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Acute effects of self-myofascial release and static stretching on shoulder range of motion and performance in overhead athletes with glenohumeral internal rotation deficit

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ACUTE EFFECTS OF SELF-MYOFASCIAL RELEASE AND STATIC STRETCHING ON SHOULDER RANGE OF MOTION AND PERFORMANCE IN OVERHEAD ATHLETES WITH GLENOHUMERAL INTERNAL ROTATION DEFICIT

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DEDICATION

I wish to dedicate my Dissertation work to my Mom, Deborah Fairall for always believing in my abilities, even when I may have doubted them myself. Mom, thank you for your love and support.

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ABSTRACT

ACUTE EFFECTS OF SELF-MYOFASCIAL RELEASE AND STATIC STRETCHING ON SHOULDER RANGE OF MOTION AND PERFORMANCE IN OVERHEAD ATHLETES WITH GLENOHUMERAL INTERNAL ROTATION DEFICIT

Ryan R. Fairall
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2014

Purpose: The purpose of this study was to examine the acute effects of a) self-myofascial release (SMR), b) static stretching (SS), and c) the combination of self-myofascial release and static stretching (SMR+SS) on glenohumeral internal rotation range of motion and markers of shoulder performance (i.e. glenohumeral external rotation isometric strength, motor unit recruitment, and throwing velocity) in male softball players with glenohumeral internal rotation deficit (GIRD).

Methods: The sample consisted of 12 male amateur softball players (age: 36.92 ±11.17 years; height: 177.42 ±6.30cm; mass: 87.58 ±18.39kg) who exhibited ≥20° less internal rotation range of motion (ROM) in the throwing shoulder compared to the non-throwing shoulder. All participants performed each of the three conditions of SMR, SS, and SMR+SS on three separate sessions. Dependent variables of glenohumeral internal rotation ROM (deg), glenohumeral external rotation isometric strength (N), motor unit recruitment using surface electromyography (EMG) of infraspinatus (agonist), pectoralis major (antagonist), and latissimus dorsi (antagonist) during isometric strength testing (% of MVC), and overhead throwing velocity (m/sec) were measured pre- and post-intervention.

Results: Glenohumeral internal rotation ROM significantly increased in all three conditions of SMR (3.84° ± 1.42; p = .0001; d = .77), SS (8.58° ± 4.42; p = .0001; d = 1.40), and SMR+SS

(10.15° ± 4.95; p = .0001; d = 1.62). The conditions of SS (p = .01; d = 1.19) and SMR (p = .001; d = 1.43) improved ROM significantly more than SMR alone. SMR+SS resulted in a slightly greater increase in ROM (1.57°) when compared to SS alone, but the difference was not statistically significant. None of the three conditions resulted in decreases in glenohumeral external rotation isometric strength, motor unit recruitment, or throwing velocity. However, SMR+SS resulted in the most significant increase in infraspinatus EMG magnitudes (7.52% ± 9.23; p = .02; d = 0.82) and decrease in pectoralis major (5.90% ± 7.98; p = .03; d = 0.62) and latissimus dorsi (11.88% ± 17.28; p = .04; d = 0.80) EMG magnitudes during glenohumeral external rotation isometric strength testing.

Conclusions: According to the results, all three conditions significantly improved glenohumeral internal rotation ROM, in theory decreasing risk of injury without negatively affecting performance (i.e. isometric strength, motor unit recruitment, and throwing velocity). However, SS and SMR+SS improved ROM significantly more than SMR alone. There was no significant difference in improvements in ROM between SS and SMR+SS, Therefore, if the athlete has a limited amount of time to perform a pre-activity warm-up period (i.e. 3-4 min), it is recommended to use SS to improve ROM. However, if the athlete has more time available to warm up (i.e. 7-8 min), it is recommended to perform SMR+SS which may result in an even greater increase in ROM and possible improvements in motor unit recruitment.

Chapter I

INTRODUCTION

Shoulder pain has been shown to affect up to 67% of the general population at some point in their lifetime (Luime et al., 2004). Although shoulder pain can be multi-factorial, individuals that participate in sports have a higher prevalence of shoulder pain when compared to their non-athlete counterparts (Jonasson et al., 2011). In addition, individuals that participate in activities that require dynamic overhead arm movements such as baseball, softball, volleyball, tennis, and swimming may be at a higher risk of shoulder pathology than individuals participating in sports that do not require dynamic overhead arm movements (Bonza, Fields, Yard, & Comstock, 2009). Overhead athletes require a delicate balance of shoulder mobility and stability to not only meet the functional demands of their sport, but also to help assist in preventing injury. There has been an abundance of research on shoulder pain in overhead athletes, specifically baseball and softball players, and research by Conte, Requa, and Garrick (2001) shows that shoulder injuries represent the highest percentage of injuries (27.8%) by body location in professional baseball players.

The overhead throwing movement associated with baseball and softball has been thoroughly researched and divided into six distinct phases consisting of the windup, stride, arm cocking, arm acceleration, arm deceleration (immediately following ball release), and follow-through (DiGiovine et al., 1992). Shoulder injuries can be a result of the need to achieve high angular velocities at the shoulder that have been shown to reach as high as 7000°/sec just before ball release during the acceleration phase (Dillman, Fleisig, & Andrews, 1993). Large forces are generated by concentric contractions of the internal rotator muscles of the shoulder during the

arm acceleration phase, which is described as the point of maximal external shoulder rotation to the point of ball release (DiGiovine et al., 1992). Along with large forces generations during the acceleration phase, there are also large force absorptions following ball release and continuing into the follow-through phase. These force absorptions are controlled by eccentric contractions of the shoulder external rotator muscles and are needed to decelerate the arm after ball release and during the follow-through phase. These deceleration forces place a significant amount of stress on the soft tissues of the posterior shoulder (Braun, Kokmeyer, & Millet, 2009). Due to the repeated acts of deceleration after ball release and during the follow-through, the posterior glenohumeral capsule, external rotator muscles (infraspinatus and teres minor), and connective tissue can develop tightness resulting in decreased internal rotation ROM at the shoulder (Borsa, Laudner, & Sauers, 2008). This decrease in shoulder internal rotation ROM has been referred to as glenohumeral internal rotation deficit or GIRD.

GIRD has been defined by as little as 10° (McClure et al., 2007) and as much as 25° (Tyler, Nicholas, Lee, Mullaney, & McHugh, 2010) less internal rotation ROM in the dominant verse non-dominant shoulder. In addition, research by Wilk et al. (2011) has shown that athletes with GIRD of greater than 20° appear to be at a greater risk for shoulder injury and surgery. This significant decrease in internal rotation ROM has been linked to shoulder pathologies such as anterior instability, rotator cuff pathologies, shoulder impingement, labral lesions, and scapular dyskinesis (Braun, Kokmeyer, & Millett, 2009; Kolber, Hanney, & Benevento, 2012). Therefore, proper injury prevention techniques are recommended during the pre-activity warm-up phase for overhead athletes to assist in improving glenohumeral internal rotation ROM and thus decreasing risk of injury.

Self-myofascial release has recently become a common injury prevention strategy used in the pre-activity warm-up period to assist in improving muscle relaxation and tissue pliability through decreasing contractile activity and motor neuron excitability (Schleip, 2003). Self-myofascial release uses external devices (e.g. foam rollers, massage balls, etc.) to apply static myofascial tension to overactive muscles and is believed to activate mechanoreceptors known as golgi tendon organs (GTO), while in turn inhibiting muscle spindles resulting in soft tissue relaxation. In addition, static stretching has been recommended immediately following self-myofascial release to assist in increasing muscle and fascial extensibility in the area of limited mobility to assist in providing optimal length-tension relationships (Clark & Lucett, 2011). Static stretching is a slow, constant stretch with the end range of motion being held for a specified duration (e.g. 30 seconds) (Jeffreys, 2008). Although static stretching provides important benefits, it is commonly discouraged just prior to activities that require maximal strength and/or power due to the fact that it has been shown to negatively affect performance (Behm & Chaouachi, 2011). Deficits in strength and power following an acute bout of static stretching have been attributed to both neural and mechanical factors (Young, 2010). Static stretching is believed to negatively affect neural activation through a decrease in available motor units for muscle contraction. This neural factor can be related to the mechanical effects of static stretching that may result in an altered length-tension relationship of the contractile elements of the muscles, decreasing the ability of the muscles to produce optimal force. However, static stretching has primarily been shown to negatively affect acute strength and power performance in the lower-body, while upper-body performance has not been shown to be affected. In addition, previous research has not looked at the effects of static stretching on the performance of

overactive/shortened muscles, such as the glenohumeral external rotators in individuals with GIRD.

