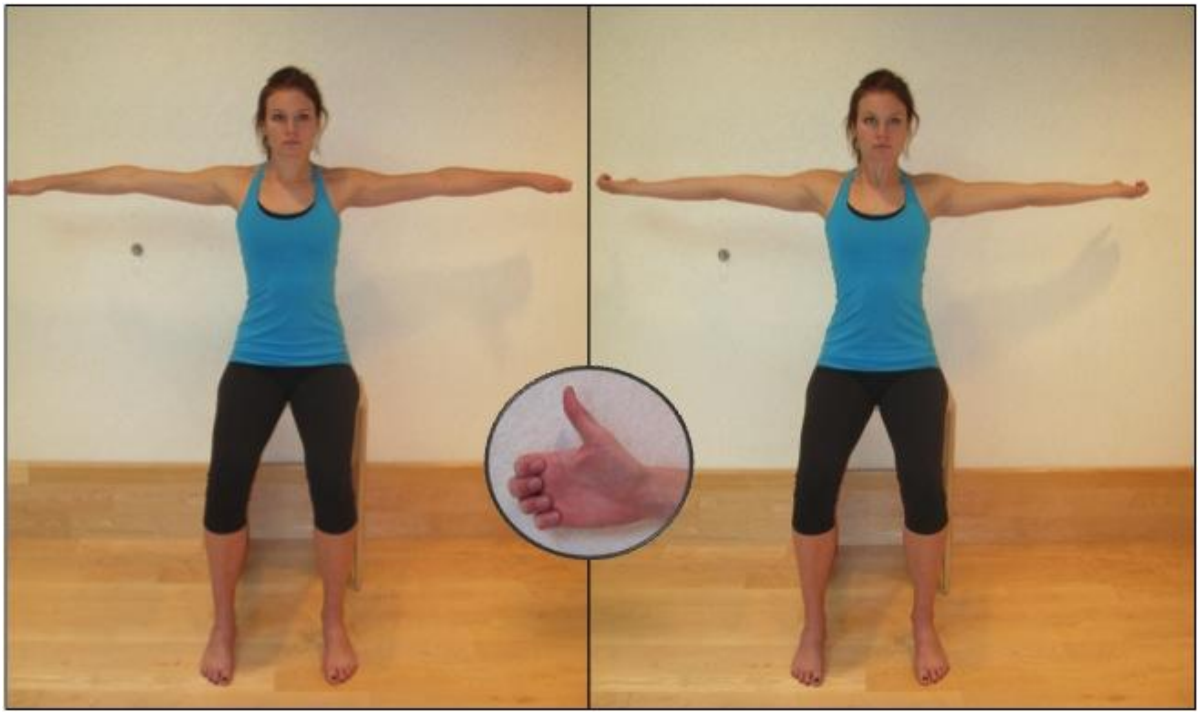


Figure 2.5. Arm circles. **Left:** Forward circles with palms down. **Right:** backward circles with palms facing up. **Center:** Hand position with knuckles curled and thumb straight (adapted from Egoscue Inc., 2009).

For both forward and backward variations of this exercise, the rotation of the humerus creates a demand for scapular stability through scapular retraction. In this exercise, the 2:1 ratio of humeral abduction and scapular protraction also applies, and the scapular retractors – namely the rhomboid group – must activate to maintain this position. During forward rotation, this scapular protraction of the scapulae is exaggerated by the medial rotation of the humerus. Thus, there is an increased demand on the scapular retractors to maintain stability throughout the exercise. During backward rotation, external rotation of the humerus during arm abduction forces scapular retraction, reinforcing the position.

Elbow curls

Participants were asked to maintain the same hand grip throughout this exercise as they had with the arm circles in order to limit motion in the wrist. In this exercise, knuckles were placed against the temples with the thumbs pointed downward. From this position, the elbows were first pulled back and were then brought together in front of the participant's head. The elbows were expected to remain at shoulder level throughout the exercise and were allowed to come as close together as possible without dropping the arms removing the knuckles from their starting position. The exercise was performed for 2 sets of 25 repetitions.

Figure 2.6. Elbow curls (adapted from Egoscue Inc., 2009).