Research Question

Can the inclusion of self-myofascial release and static stretching into a pre-activity warm-up assist in improving glenohumeral internal rotation ROM without subsequent negative effects on shoulder performance variables such as strength, motor unit recruitment, and power?

Purpose Statement

The purpose of this study is to examine the acute effects of a) self-myofascial release, b) static stretching, and c) a combination of self-myofascial release and static stretching on glenohumeral internal rotation ROM and markers of shoulder performance (i.e. isometric strength, motor unit recruitment, and throwing velocity) in male softball players with GIRD.

Following the three conditions (self-myofascial release, static stretching, and a combination of self-myofascial release and static stretching) of the independent variable (intervention), the participants will be re-tested to determine any changes in the dependent variables of glenohumeral internal rotation ROM, external rotation maximal isometric strength, motor unit recruitment of the glenohumeral external rotator (infraspinatus) and internal rotators (pectoralis major and latissimus dorsi) during external rotation isometric strength testing via surface electromyography, and maximal overhead throwing velocity.

Research Hypotheses

Hypothesis$_1$: Glenohumeral internal rotation ROM **will be** significantly different following a bout of self-myofascial release

Hypothesis $_2$: External rotation maximal isometric strength **will not be** significantly different following a bout of self-myofascial release

Hypothesis $_3$: Motor unit recruitment of the glenohumeral external rotator (infraspinatus) and internal rotators (pectoralis major and latissimus dorsi) during maximal isometric external rotation **will not be** significantly different following a bout of self-myofascial release

Hypothesis $_4$: Overhead throwing velocity **will not be** significantly different following a bout of self-myofascial release

Hypothesis $_5$: Glenohumeral internal rotation ROM **will be** significantly different following a bout of static stretching

Hypothesis $_6$: External rotation maximal isometric strength **will not be** significantly different following a bout of static stretching

Hypothesis $_7$: Motor unit recruitment of the glenohumeral external rotator (infraspinatus) and internal rotators (pectoralis major and latissimus dorsi) during maximal isometric external rotation **will not be** significantly different following a bout of static stretching

Hypothesis $_8$: Overhead throwing velocity **will not be** significantly different following a bout of static stretching

Hypothesis $_9$: Glenohumeral internal rotation ROM **will be** significantly different following a bout of a combination of self-myofascial release and static stretching

Hypothesis $_{10}$: External rotation maximal isometric strength **will not be** significantly different following a bout of a combination of self-myofascial release and static stretching

Hypothesis $_{11}$: Motor unit recruitment of the glenohumeral external rotator (infraspinatus) and internal rotators (pectoralis major and latissimus dorsi) during maximal isometric external rotation **will not be** significantly different following a bout of a combination of SMR+SS

Hypothesis $_{12}$: Overhead throwing velocity **will not be** significantly different following a bout of a combination of self-myofascial release and static stretching

Hypothesis $_{13}$: Changes in glenohumeral internal rotation ROM **will not be** significantly different between SMR, SS, and SMR+SS.

Hypothesis $_{14}$: Changes in external rotation isometric strength, motor unit recruitment, and overhead throwing velocity **will not be** significantly different between the three conditions of SMR, SS, and SMR+SS

Definition of Terms

For the purposes of this study, terms that may be unfamiliar have been defined:

1. Overhead athlete: An athlete participating in a sport or activity that requires dynamic overhead movements (e.g. baseball, softball, tennis, and volleyball). In the case of this study, the overhead athlete is an amateur male softball position player (non-pitcher).

2. Glenohumeral internal rotation deficit (GIRD): The loss of degrees of glenohumeral internal rotation of the throwing shoulder compared with the non-throwing shoulder (Burkhart, Morgan, & Kibler, 2003).

3. Self-myofascial release: A flexibility technique used to inhibit overactive muscle fibers through the use of an external device (e.g. foam roller, massage ball, massage cane, etc.) to apply pressure to the specific myofascial area. This pressure is believed to stimulate receptors located throughout the muscle, fascia, and connective tissues of the human movement system to override the dysfunctional, yet protective mechanism cause by the cumulative injury cycle (Clark & Lucett, 2011).

4. Static Stretching: A flexibility technique used to increase the extensibility of the muscle and connective tissue (lengthening) and thus ROM at a joint. The stretch is held at the point of tension or resistance barrier for approximately 30 seconds (Clark & Lucett, 2011).

Significance of the Study

Self-myofascial release and static stretching are commonly prescribed by strength and conditioning professionals during the pre-activity warm-up period to assist in muscle relaxation and soft tissue pliability in overhead athletes with GIRD. These strategies are utilized in hopes of improving shoulder internal rotation ROM, thus decreasing risk of injury and possibly improving upper-body performance. However, there has been very limited research examining the efficacy of self-myofascial release and there has been no research examining the effects of the combination of self-myofascial release and static stretching on joint ROM. In addition, there has been no research investigating the effects of pre-activity self-myofascial release and static

stretching on markers of upper-body performance. Therefore, research is warranted examining the efficacy of these recently popular pre-activity warm-up strategies commonly utilized in the field of strength and conditioning.

Theoretical Basis for the Study

Despite the limited research examining the effects of self-myofascial release through an external device, there has been promising studies that have recently shown that self-myofascial release may increase ROM without negatively affecting subsequent muscular performance (Healy et al., 2013; MacDonald et al., 2013; Sullivan, Silvey, Button, & Behm, 2013). Although these results have only been shown in the lower-body, it can be theorized that similar effects may be seen in the upper-body as well. Due to the fact that decreased glenohumeral internal rotation ROM is strongly correlated with numerous shoulder pathologies, it can further be assumed that performing self-myofascial release may improve glenohumeral internal rotation ROM and thus decrease risk of shoulder injuries.

There is a general consensus that performing static stretches for the glenohumeral external rotators can acutely increase glenohumeral internal rotation ROM (Laudner, Sipes, &Wilson, 2008; Oyama, Goerger, Goerger, Lephart, & Myers, 2010; Sauers, August, & Snyder, 2007), thus decreasing injury risk. In addition, pre-activity stretching has predominately been shown to negatively affect maximal strength and power performance in the lower-body (Kay & Blazevich, 2012; Rubini, Costa, & Gomes, 2007), but not in the upper-body (Beedle, Rytter, Healy, & Ward, 2008; Faigenbaum et al., 2006; Hagg, Wright, Guillette, & Greany, 2010; Knudson, Noffal, Bahamonde, Bauer, & Blackwell, 2004). Therefore, it can be theorized that

performing static stretches will assist in increase glenohumeral internal rotation ROM, decreasing risk of injury without negatively affecting performance.

It has recently been suggested that performing self-myofascial release immediately followed by static stretching may maximize increases in ROM and further decrease risk of injury (Clark & Lucett, 2011). To the author's knowledge, there has been no published peer-reviewed research supporting this suggestion. Conversely, from the aforementioned benefits of performing self-myofascial release and static stretching unaccompanied, it may be theorized that combining self-myofascial release and static stretching may result in greater increases in ROM and decreases in injury risk without negatively affecting performance. However specific research is needed for this to be claimed.

Chapter II

REVIEW OF RELATED LITERATURE

GIRD: Anatomical and Biomechanical Considerations

In activities such as throwing, the dominant arm is repetitively raised overhead and is forcefully propelled forward from maximal or near maximal external shoulder rotation (i.e. cocking) to internal rotation (i.e. acceleration) in fractions of a second. This explosive movement requires the musculature and connective tissue of the posterior shoulder complex to act eccentrically to decelerate the arm as it forcefully internally rotates (i.e. acceleration) and adducts across the body (i.e. follow-through). Due to the extreme external rotation ROM at the shoulder during these overhead athletic movements, the anterior shoulder can often become lax and unstable (Borsa, Laudner, & Sauers, 2008). Concurrently, due to the repeated acts of deceleration during the follow-through, the posterior glenohumeral capsule, muscles (e.g. shoulder external rotators) and connective tissue can develop tightness resulting in decreased internal rotation ROM at the shoulder. This decrease in internal rotation ROM may be a result of a contracture and thickening of the posterior inferior portion of the glenohumeral capsule (Myers et al. 2007). Limited internal rotation is also believed to be related to soft tissue changes (i.e. muscles, fascia, and tendons) caused by repetitive overhead movements. If the loss of internal rotation exceeds the gain in external rotation, the GIRD is attributed to soft tissue changes and is considered pathologic (Litner, Mayol, Uzodinma, Jones, & Labossiere, 2007). It is important to mention that research has also shown that GIRD may be a result of an osseous adaptation referred to as humeral head retroversion, rather than soft tissue adaptations (Chant, Litchfield,

Griffin, & Thain, 2007; Crockett et al., 2002; Reagan et al., 2002). If the loss of internal rotation equals the gain in external rotation, the GIRD can be attributed to osseous changes and therefore be considered a physiological adaptation (Litner, Mayol, Uzodinma, Jones, & Labossiere, 2007). Since osseous changes are not able to be corrected by clinician intervention, this paper will only be dedicated to the explanation of GIRD as a result of soft tissue changes and available strategies to correct this disorder.