This exercise is similar to the arm circles as it relates to the position of the scapula in relation to the arms. The unique aspect of this exercise is that additional demand was placed on the scapular muscles as the elbows first moved behind the head, emphasizing the retracted scapular position, and then moved in front of the head, bringing the scapulae into full protraction. However, full scapular protraction was limited by asking the participant to maintain the hands in a constant position with the arms at shoulder height. As a result, additional demand was placed on the muscles of the thoracic spine, such as the latissimus dorsi, to release and allow the thoracic spine to flex and extend normally.

Shoulder Rolls

While allowing the arms to relax and hang, participants were asked to roll the shoulders forward and then backward for 25 repetitions each. This exercise simply took the scapula through their full range of motion in both directions, allowing for increased activation through repetition.

Downward dog

To ensure proper spacing between the hands and feet, participants started on hands and knees with the shoulders positioned directly above the hands and the hips directly above the knees with the knees hip-width apart. Once participants reached the downward dog position on hands and feet, they were asked to relax the head and neck and pull the chest toward the knees, causing an anterior pelvic tilt. The exercise was held for one minute.

Figure 2.7. Shoulder rolls (adapted from Egoscue Inc., 2009).

Figure 2.8. Downward dog. **Top:** starting position, with shoulders and hips directly above hands and knees, respectively. **Bottom:** final position (adapted from Egoscue Inc., 2009).

The purpose of this exercise was to engage all of the exensor muscles of the body while simultaneously creating a discrepancy between the load demands on the upper and lower torso. In this position, the arms were forced into external rotation, producing demand on both the shoulder and upper back simultaneously during this activity. More specifically, the infraspinatus and teres minor muscles of the rotator cuff laterally rotate the shoulder joint (Kendall *et al*, 2005). Meanwhile, the low back does not experience a load demand and is therefore separated from the rest of the body during the exercise. With the proper degree of flexibility, the latissimus dorsi may also become lengthened during this exercise.

CHAPTER 3: RESULTS

The recorded sEMG signals were rectified and calculated using a time-constant decay integral with a reset value of 0.2 seconds. This calculation was performed on both muscle groups, the latissimus dorsi (Lat) and the obliques and quadratus lumborum (Ob-QL) during the movment tests of lateral rotation (LR) and arm flexion (AF) for a total of four calculations per participant, seen in Figure 3.1. Since the main goal of this study was to test for a significant difference before and after rotator cuff mobilization, the relevant quantity is the difference in the muscle activity, measured by the level of calculated sEMG activity.

Individuals perform each motion at different speeds. In order to account for this discrepancy, the muscle activation for each run was taken as the average of the maximum value of muscle activation during the run and the 0.2, 0.4, and 0.6 seconds of measurements on either side of the maximum value. To test for a significant change in muscle activity between trials, the difference in the level of activation was first calculated for each individual participant. These differences were then averaged to arrive at the average difference in muscle activation.

In order to test for significance, the sample standard deviation of the differences was calculated. While the sample size was moderately large (n=40) enough that the application of a z-statistic would yield fairly accurate results, the more precise t-statistic was used instead. To perform the test, the calculated t-statistic was compared against the critical value for this test, determined in part by the degrees of freedom (df=39). The critical values for the t statistic with 39 degrees of freedom are 2.423, 1.684, and 1.303 for the 1%, 5%, and 10% levels of significance, respectively.

	Seconds Around Maximum			
Muscle Group / Movement Test	**0**	**0.2**	**0.4**	**0.6**
Ob-QL/ LR	1.08	0.50	0.45	0.19
Lat/ LR	0.19	0.72	1.10	1.48
Ob-QL/ Arm	1.15	1.55	1.68	1.59
Lat/ Arm	1.39	1.41	1.41	1.35

Figure 3.1. Values of significance for the four variations of muscle groups and movement types. Highlighted portions indicate areas of significance at the 10% level (O-QL=oblique-quadratus lumborum, Lat=latissimus dorsi, LR=lateral rotation test, Arm= arm flexion test).

The statistical test showed no significant difference in the oblique-quadratus lumborum muscles during lateral rotation (Ob-QL/ LR) and a 10% significance level (t=1.48) for the test of latissimus dorsi activity during lateral rotation (Lat/ LR) when the value was taken at 1.4 seconds around the maximum (see Appendix, Graphs 1-4). The arm flexion movement test showed the highest level of significance when measuring oblique and quadratus lumborum (Ob-QL/ AF) activity (t=1.68) at 1.0 second around the maximum, a value which approached the 5% significance level (t=1.684). The arm flexion test for latissimus dorsi (Lat/ AF) activity reached 10% significance on all accounts, with the highest level residing in the 0.6 to 1.0 second range (t=1.41). Thus, sEMG activity in the oblique and quadratus lumborum region during full arm flexion yielded the most statistically significant results about the maximum after rotator cuff mobilization (see Appendix, Graphs 5-8).

However, when examining the differences in overall muscle activation, these results appear to have different implications. The average level of muscle activity was found for each combination of muscle group and movement test during the time periods both before and after the maximum point. These averages were calculated for statistical significance using a t-statistic and were then compared to find a difference, if any, in muscle activation once the participant had performed the mobilization exercises.

Muscle Group / Movement Test	**Average Activation Before Peak**		**Average Activation After Peak**		**Total**	
	%Δ	*t*	%Δ	*t*	%Δ	*t*
Ob-QL/ LR	0.3	0.19	0.3	0.25	0.3	0.31
Lat/ LR	4.0	1.57	1.4	0.52	2.74	1.47
Ob-QL/ Arm	0.5	0.33	1.6	1.10	1.07	1.03
Lat/ Arm	5.7	1.54	5.0	1.10	5.35	1.84

Figure 3.2. Percent change in muscle activation and values of significance before and after the peak for the four variations of muscle groups and movement types. Highlighted portions indicate areas of significance at the 10% level (Ob-QL=oblique-quadratus lumborum, Lat=latissimus dorsi, LR=lateral rotation test, Arm= arm flexion test).

Here, the change in activity for the latissimus dorsi during lateral rotation (Lat/ LR) was highest during the period before lateral rotation was performed (4.0% change, t=1.57) compared to a 10% (t=1.48) level of significance when comparing peak activations. Activity for the latissimus dorsi during arm flexion (Lat/ AF) decreased before the movement test (5.7% change, t=1.54) and in activity overall (5.35% change, t=1.84) compared to a maximum t-statistic of 1.41 when comparing the average maximum values. Thus, for both movement tests involving activity of the latissimus dorsi, there was a greater value of change at the 10% significance level when comparing overall muscle activation than when comparing maximum activity alone.

While oblique and quadratus lumborum activity during arm flexion (Ob-QL/ AF) showed a significant change at the 10% level when comparing maximum points only (t=1.68), and while this was the highest t-statistic available for this mode of comparison, there was no statistically significant difference whatsoever in this area while using the change in overall activity level as a mode of comparison. When comparing the oblique pair and quadratus lumborum during lateral rotation (Ob-QL/ LR), there was no significant change on any account.

CHAPTER 4: DISCUSSION

Disparities in muscular activation

The results of this study indicate that the exercises used here are not significantly involved in the reduced compensatory activation of the trunk musculature. However, due to several limitations in the experimental process and the availability of resources, the possibility that rotator cuff mobility is linked to trunk over-activation should not be ruled out completely.

The downward trend in average peak activation had a greater level of significance when comparing activity of the latissimus dorsi muscle versus the oblique and quadratus lumborum muscles. This difference was also observed when measuring the average overall muscular activation: here, there was also a greater level of significance for comparisons between measurements of the latissimus dorsi muscle. This relationship showed an upward trend during the second trial and this finding was observed to be stronger and more significant than a comparison of peak activation alone.

This discrepancy in the change in activity may have been due to the fact that this muscle group has stronger links – both in the musculature and fascia – to the arm and shoulder muscles. This is especially the case in the movement test of arm flexion, a movement in which this muscle is an active part. The same principle applies in some of the mobilization exercises as well – namely the seated arm circles, seated elbow curls, and downward dog – as the participants were frequently asked to raise their arms in flexion. Thus, it seems logical that the latissimus dorsi was more affected by the mobilization exercises.