GIRD: Measurement and Quantification

The suggested technique for measuring internal rotation ROM at the shoulder is to measure the subject in the supine position with the shoulder abducted to 90° and the elbow flexed at 90° (Starkey & Ryan, 2003). While this technique has been used in nearly all research measuring shoulder internal rotation, it has been proposed that the position of the scapula during testing affects internal rotation ROM. Research has shown that shoulder internal rotation ROM is significantly less with the scapula passively stabilized when compared to not stabilized (Awan, Smith, & Boon, 2002; Boon & Smith, 2000). When not stabilized, the scapula is susceptible to unwanted motion and can affect the validity and the reliability of the measurement (McCully, Kumar, Lazarus, & Karduna, 2005). In addition, when comparing the measurement of internal rotation ROM with the scapula passively stabilized and not stabilized, it has been shown that intra-tester and inter-tester reliability increases when the scapula is passively stabilized (Awan, Smith, & Boon, 2002; Boon & Smith, 2000; Wilks et al., 2009). More recently, research by Lunden, Muffenbier, Giveans, and Cieminski (2010) compared the reliability of using supine versus side-lying position for measuring passive glenohumeral internal rotation ROM in individuals with and without shoulder pathology. The results showed the supine measurements to

exhibit good to excellent ($ICC_{3, 1}$ = 0.70-0.93) intra-rater reliability, while the side-lying measurements showed excellent ($ICC_{3, 1}$ = 0.94-0.98) intra-rater reliability. In addition, the inter-rater reliability for the supine measurements was fair to good ($ICC_{2, 2}$ = 0.74-0.81) compared to good to excellent ($ICC_{2, 2}$ = 0.88-0.96) inter-rater reliability for the side-lying measurements. Therefore, the side-lying testing position may be superior to the supine testing position for improving shoulder internal rotation measurement reliability by means of limiting scapular movement. Moreover, the side-lying testing position eliminates the need for a second clinician that is required to stabilize the scapula while measuring internal rotation during the supine test.

GIRD and the Overhead Athlete

There has been a significant amount of research linking GIRD to shoulder pathologies. Research by Tyler, Nicholas, Roy, and Gleim (2000) has shown a significant negative correlation between posterior shoulder tightness and reduced internal rotation ROM in participants with impingement. Burkhart, Morgan, and Kibler (2003) reported a lack of shoulder internal rotation in throwers with arthroscopically proven superior labral lesions. Research by Ruotolo, Price, and Panchal (2006) found that college baseball players with pain in their throwing shoulders exhibited significantly less internal rotation in their throwing shoulders when compared to their non-throwing shoulders. Scher et al. (2010) found that baseball non-pitchers with a history of shoulder injury had less internal rotation of the shoulder than non-pitchers with no history of shoulder injury.

In addition to being witnessed in individuals with known pathologies, GIRD has been seen in asymptomatic athletic individuals as well. Reagan et al. (2000) found that asymptomatic pitchers exhibited significantly less internal rotation in the dominant shoulders when compared

to the non-dominant shoulders. Research by Downer and Sauers (2005) showed that professional baseball players have significant decreases in internal shoulder rotation in the dominant arm when compared to the non-dominant arm. Additionally, Hurd et al. (2011) found that uninjured high school baseball pitchers exhibited significantly decreased internal rotation in the dominant shoulder when compared to the non-dominant shoulder. Similarly, research by Laudner, Moline, and Meister (2010) showed that professional baseball pitchers and position players exhibited decreased internal rotation in their dominant arm compared to their non-dominant arm. Along with baseball and softball players, GIRD has been observed in athletes performing overhead movements similar to overhead throwing. Ellenbecker, Roetert, Piorkowski, and Schulz (1996) measured internal rotation in dominant and non-dominant arms of elite junior tennis players and found limited internal rotation in the players' dominant arm compared to their non-dominant arms. Similarly, Giles and Musa (2008) found that cricket players that regularly bowl overhead, which is similar to pitching in baseball, showed significantly less internal rotation in the dominant shoulders compared to the non-dominant. Moreover, Giles and Musa also found that the overhead bowlers showed significantly less internal rotation in their dominant shoulder when compared to cricketers who throw underhand. Recently, Almeida et al. (2013) found that handball players with shoulder pain exhibited significantly less internal rotation in their throwing shoulder when compared to asymptomatic handball players. As previously mentioned, GIRD has been linked to many shoulder pathologies; therefore, individuals presenting limited shoulder internal rotation ROM are at an increased risk of shoulder injury.

GIRD in overheard athletes is thought to be the result of years of repetitive muscular demand placed on the shoulder complex (Burkhart, Morgan, & Kibler, 2003). However, recent research has shown that a decrease in shoulder internal rotation can result after a single

competitive season. Following a single sports season, female overhead athletes competing in high school swimming, volleyball, and tennis exhibited significant decreases in internal shoulder rotation from preseason to postseason (Thomas, Swanik, Swanik, & Huxel, 2009). In another study, competitive high school baseball players showed a significant decrease in internal rotation in the dominant arm compared to their non-dominant arm from preseason to postseason (Thomas, Swanik, Swanik, Huxel & Kelly IV, 2010). Furthermore, Reinhold et al. (2008) tested shoulder internal rotation ROM in professional baseball pitchers immediately and 24 hours following a single throwing session and found significant decreases in throwing shoulders immediately and 24 hours after throwing. Kibler, Sciascia, and Moore (2012) found that an acute throwing session by professional baseball pitchers resulted in a significant decrease in shoulder internal rotation ROM immediately following throwing as well as 24, 48, and 72 hours after throwing. These results suggest that GIRD can be caused by acute musculoskeletal adaptations, in addition chronic adaptations.

Self-Myofascial Release

Repetitive overhead throwing can cause anatomical adaptations limiting shoulder ROM, such as shortening of the muscles and connective tissue, including tendons, fascia, as well as the joint capsule (Litner, Mayol, Uzodinma, Jones, & Labossiere, 2007). A commonly used corrective exercise strategy is manual therapy to improve ROM and function. One of the more popular forms of manual therapy utilized by manual therapists, physical therapists, and athletic trainers is myofascial release. Myofascial release, similar to ischemic compression, is a technique developed to treat the fascial system of the body (Ramsey, 1997). Fascial tissue is a tough connective tissue that is located around individual muscle fibers, groups of muscle fibers,

and in the tendons. It is believed that fascial tissue has similar stretchable elements as muscles and tendons. Like muscle and tendon tissue, fascia can be stretched, but will return to its original length after unloading (Remvig, Ellis, & Patijn, 2008). Fascial tissue can become shortened and tight due to histological, physiological, and/or biomechanical protective mechanisms and over time can lead to poor muscular biomechanics, altered structural alignment, decreased muscular strength and endurance, and altered motor coordination (Barnes, 1997). These mechanisms can accompany active and/or latent trigger points in the fascial tissue. Active trigger points are those that are responsible for presenting constant pain complaints, while latent trigger points are characterized by muscle shortening and pain only with direct applied pressure (Huguenin, 2004).

Myofascial release applies the principle of biomechanical loading of soft tissue and neural reflex modifications by stimulating mechanoreceptors in the muscles, tendons, and fascia (Remvig, Ellis, & Patijn, 2008). The stimulation of these mechanoreceptors results in a phenomenon known as autogenic inhibition, which is the stimulation of the golgi tendon organs (GTO) resulting in inhibition of the muscle spindles in the muscles. The GTO, along with other interstitial receptors and Ruffini endings throughout the fascia, respond to tension and it is believed that applying static myofascial tension will activate these receptors, thus inhibiting the muscle spindles and allowing the muscle to relax and become more pliable (Schleip, 2003). Myofascial release is performed by applying gentle and sustained pressure to a tender area in the fascia, while maintaining the position and load until the tissue responds by relaxing and allowing the fascia to release (Ramsey, 1997). This sustained pressure will normally be held for 90-120 seconds, where then the tissue will undergo histological length changes allowing a release to be felt (Barnes, 1997). The practitioner then moves to another tender area along the same muscle repeating this technique and after a few releases the tissue will feel softer and more pliable. At

this point, it is believed that the application of static stretching can be used to increase muscle and fascial extensibility in the area of limited mobility to assist in providing optimal length-tension relationships (Clark & Lucett, 2011).

There has been a large amount of scientific research examining the effects of myofascial release/ischemic compression on variables such as joint ROM, posture, electromyography (EMG) activity, muscle strength, pain perception and tolerance of trigger points, sensory organization, functional and sport impairments, and mood state. There was limited research found on the effects of myofascial release in relation to shoulder pain and function. However, a study performed by Hains, Descarreaux, and Hains (2010) looked to evaluate the effects of 15 myofascial ischemic compression therapy sessions on shoulder trigger points in patients with chronic shoulder pain. With the use of two questionnaires measuring shoulder pain, function, and amelioration, individuals receiving ischemic compression therapy showed significant reduction in shoulder pain and increases in shoulder function and amelioration when compared to a control group. Another study by Kain, Martorello, Swanson, and Sego (2011) compared the effects of 3-minutes of myofascial release therapy versus 20-minutes of hot pack on passive glenohumeral flexion, extension, and abduction ROM using goniometry. According to the results, the myofascial release and hot packs groups showed similar improvements in glenohumeral ROM, showing that the two interventions may be equally effective.

A large amount of the research on myofascial release/ischemic compression has looked at its effect on trigger points located in the trapezius muscle. Montañez-Aguilera et al. (2009) compared the immediate effects of ischemic compression versus ultrasound and a control on active cervical ROM, basal electrical activity of the trapezius using EMG, and upper trapezius trigger point pain tolerance in healthy participants. The results showed that ischemic

compression and ultrasound had similar effects on basal electrical activity of the trapezius and reductions in myofascial trigger point sensitivity when compared to the control. However, the ischemic compression group exhibited a significant increase in cervical ROM through an improved length-tension relationship when compared to ultrasound and the control. Similarly, Hou, Tsai, Cheng, Chung, and Hold (2002), found that ischemic compression of the upper trapezius muscle similarly improves indexes of pain threshold, pain tolerance, and cervical ROM when compared to alternative therapies including hot packs, active ROM exercise, transcutaneous electric nerve stimulation, and spray and stretch. Hou et al. (2002) suggest combining ischemic compression with the aforementioned therapies for further improvements in trigger point pain tolerance and cervical ROM. Fryer and Hodgson (2005) investigated the effects of manual pressure release versus sham myofascial release with very light pressure on pressure sensitivity of latent trigger points in the upper trapezius using a pressure algometer. The researchers found that pressure pain threshold was significantly increased in the manual pressure release group when compared to the sham myofascial release group. These results show that the intensity of the pressure applied may have an effect on pressure sensitivity of latent trigger points. A pilot study performed by Fernández-de-la-Peñas, Alonso-Blanco, Fernández-Carnero, and Miangolarra-Page (2006) compared the effects of a single treatment of ischemic compression versus transverse friction massage on trigger point tenderness in the upper trapezius muscle through the use of a pressure algometer. Both ischemic compression and transverse friction massage exhibited significant improvements in pressure pain threshold, showing that ischemic compression may be an efficient therapy for improving pressure pain threshold of latent trigger points in the upper trapezius.

The effects of myofascial release/ischemic compression has also been researched in individuals with specific pathologies and structural impairments. Lin et al. (2012) examined the immediate clinical effects of ischemic compression on sensory organization, cervical ROM, isometric neck strength, and ankle strategies in individuals with cervicogenic cephalic syndrome. Visual and vestibular ratios, cervical ROM, isometric neck strength, and ankle strategy scores all significantly improved after a single bout of ischemic compression therapy. In another study, Castro-Sánchez et al. (2011) looked to determine the effects of 20-weeks of myofascial release treatment on the number of tender points, tender point pain, postural stability, physical function (via Fibromyalgia Impact Questionnaire), and clinical severity (via Clinical Global Impression Severity Scale) in individuals with fibromyalgia syndrome when compared to a control group given sham short-wave and ultrasound. According to the results, the myofascial release group showed significant improvements in the number of painful tender points, tender point pain, physical function, and clinical severity when compared to the control group. Hains, Descarreaux, Lamy, and Hains (2010) evaluated the effects of 15 sessions of ischemic compression therapy on severity of symptoms and functional status through the use of standard validated questionnaires in individuals with carpal tunnel syndrome. Fifty-five individuals were randomized into either an experimental group receiving ischemic compression at the axilla of the shoulder, the length of the bicep muscle, at the bicipital aponeurosis and the pronator teres muscle in the hallow of the elbow, or a control group receiving ischemic compression on trigger points in the deltoid muscle. The results showed that the experimental group exhibited a significant reduction in symptoms when compared to the control group. LeBauer, Brtalik, and Stowe (2008) performed a case study exploring the use of myofascial release as an effective means of controlling spinal curvature progression in an adolescent with idiopathic scoliosis. The individual received 6-weeks of

myofascial release therapy consisting of two 60-minute sessions per week. The researchers measured pain, pulmonary function, quality of life, static posture, and trunk flexion, extension and rotation ROM. Although this was a only a case study, the individual showed improvement in thoracic and lumbar rotation, static posture, pain levels, quality of life, and pulmonary function. For this reason, more research is warranted in this population. Research by Barnes, Gronlund, Little, and Personius (1997) investigated the efficacy of myofascial release on obtaining pelvic symmetry in symptomatic patients with unilateral anterior rotation and perceived low back and/or sacroiliac region pain. Ten participants were randomly assigned into an experimental group consisting of 10 minutes of myofascial release of the quadriceps, iliopsoas, and public ramus or a control group of laying supine for 10 minutes and receiving no myofascial release. Although the sample size was small, the experimental group showed significant improvements in pelvic symmetry when compared to the control group.

Although myofascial release/ischemic compression has been shown to be effective in improving variables such as joint ROM, posture, EMG activity, muscle strength, pain perception and tolerance of trigger points, sensory organization, and function, the presence of a health professional is required to apply the myofascial pressure. Over the past decade, the use of external devices such as foam rollers, massage balls, and j-shaped canes to apply self-myofascial release to treat myofascial restrictions and normal soft-tissue extensibility has become increasing popular in the fields of physical therapy, athletic training, and especially strength and conditioning (Curran, Fiore, & Crisco, 2008). However, there has been limited research on the efficacy of self-myofascial release on the variables mentioned above. Research by Gulick, Palombaro, and Lattanzi (2011) looked at the effectiveness of self-applied ischemic pressure with the use of a Backnobber II on myofascial trigger point pain threshold through the use of a

pressure algometer. Twenty-eight individuals with two myofascial trigger point areas in the neck or upper back were randomly assigned to treatment which consisted of three to four sessions (six repetitions of 30 seconds) with the Backnobber II on one area of trigger points over one week and a control which consisted of non-treatment of the other trigger point area. The results showed that the treatment significantly improved trigger point thresholds in the treated trigger points and also to a lesser extent in the non-treated trigger points. MacDonald et al. (2013) examined the effect of an acute bout of self-myofascial release through the use of a foam roller on maximal knee extensor contraction force, evoked force and activation, and knee flexion ROM. On two separate sessions, 11 healthy males performed either a) two, one minute trials of foam rolling on the quadriceps, or b) no foam rolling. The participants were measured in each variable prior to, 2-minutes, and 10-mintes following each condition. According to the results, there were no significant differences between the two conditions for any of the neuromuscular dependent variables. However, the foam rolling did result in a significant increase in knee flexion ROM at 2 minutes (10%) and 10 minutes (8%). Sullivan, Silvey, Button, and Behm (2013) looked to examine the effects of foam rolling volume (i.e. 1 set of 5 sec, 1 set of 10 sec, 2 sets of 5 sec, 2 sets of 10 sec) on sit & reach ROM, along with maximal voluntary contraction force and EMG activation of the hamstrings. The researchers found that foam rolling resulted in a significant main effect for time with a 4.3% increase in sit & reach ROM and 10 seconds of foam rolling being superior to 5 seconds. However, there were no significant differences in hamstring maximal voluntary contraction force or EMG activation between the conditions. In 2013, Healey et al. performed a study comparing the effects of series planking exercises versus a series of foam rolling exercises on performance variable of vertical jump height and power, isometric force, and agility, as well as post-exercise fatigue. The results showed that there were