Experimental limitations

This experimental process was limited in several aspects, and these factors may have affected the quality of data collection. The present research made use of surface EMG data collection; however, this is not the most current or most precise means of recording muscle activity. During the trials, electrodes were intended to record signals from one or two specific muscles; however, because electrodes were placed on the surface of the skin, one cannot be entirely confident that there was not cross-talk with other muscles in the recorded signal. For example, the quatratus lumborum is a deeper muscle of the back, and a surface recording for this muscle would undoubtedly encounter signals from other muscles as well. The latissimus dorsi is superficial to the lumbar paraspinals, which are always active in trunk stabilization whenever the body is upright, and therefore, activity in these muscles may have interfered with readings of the latissimus dorsi activation.

Alternatively, EMG studies that utilize needle electrodes rather than surface electrodes are capable of recording from very specific sites with very little noise, as the needle electrodes may be placed directly into a single motor unit of the muscle in question. A recording method of this type would have been extremely beneficial, especially because the muscle contractions measured in this study were of low force magnitude (Basmajian and de Luca, 1985). This type of data collection would have yielded more accurate and reliable results regarding the source of the EMG signal.

The experimental results were also limited because they were based on a very specific sample population of physically active college students, and these results are hardly representative of the population at large. Participants were required to be free of pain at the time of the experiment in order to avoid risk of injury and further complications with the results; however, an uninjured population skews the data due to this same lack of current injury. Most importantly, however, while this type of therapy may ideally be used to restore strength and flexibility in the joints of injured or less mobile individuals in addition to healthy athletes, the participants in this study were drawn from a college campus setting with a limited age and health distribution: on average, these students are younger and in better physical condition than the average population. Therefore, students of the Claremont Colleges are unlikely to be representative of the population as a whole.

Finally, the exercises performed in this study were chosen based on their functional purposes and muscle recruitment tendencies as they related to the movements involved in the throwing pattern. In addition, these exercises were selected because it was thought that all participants would be capable of completing them and that the movements were simple enough so that the experimental process would have as little variability as possible. However, because there were five separate exercises involved in the study, and even though many of the movements recruited the same or similar muscles, it is impossible to be certain about whether some exercises were more beneficial than others for achieving heightened shoulder mobility. In addition, while these five were chosen for the study, many alternatives may have been substituted and may have yielded similar or even more significant results.

The most logical extension of this study would be the inclusion of a broader sample population, including younger and older individuals. Drawing from a wider distribution of individuals will have the added benefit of increasing the distribution of the strength of the shoulder, including some individuals who have sustained injuries. Ideally, the additional study would focus only on the injured volunteers, allowing for a true test for the efficacy of the therapy.

In addition, it was not possible, given the participants and the time frame of the current research, to require participants to repeat the given exercises outside of the laboratory. Ideally, participants would be willing and able to reliably repeat these exercises on a daily basis for a specified amount of time before the second measurement of muscle activity was conducted. The reason for this alteration is that the data approached significance and may produce more statistically profound with continued use of therapy. If this were to be applied to a different experiment, however, it would be necessary to ensure that all participants follow the exercise regimen correctly.

CHAPTER 5: CONCLUSION

The purpose of this research is to substantiate, if possible, the effects that a mobilized rotator cuff has on the muscle activity in the lower back and trunk. Although only some results reached a 10% significance level, it is still believed that the overall downward trend of muscle activity suggests that some efficacy exists for rotator cuff mobilization to reduce muscular activity in the low back.

One alternate conclusion with respect to these results is that after shoulder mobilization, the need for compensatory trunk muscle activation during the initiation of arm movement was reduced. This was seen by the downward trend in the average peak value between trials. However, the muscles of the shoulder and rotator cuff are not isolated to and do not solely move the upper extremity. It has been established that muscles such as the latissimus dorsi are active during both the movement tests and some of the mobilization exercises used in this experiment (Kendall *et al*, 2005; Kelley, 1971).

It is possible that these exercises, while meant to activate the muscles in the shoulder, may have indirectly activated other muscles of the trunk as well due to the interconnectedness of the fibers. Thus, this would lead to the observed increase in overall muscle activity during the second trial. Not only would this theory support the observed upward trend in average overall muscular activity, but it also supports the view that mobilizing a joint by working the body in proper function and posture, rather than stretching or strengthening one focused muscle or muscle group, will activate and engage the entire muscular system.

LITERATURE CITED

Basmajian, JV & de Luca, CJ, 1985. *Muscles Alive: Their Functions Revealed by Electromyography* (5th ed.). Baltimore, MD: Williams and Wilkins. 561 pp.