no significant differences between the two conditions in the performance variables, but participants who foam rolled reported significantly less post-exercise fatigue when compared to the participants that performed the planking exercises. A study by Hanten, Olson, Butts, and Nowicki (2000) set out to determine the effectiveness of a home program of self-applied ischemic pressure followed by sustained stretching on trigger point pressure pain threshold, average pain intensity over a 24-hour period, and percentage of time in pain over a 24-hour period. Forty adults with one or more trigger points in the neck or upper back were randomly assigned to a) an experimental group receiving a 5-day home program of self-applied ischemic pressure through the use of Theracane followed by a general sustained stretching of the neck and upper back musculature, or b) a control group that performed a 5-day home program of active ROM exercises. The results showed that the experimental group showed significant decreases in average pain intensity over 24-hours and trigger point pain thresholds when compared to the control, but no differences were seen in percentage of time in pain. The limited research on self-myofascial release has shown it to provide similar benefits to myofascial release/ischemic compression performed by a trained health professional on measures of ROM and tender point sensitivity. However, more research on forms of self-myofascial release techniques is warranted to provide more evidence of its potential benefits.

Static Stretching

Stretching has long been a common staple in strength and conditioning programs. Stretching is believed to improve joint ROM by increasing the length and elasticity of the muscle contractile properties and connective tissue, such as tendons and fascial sheaths. These benefits can be attributed to the neural adaptation of decreased contractile activity in response to the

stretch and decreases in the indices of motor neuron excitability (McHugh & Cosgrave, 2010). There are multiple forms of stretching techniques that have been utilized in the area of strength and conditioning including static, dynamic, ballistic, and proprioceptive neuromuscular facilitation (PNF) (Jeffreys, 2008). For the sake of this paper, static stretching will be the lone form of stretching discussed. Static stretching is a slow, constant stretch with the end ROM being held for a specified duration (i.e. 30 seconds) (Jeffreys, 2008). Static stretching is easy to learn and because the stretch is static, the risk of injury to the muscle and/or connective tissue is reduced when compared to ballistic and dynamic forms of stretching. Static stretching is recommended to be performed immediately following an exercise bout and possibly after a 5-10 minute warm-up and should consist of 1-3 sets and for duration of 15-30 seconds (Jeffreys, 2008).

When performing stretching with the goal of improving GIRD, the two most common stretches utilized in the literature are a side-lying posterior shoulder internal rotation stretch, also known as the sleeper stretch, and a horizontal adduction stretch, also known as the cross-body stretch (Corrao, Kolber, & Wilson, 2009; McClure et al., 2007;). Both stretches are often performed by the subject themselves. The sleeper stretch is performed in the side-lying position with the arm to be stretched against the ground or table. The shoulder to be stretched is flexed to 90° and the elbow flexed to 90°. The subject then uses the hand of the opposite arm to push the stretched arm downward towards the ground or table at the wrist. In this side-lying position, the ground or table serves in stabilizing the scapula. By stabilizing the scapula, scapular anterior tilting, upward rotation, and protraction are limited and the desired movement is achieved only at the glenohumeral joint. The cross-body stretch can be performed in either the side-lying or standing position. While in the side-lying position, the subject again, lies on the side to be

stretched and flexes the shoulder to 90°. The subject then uses their opposite arm to pull the stretched arm across the chest. The standing cross-body stretch is performed by leaning the side to be stretched against a wall, flexing the shoulder to 90°, and using the opposite arm to pull the stretched arm across the chest. During both the side-lying and standing cross-body stretches, the scapula is stabilized by the ground/table or wall. Again, this technique will limit movement to just the glenohumeral joint.

There have been multiple research studies on the effects of stretching on GIRD. Manske, Meschke, Porter, Smith, and Reiman (2010) looked at the effects of the 4-weeks of cross-body stretching without scapular stabilization on passive shoulder internal rotation ROM in individuals with GIRD of the dominant shoulder. The researchers reported significant increases in internal rotation following the stretching intervention. Tyler, Nicholas, Lee, Mullaney, and McHugh (2010) examined the effects of physical therapy treatment lasting an average of approximately seven weeks, including the sleeper stretch and cross-body stretch, on shoulder internal rotation ROM in individuals with GIRD and internal impingement. Internal rotation ROM was compared in participants with complete resolution of symptoms versus those with residual symptoms at the end of treatment. The researchers reported a significant improvement in shoulder internal rotation ROM in both groups, with the group with complete resolution showing greater improvements. McClure et al. (2007) compared changes in shoulder internal rotation ROM over four weeks from performing the sleeper stretch and cross-body stretch. The researchers found that the cross-body stretch to be beneficial in improving internal rotation ROM when compared to a control, with the sleeper stretch exhibiting no significant changes in internal rotation ROM. However, research by Maenhout, Van Eessel, Van Dyck, Vanraes, and Cools (2012) found that a 6-week sleeper stretch program not only improved shoulder internal rotation

ROM in the dominant shoulder of overhead athletes with GIRD, but also was found to increase subacromial space in the dominant shoulder. These results provide insight into the possibility of internal rotation stretching decreasing the risk of subacromial impingement. Although the use of a sleeper or cross-body stretch was not used in a research study by Kibler and Chandler (2003), the researchers showed that shoulder internal rotation ROM can be significantly improved in junior tennis players with the use of behind the back shoulder internal rotation stretch utilizing a towel or tennis racket. In addition to interventions lasting a few weeks, the effects of stretching on GIRD have also been shown to continue to improve over a span of years. Research by Litner, Mayol, Uzodinma, Jones, and Labossiere (2007) found that professional pitchers enrolled in an internal rotation stretching program of three or more years showed greater shoulder internal rotation ROM than professional pitchers not enrolled in the program.

Research has not only looked at the effects of stretching on GIRD over time, but also the acute effects of stretching on shoulder internal rotation ROM. Laudner, Sipes, and Wilson (2008) looked at the acute effects of an assisted sleeper stretch on shoulder internal rotation in college baseball players. The researchers found that the sleeper stretch significantly increased shoulder internal rotation ROM. Research by Oyama, Goerger, Goerger, Lephart, and Myers (2010) examined the acute effects of a non-assisted shoulder stretches including a standing cross-body stretch against the wall, a sleeper stretch standing against the wall with the shoulder flexed to 90°, and a sleeper stretch standing against the wall with the shoulder flexed to 45°. All three of the non-assisted stretches produced significant increases in shoulder internal rotation ROM, with no significant differences seen between the groups. Very often, stretches to improve GIRD are accompanied by other stretches to improve overall shoulder mobility and function. This is the case with the inclusion of a supine internal rotation stretch into the Fauls modified passive

shoulder stretching routine, which has been a widely used stretching routine used since the 1980s to improve throwing shoulder ROM. In a study by Sauers, August, and Snyder (2007) examining the acute effects of the Fauls stretching routine on shoulder ROM in college baseball players. The stretching program produced significant increases in shoulder internal rotation ROM when compared to a control. The Fauls stretching routine includes multiple upper extremity stretches; therefore it is possible the improvements in shoulder internal rotation ROM may have been a result of the stretching program itself, rather than solely the internal rotation stretch.

Effects of Static Stretching on Strength, Power, and Motor Unit Recruitment

There is a general consensus that performing static stretching prior to activities that require lower-body maximal strength and power may negatively affect performance (Kay and Blazevich, 2012; Rubini, Costa, and Gomes, 2007). Although evidence on the exact mechanism is lacking, the reduction in muscle performance has been suggested to be a result of both structural and neurological adaptations. One theory is that stretching before activity can result in a loss of tension in the muscle from decreased overlapping of muscle filaments. This structural adaptation produces an altered length-tension relationship and in turn negatively affects the muscle's compliance to produce force. Another theory is that static stretching causes a reduction in the sensitivity of the muscle spindles and activity of the large-diameter afferents, resulting in decreased motor unit recruitment and force production. Although the phenomenon of decreased performance following static stretching has been witnessed in the lower-body, pre-activity static stretching has not been shown to negatively affect upper-body maximal strength and power performance. Beedle, Rytter, Healy, and Ward (2008) tested the effects of 3 sets of 15 second static stretches for the chest, shoulder, and triceps muscles with 15 seconds rest between sets on

1 repetition maximum (1RM) bench press in college-aged males and females. The researchers found that there were no significant adverse effects on 1RM bench press performance following the static stretching. In 2008, Torres et al. researched the effects of 2 sets of 15 second static stretches for the shoulder and arm muscles on isometric bench press, 30% of a 1RM bench press throw, overhead medicine ball throw, and lateral medicine ball throw of NCAA Division I track and field athletes and found no significant effects on performance following static stretching. Similarly, Faigenbaum et al.(2006) found that 2 sets of 30 second upper-body static stretches with 5 seconds rest between sets does not significantly affect seated medicine ball chest throwing performance in teenage male or female athletes.