Bunn, JW, 1972. *Scientific Principles of Coaching* (2nd ed.). Englewood Cliffs, NJ: Prentice Hall. 338 pp.

Cram, JR, & Kasman, GS, 1998. *Introduction to Surface Electromyography.* Gaithersburg, MD: Aspen Publishers. 408 pp.

Egoscue Inc., 2009. E-Cises. San Diego, CA

Escamilla, RF & Andrews, JR, 2009. Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. *Sports Medicine* 39(7): 569-90.

Escamilla, RF, Yamashiro, K, Paulos, L, Andrews, JR, 2009. Shoulder muscle activity and function in common shoulder rehabilitation exercises. *Sports Medicine* 39(8): 663-85.

Hashemirad F, Talebian S, Hatef B, Kahlaee AH, 2009. The relationship between flexibility and EMG activity pattern of the erector spinae muscles during trunk flexion-extension. J. Electromyography and Kinesiology 19: 746-53.

Hay, JG, & Reid, GJ, 1982. *The Anatomical and Mechanical Bases of Human Motion.* Englewood Cliffs, NJ: Prentice Hall. 442 pp.

Jobe FW, Moynes, DR, Tibone, JE, Perry, J, 1984. An EMG analysis of the shoulder in pitching: A second report. *American Journal of Sports Medicine* 12(3): 218-20.

Kelley, DL, 1971. *Kinesiology: Fundamentals of Motion Description.* Englewood Cliffs, NJ: Prentice Hall. 337 pp.

Kendall FP, McCreary KE, Provance PG, Rodgers MM, Romani WA (2005). *Muscles: Testing and function with posture and pain* (5th ed.). Baltimore, MD: Lippincott Williams & Wilkins. 480 pp.

Kibler, BW, 1998. The role of the scapula in athletic shoulder function. *American Journal of Sports Medicine,* 26(2): 325-37.

Knudson, DV & Morrison, CS, 2002. *Qualitative Analysis of Human Movement.* Champaign, IL: Human Kinetics. 252 pp

Kreighbaum, E & Barthels, KM, 1985. *Biomechanics: A Qualitative Approach for Studying Human Movement* (2nd ed.). New York, NY: Macmillan Publishing Company. 684 pp.

Lanka, J, 2000. Shot putting. In: *The Encyclopedia of Sports Medicine.* IX. *Biomechanics in Sport* (V. Zatsiorsky, ed) Malsden, MA: International Olympic Committee, Blackwell Science. pp. 435-457.

Marchall, RN & Elliott, BC, 2000. Long-axis rotation: The missing link in proximal-to-distal segmental sequencing. *Journal of Sports Sciences* 18: 247-54.

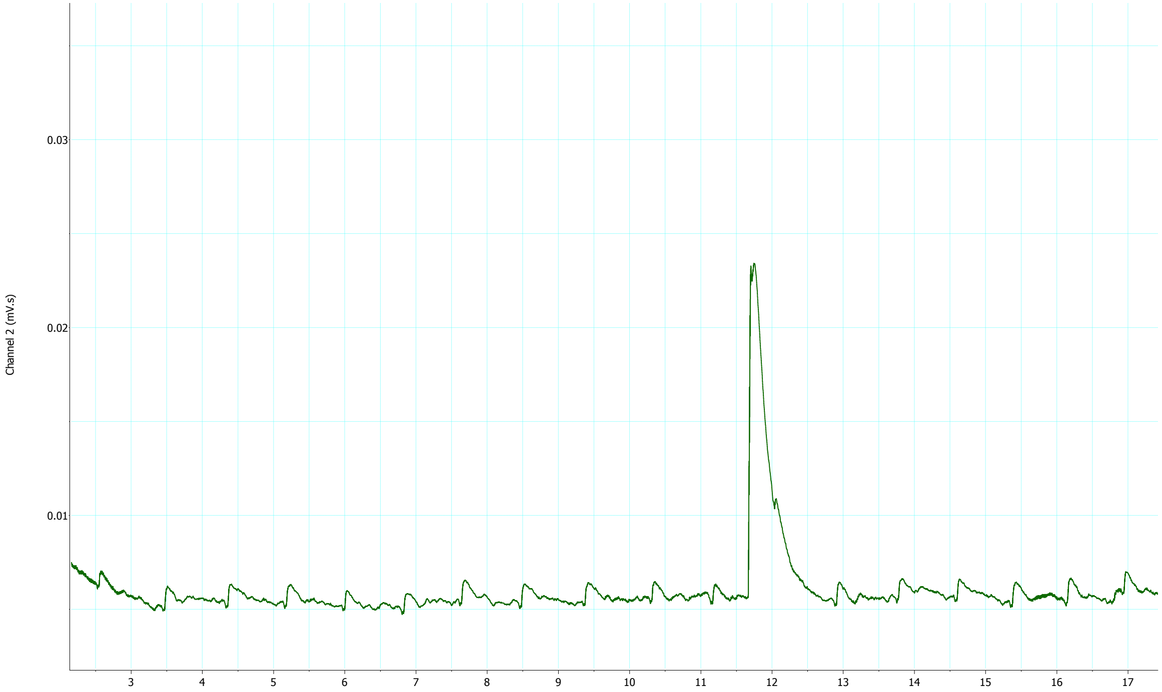
Meyers, TW, 2009. *Anatomy Trains: Myofascial Meridians for Manual and Movement Therapists* (2nd ed.). New York, NY: Churchill Livingstone. 440 pp.