Research has also been performed examining the effects of pre-activity static stretching on more sports-specific variables of athletic performance. Knudson, Noffal, Bahamonde, Bauer, and Blackwell (2004) researched the effects of the combination of a traditional tennis warm-up period and 2 sets of static stretches with 10 second rest for the upper and lower-body on tennis serve velocity and serve percentage in adult tennis players. It was shown that adding static stretching to a traditional tennis warm-up period had no significant short-term effects on the tennis serve performance variables. In 2010, Hagg, Wright, Guillette, and Greany examined the effects of 1 set of 30 second static stretching for the muscles of the throwing shoulder following an active warm-up on throwing performance variables in NCAA Division III baseball pitchers and position players. The research showed that the pre-activity static stretching had no significant impact on average throwing velocity, maximum throwing velocity, or throwing accuracy.

In addition to research done on the effects of pre-activity static stretching on variables of strength and power, there has also been research examining the effects of pre-activity static

stretching on motor unit recruitment through the use of electromyography (EMG). However, to the author's knowledge, this research has only looked at the effects of static stretching on motor unit recruitment in the lower-body. In 2013, Miyahara, Naito, Ogura, Katamoto, and Aoki examined the effects of 5 sets of 45 seconds of an assisted hamstring stretch with 15 seconds rest on biceps femoris EMG activity in college-aged males. The researchers found no significant effect from pre-activity static stretching when compared to a control group. Similarly, Herda, Cramer, Ryan, McHugh, and Stout (2008) found no significant effect in EMG activity of the biceps femoris in healthy male participants (mean age =25) during isometric contractions at multiple knee angles following 4 sets of a 30 second hamstring stretch with 15 seconds rest between sets. Research by Hough, Ross, and Howatson (2009) measured the effects of one set of a 30 second passive stretch for the plantar flexors, hip extensors, hamstrings, hip flexors, and quadriceps on vastus medialis EMG activity in male college-aged athletes during a vertical jump and found no significant effect.

The aforementioned research studies utilized what can be considered a lower volume (i.e. amount of stretches, sets, and duration) of stretching when compared to other studies examining the effects of pre-activity static stretching on motor unit recruitment. In 2005, Marek et al. looked at the effects of 4 sets of four different 30 second static stretches with 20 seconds rest for the knee extensors on EMG activity of the vastus lateralis and rectus femoris during maximal contraction isokinetic leg extension at 60°-s and 300°-s in college-aged males and females and found a significant decrease in EMG activity. Also in 2005, Cramer et al. found similar significant decreases in EMG activity of the vastus lateralis and rectus femoris during maximal concentric isokinetic knee extension at 60°-s and 240°-s in college-aged males and females following the exact same stretching protocol. Cronwell, Nelson, and Sidaway (2002) used a pre-

activity stretching protocol of 3 sets of two different 30 second static stretches (with no rest) for the plantar flexors and looked at its effect on EMG activity of the soleus and gastrocnemius and jump height during a static vertical jump (knees flexed) and counter-movement vertical jump. The researchers found a significant decrease in EMG for the soleus and gastrocnemius during the static vertical jump, but not the counter-movement vertical jump. These conflicting results were puzzling to the researchers considering that jump height did not significantly change in the static vertical jump and significantly decreased in the counter-movement vertical jump. The body of research cited above, raises the interesting theory that the effects of pre-activity static stretching on motor unit recruitment may be dose specific, given that a higher volume of stretching may result in a significant decrease in motor unit recruitment when compared to a lower volume.

Gaps in the Literature

From the review of the literature, it is known that pre-activity static stretching acutely increases glenohumeral internal rotation ROM. In addition, pre-activity static stretching for the upper-body has not been shown to negatively affect upper-body strength and power performance. Although only three studies have been published to date, they have shown that self-myofascial release may acutely improve ROM without negatively affecting performance in the lower-body. However, a few questions arise from the limited literature in these relatively new areas of research. First, does self-myofascial release affect shoulder ROM and/or performance? Secondly, does the combination of self-myofascial release and static stretching affect ROM and/or performance? Lastly, which of these two interventions would bring about most significant change in ROM and/or performance, if any?

Chapter III

METHODS

Research Design

The design of this study was quasi-experimental, in that there was no randomization or control group. A repeated measures procedure was followed, whereas all participants performed each of the three conditions (i.e. self-myofascial release, static stretching, and a combination of self-myofascial release and static stretching) on three separate sessions with at least one week between sessions to eliminate the risk of residual effects from the prior session. Participants served as their own control through pre-test and post-test measures and experimental randomization was used for the order of the three conditions and order of the two static stretches to eliminate the possibility of order effect.

Subject Sampling Procedure

The procedure for this study was convenience sampling and 12 male recreational softball players (mean age: 36.92 ±11.17 years; baseball/softball playing experience: 28.42 ±10.93 years) were recruited and participated in the study. From the results of the power analysis of the pilot study using G*Power Version 3 software (Faul, Erdfelder, Lang, & Buchner, 2007), 12 participants was the highest recommended feasible sample size for all dependent variables exhibiting significance to achieve an alpha of .05 and power of .80 (Table 1). Participants were recruited from multiple amateur male softball leagues in the New York City area through fliers

passed out at league games, supplied to league Commissioners, and posted on league websites (Appendix A).

Table 1

Pilot Study Power Analysis Results for All Dependent Variables Exhibiting Significance

Dependent Variable	Condition	Power	Effect Size	Sample Size
GH IR ROM (pre-post)	SMR	0.81	0.95	11
	SS	0.86	1.84	5
	SMR+SS	0.85	1.81	5
Throwing Velocity (pre-post)	SMR	0.80	0.15	374
INFRA EMG % MVC (pre-post)	SMR+SS	0.81	0.91	**12**
PEC MAJOR EMG % MVC (pre-post)	SMR+SS	0.80	0.89	**12**
GH IR ROM (condition vs. condition)	SMR vs. SS	0.86	1.26	8
	SMR vs. SMR+SS	0.83	1.21	8

IRB Approval and Informed Consent Form

Institutional Review Board (IRB) approval was obtained through St. Michael's Medical Center (SMMC) in Newark, New Jersey. All participants were verbally informed of the nature and requirements of the study, after which participants read and signed an informed consent form (Appendix B). Prior to data collection, participants were screened for eligibility by completing the "Eligibility to Participate Flow Sheet" (Appendix C). Any player to not successfully complete and pass this form was excluded from this study.

Inclusion Criteria

Participants were required to be male and between the ages of 18 and 50. All participants were required to be position players (i.e. any positon on the field other than the pitcher) because the position players in softball throw overhand at all times, which is the biomechanical shoulder movement most associated with GIRD. Due to the limited scope of practice of the researcher, the participants were required to be healthy with no previously diagnosed shoulder pathology in the throwing shoulder. Of the 12 participants recruited, nine threw right-handed and three left-handed. Participants were required to display ≥ 20° less glenohumeral internal rotation ROM in their throwing shoulder when compared to their non-throwing shoulder. This specific difference in ROM was used because research has shown that athletes with GIRD of greater than 20° appear to be at a greater risk for shoulder injury and surgery (Wilk et al., 2011).

Exclusion Criteria

Players under the age of 18 and over the age of 50 were excluded from this study. Female participants were excluded from this study due to easier accessibility to male softball players. Any softball pitchers were excluded from this study due to the fact that softball pitchers throw underhand, which is a biomechanical movement not specifically associated with GIRD. Any player who has been previously diagnosed with any shoulder pathology in their throwing shoulder was excluded from this study, because the scope of practice allows the researcher to only work with healthy individuals. Any players who exhibited < 20° less glenohumeral internal rotation ROM in their throwing shoulder when compared to their non-throwing shoulder were excluded from this study.

Independent Variable

1) Intervention: three conditions
    a) Self-myofascial Release (SMR)
    b) Static Stretching (SS)
    c) Self-myofascial Release combined with Static Stretching (SMR+SS)

Dependent Variables

1) Glenohumeral internal rotation ROM (deg)
2) Maximal glenohumeral external rotation isometric strength (N)
3) Mean motor unit recruitment (EMG) of the glenohumeral external rotator (infraspinatus) and internal rotators (pectoralis major and latissumus dorsi) during maximal isometric external rotation test (% of MVCs)
4) Maximal overhead throwing velocity (m/s)

Instrumentation

Self-myofascial release was performed using a standard sized lacrosse ball (Under Armour; Baltimore, MD). Glenohumeral internal rotation ROM was measured using a Baseline digital inclinometer (Fabrication Enterprises; White Plains, NY). Research by Kolber, Vega Jr., Widmayer, and Cheng (2011) showed this instrument to be reliable with an intra-rater ICC of 0.87 and inter-rater ICC 0.93. Maximal glenohumeral external rotation isometric strength was measured using a MicroFET2 handheld digital dynamometer (Hoggan Health; Salt Lake City, UT). This device was shown to be reliable with an intra-rater ICC of 0.85 and inter-rater ICC of 0.85 (Hayes, Walton, Szomor, & Murrell, 2002). Motor Unit recruitment was measured using a

Delsys Bagnoli portable surface electromyography (sEMG) system (Delsys, Boston, MA, USA). Surface electrodes placed on the muscles tested were Delsys parallel-bar AgCl 4 x 2 cm electrodes, while Noraxon 3.8 cm diameter disc electrodes (Noraxon, Scottsdale, AZ, USA) was used as the ground electrodes. Maximal overhead throwing velocity was measured using a Bushnell speed gun (Bushnell Outdoor Products; Overland Park, KS). The manufacturer claims the instrument to be accurate within ± 1 mph (2 kph). The softball used for during maximal overhead throwing was a deBeer F12 Clincher 12" softball (deBeer; St. Louis, MO).

Procedures

Self-Myofascial Release

The self-myofascial release (SMR) condition was performed in a side-lying position on the side of the throwing shoulder with the throwing shoulder and elbow both flexed to 90° (Figure 1). The lacrosse ball was positioned in the area of the infraspinatus muscle on the posterior side of the throwing shoulder's scapula. The participants were instructed to locate the most tender area along the posterior aspect of the scapula with the lacrosse ball and were then instructed to stay in that location and keep constant pressure on the tender area for 60 seconds. The participants performed two sets of 60 seconds with 30 seconds rest between sets (MacDonald et al., 2013).

Figure 1. Self-myofascial release performed with a lacrosse ball in the side-lying position. (Photo by Ryan R. Fairall)

Static Stretch: Sleeper Stretch

The static stretching (SS) condition was performed by the participants on themselves. Similar to SMR, the sleeper stretch was performed in the side-lying position on the side of the throwing shoulder with the throwing shoulder and elbow flexed to 90°. The participants were instructed to allow the throwing shoulder to naturally fall into internal rotation to the end ROM where resistance was felt. The participants were then instructed to use the non-throwing hand to push the throwing shoulder into further internal rotation to the point of mild discomfort by applying pressure at the area of the wrist joint (Figure 2). The participants held the static stretch for 30 seconds and performed three sets with 30 seconds rest between sets (Oyama, Goerger, Goerger, Lephart, & Myers, 2010).

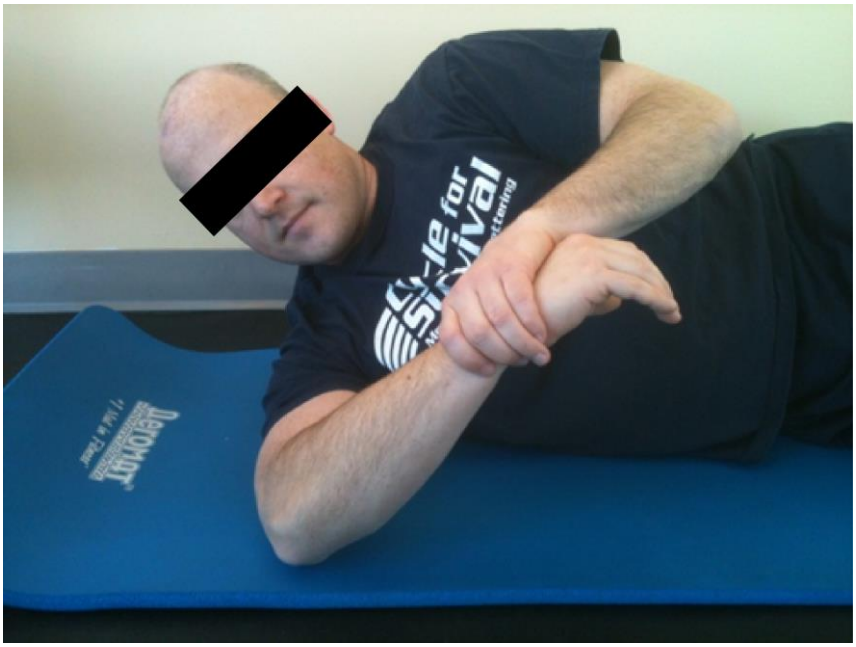

Figure 2. The sleeper stretch performed in the side-lying position. (Photo by Ryan R. Fairall)

Static Stretch: Cross-body Stretch

The cross-body stretch was performed in the side-lying position on the side of the throwing shoulder with the throwing shoulder flexed to 90°. The participants were instructed to wrap the non-throwing arm under the throwing arm just proximal to the elbow and then to pull the throwing arm into horizontal shoulder adduction across the body to the point of mild discomfort (Figure 3). The cross-body stretch was also performed for three sets of 30 seconds with 30 seconds rest between sets (Oyama, Goerger, Goerger, Lephart, & Myers, 2010). Following the condition performed, the participants were then given a 3-minute rest period between the intervention (i.e. SMR, SS, SMR+SS) and post-intervention testing (Torres et al., 2008).

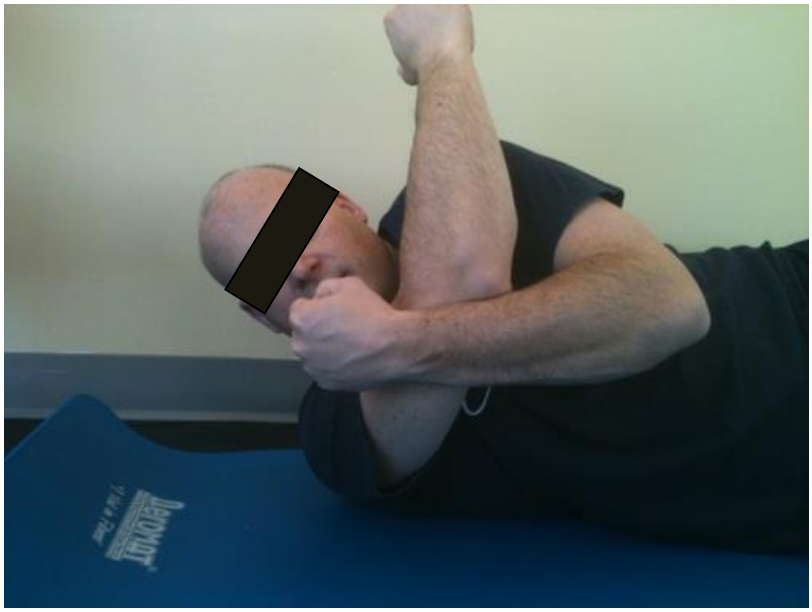

Figure 3. The cross-body stretch performed in the side-lying position. (Photo by Ryan R. Fairall)

Glenohumeral Internal Rotation Range of Motion

Measurement of glenohumeral internal rotation ROM was performed in the side-lying position on the side of the throwing shoulder with the throwing shoulder and elbow both flexed to 90°. The side-lying measuring protocol has shown greater intra- and inter-rater reliability when compared to the supine measurement protocol (Lunden, Muffenbier, Giveans, & Cieminski, 2010). The participants were instructed to allow the throwing shoulder to naturally fall into internal rotation to the end ROM where resistance was felt. At this point, the rater aligned the digital inclinometer along the unla of the throwing arm and took three measurements to calculate a mean internal rotation ROM (Figure 4).