Milton, J, 2010. The kinematic sequence. Lecture notes from *Analysis of Human Motor Skills*, Joint Science Department, Claremont, CA.

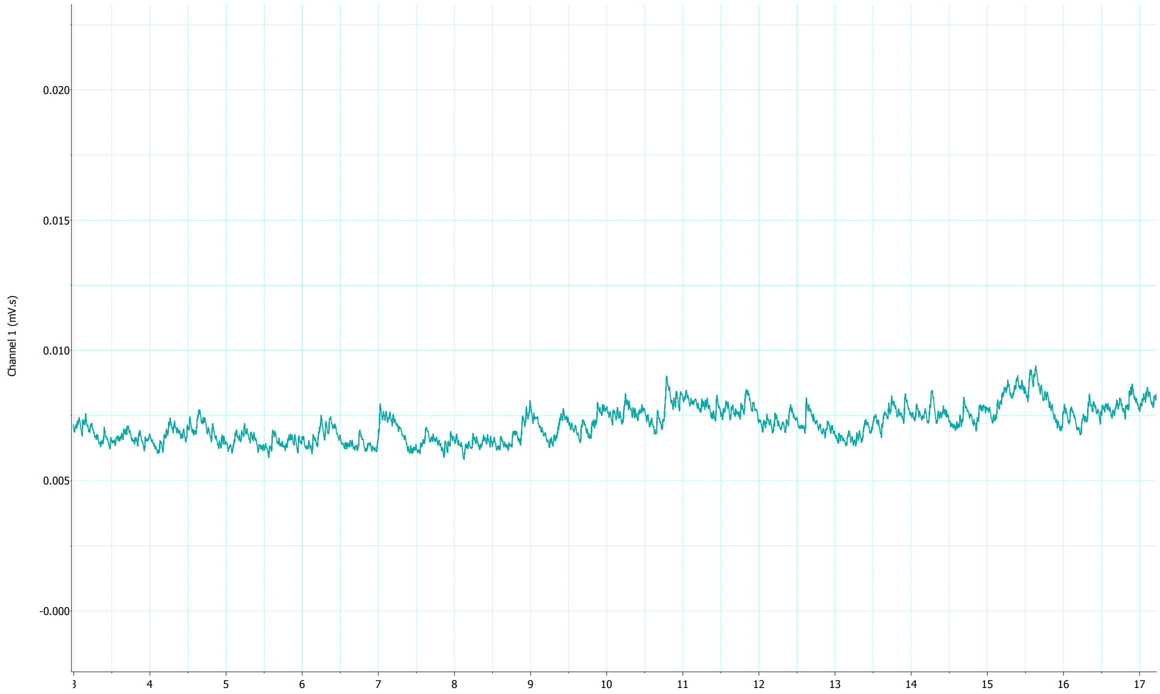
Plagenhoef, S, 1971. *Patterns of Human Motion: A Cinematographic Analysis.* Englewood Cliffs, NJ: Prentice Hall. 224 pp.

APPENDIX

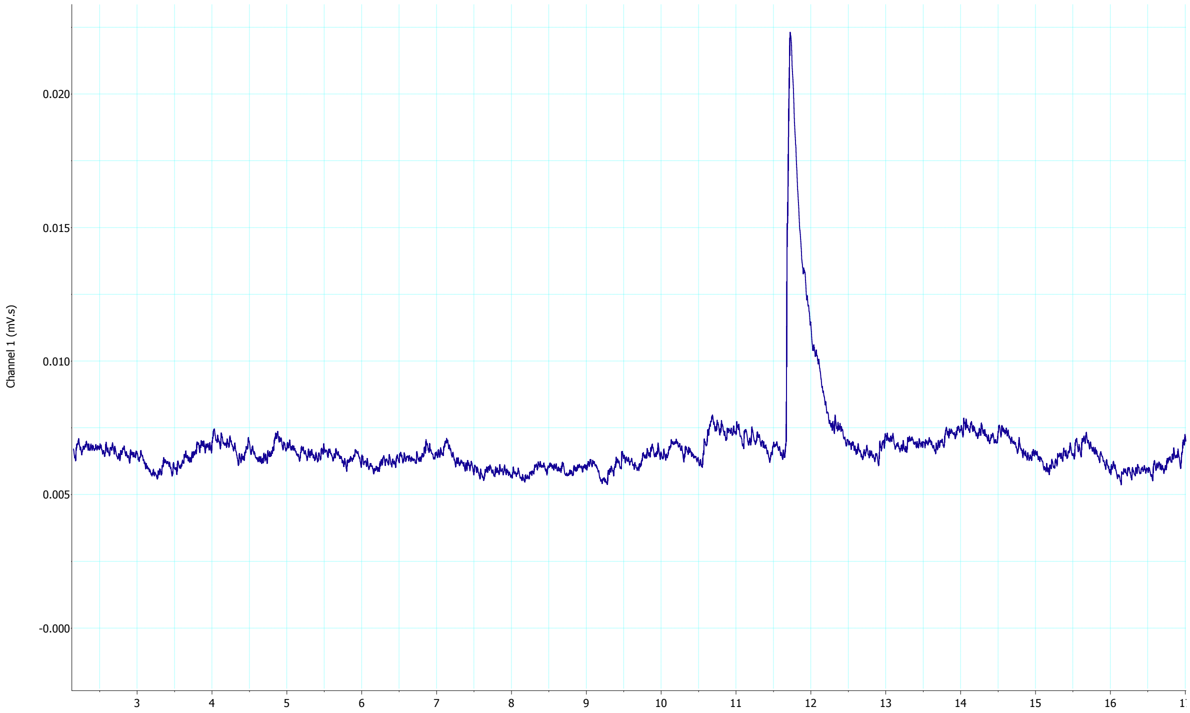
Graph 1: Example reading of oblique and quadratus lumborum over time (seconds), during lateral rotation, before mobilization.



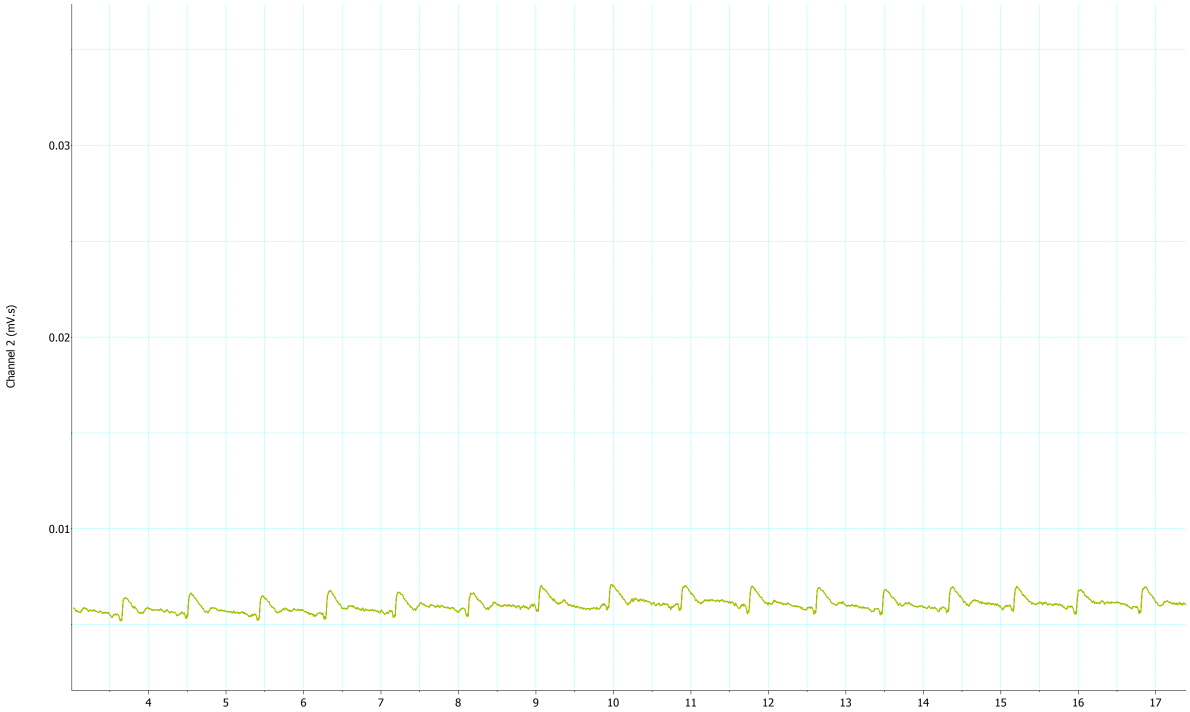
Graph 2: Example reading of oblique and quadratus lumborum over time (seconds), during lateral rotation, after mobilization.



Graph 3: Example reading of latissimus dorsi over time (seconds), during lateral rotation, before mobilization.



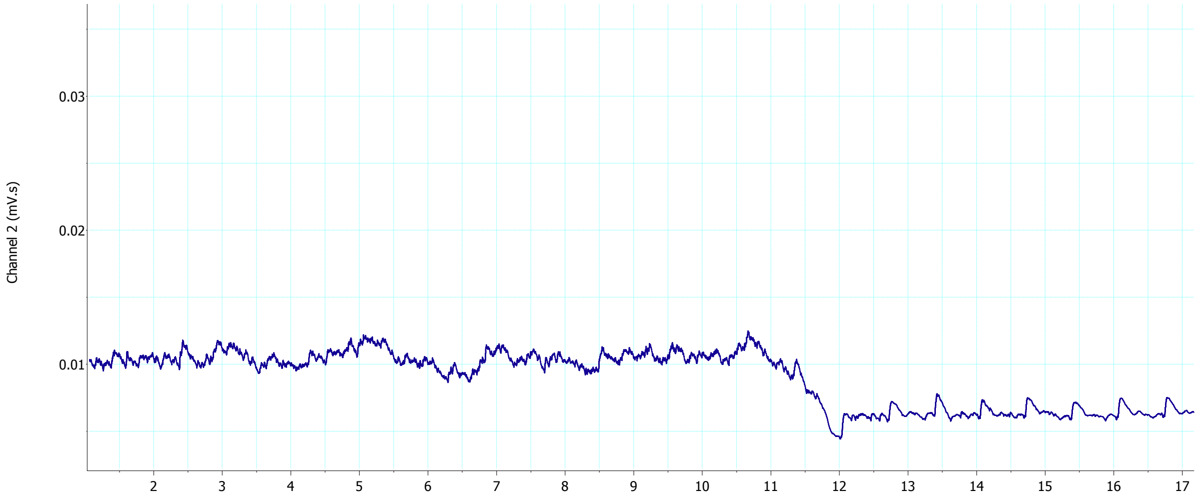
Graph 4: Example reading of latissimus dorsi over time (seconds), during lateral rotation, after mobilization.



Graph 5: Example reading of oblique and quadratus lumborum over time (seconds), during arm flexion, before mobilization.

Graph 6: Example reading of oblique and quadratus lumborum over time (seconds), during arm flexion, after mobilization.

Graph 7: Example reading of latissimus dorsi over time (seconds), during arm flexion, before mobilization.



Graph 8: Example reading of latissimus dorsi over time (seconds), during arm flexion, after mobilization.