Figure 4. Measurement of glenohumeral internal rotation in the side-lying position. (Photo by Ryan R. Fairall)

Glenohumeral External Rotation Isometric Strength

Measurement of glenohumeral external rotation isometric strength was measured in the prone position with the shoulder abducted to 90 ° and in 0° internal/external rotation (neutral) position) with the elbow flexed to 90° and a folded towel placed under the humerus to bring the arm in line with the trunk (Riemann, Davies, Ludwig, & Gardenhour, 2010). With the hand-held dynamometer placed just proximal to the wrist, the participants were instructed to maximally externally rotate the shoulder against the resistance of the rater for a five second count (Figure 5). The dynamometer displayed the maximal output and three measurements were taken to calculate a mean strength output.

Figure 5. Measurement of glenohumeral external rotation isometric strength. (Photo by Ryan R. Fairall)

Motor Unit Recruitment Data Collection

Motor unit recruitment of the glenohumeral external rotator (infraspinatus) and internal rotators (pectoralis major and latissimus dorsi) were measured through the use of surface electromyography (sEMG). Motor unit recruitment was measured in synchronization with glenohumeral external rotation isometric strength testing. Prior to measurement, the skin surface over the infraspinatus, pectoralis major (sternal fibers), and latissimus dorsi of the dominant arm was shaved (if needed) and rubbed with an alcohol cleaning pad. For infraspinatis motor unit recruitment measurement, a Delsys parallel-bar AgCl 4 x 2 cm electrode was applied parallel to the fiber pennation angle and approximately 4cm below the spine of the scapula over the infrascapular fossa of the scapula, while avoiding placement over the posterior deltoid (Criswell, 2011). For pectoralis major motor unit recruitment measurement, a Delsys parallel-bar AgCl 4 x 2 cm electrode was applied parallel to the fiber pennation angle horizontally on the chest wall

over the muscle mass that arises approximately 2cm out from the axillary fold (Criswell, 2011). For latissimus dorsi motor unit recruitment measurement, a Delsys parallel-bar AgCl 4 x 2 cm electrode was applied parallel to the fiber pennation angle approximately 4cm below the inferior tip of the scapula, half the distance between the spine and lateral edge of the torso and oriented in a slightly oblique angle of approximately 25°(Criswell, 2011). The EMG signal was amplified 1000x through the use of a dial on the Delsys Bagnoli portable amplifier.

Maximal voluntary contractions (MVC) were collected from the infraspinatus, pectoralis major, and latissimus dorsi during pre-invention testing for normalization. Infraspinatus MVCs were collected with the participants in the prone position with the throwing shoulder abducted to 90° and 0° internal/external rotation (neutral) position) with the elbow flexed at 90° with a towel placed under the humerus (Riemann, Davies, Ludwig, & Gardenhour, 2010). With the hand-held dynamometer placed just proximal to the wrist, the participants were instructed to maximally externally rotate the shoulder against the resistance of the rater for a five second count. Pectoralis major (sternal fibers) MVCs were collected with the participants in the supine position with the throwing shoulder abducted to 120° and elbow flexed to 90° (Hislop & Montgomery, 2002). The participants' throwing shoulder was then horizontally adducted across the body to be tested with the humerus in a flexed position. With the hand-held dynamometer placed just proximal to the wrist, the participants were instructed to horizontally adduct the shoulder in the direction of the opposite hip against the resistance of the rater for a five second count. Latissimus dorsi MVCs were collected with the participants in the prone position with the throwing shoulder internally rotated and in approximately 45° of extension (Hislop & Montgomery, 2002). With the hand-held dynamometer placed just proximal to the elbow, the participants were instructed to maximally extend the shoulder against the resistance of the rater for a five second count. Three

trials were performed to calculate mean EMG magnitudes. Pre and Post-intervention motor unit recruitment testing for all three conditions were collected during glenohumeral external rotation isometric strength testing. The data were then analyzed against the original MVC to obtain and report as a percentage of the MVCs. Three trials were performed to calculate mean EMG magnitudes.

Motor Unit Recruitment Data Analysis

All EMG data were analyzed using LabVIEW Version 7.1 (National Instruments, Austin, TX, USA). A virtual instrument (VI) program was used to analyze the data (A. McDonough, personal communication, May 1, 2013). The data were collected for five seconds and three seconds (1-4 sec) were used for analysis to account for electromechanical delay during the initiation of testing and possible altered activation patterns during the conclusion of testing due to fatigue. The protocol was used to discard the first second of data collection where motor unit recruitment initially begins and the last second where fatigue may alter motor recruitment patters. Data were sampled at a frequency of 1000 Hz and a band-pass filter was used at a 20 Hz low frequency cut-off and 500 Hz high frequency cut-off (Kamen & Gabriel, 2010). A linear envelope was utilized in which all raw EMG signals were rectified and filtered with a LP filter at 3 Hz (Kamen & Gabriel, 2010).

Overhead Throwing Velocity

For measurement of maximal overhead throwing velocity, the participants were instructed to stand with the feet approximately hips width apart, take one step towards the target (i.e. a net approximately 10 m away) with their non-dominate leg and throw the softball as fast as

possible. This protocol was used to standardize the biomechanical throwing motion for all participants to eliminate the possibility of varying wind-up movements. Prior to maximal throwing, the participants performed three sub-maximal warm-up throws to become accustom to the movement (Haag, Wright, Gillette, & Greany, 2010). Three maximal throws were then completed to calculate a mean throwing velocity.

Statistical Analysis

All statistical data were analyzed using SPSS Version 21 software (SPSS Inc., Chicago, IL) for Windows operating system. Statistical significance was set at a $p \leq .05$ for all statistical tests. The magnitude of the differences in means was used to calculate an effect size (ES) (change in mean/SD) for all dependent variables exhibiting significance and interpreted as: < 0.2 = trivial, 0.2 – 0.4 = small, 0.5 – 0.8 = moderate, > 0.8 = large (Portney & Watkins, 2009). An independent t-test was used to compare the internal rotation ROM of the throwing shoulder versus the non-throwing shoulder. Dependent t-tests were used to compare pre-test and post-test values of glenohumeral internal rotation ROM, glenohumeral external rotation isometric strength, motor unit recruitment (infraspinatus, pectoralis major, and latissimus dorsi), and overhead throwing velocity *within* the conditions (SMR, SS, SMR+SS). A Kolmogorov–Smirnov test (K–S test) was used for all t-tests to verify the assumption of normality. A majority of the 33 dependent variables measured in this study met the assumption of normality, therefore parametric tests were used. A 3 x 2 (condition x time) repeated-measures ANOVA tests was used to determine if there was a significant main effect for time within the three conditions, a significant main effect for condition between the three conditions, and/or a significant interactive effect between time and condition for glenohumeral internal rotation ROM, glenohumeral

external rotation isometric strength, motor unit recruitment (infraspinatus, pectoralis major, and latissimus dorsi), and overhead throwing velocity for the three conditions (SMR, SS, SMR+SS). If a main effect was found for time (within the three conditions), a dependent t-tests was used as a post-hoc test to determine where the significance lies. If a main effect was found for condition (between the three conditions), a one-way ANOVA using the differences between three conditions and a Tukey's post hoc test were used to determine where the significance lies. All of the dependent variables met the assumption of sphericity. Intra-class correlation coefficients (ICC) were calculated to determine validity and reliability for the testing of glenohumeral internal rotation ROM, glenohumeral external rotation isometric strength, motor unit recruitment (infraspinatus, pectoralis major, and latissimus dorsi), and overhead throwing velocity. The ICC ranges between .00 and 1.00, with values closer to 1.00 representing stronger reliability (Portney & Watkins, 2009). Values of greater than .75 are indicative of good reliability and those below .75 represent poor reliability.

Chapter IV

RESULTS

Glenohumeral Internal Rotation Range of Motion

To be included in this study, participants were required to exhibit ≥ 20° less internal rotation ROM in their throwing shoulder when compared to their non-throwing shoulder. The participants' mean glenohumeral internal rotation ROM for their throwing shoulders was 19.10° (± 5.19) and 43.96° (± 5.35) for their non-throwing shoulders. The participants exhibited significantly less internal rotation ROM (25.63° ± 3.88; p = 0.0001) in their throwing shoulders when compared to their non-throwing shoulders (Table 2). For pre-test to post-test *within* condition measures, all three conditions produced significant increases in glenohumeral internal rotation ROM. SMR+SS produced the greatest increase at 10.15° ± 4.95 (p = .0001; d = 1.62), followed by SS at 8.58° ± 4.42 (p = .0001; d = 1.40), and SMR at 3.84° ± 1.42 (p = .0001; d = .77) (Figure 6). There was no significant main effect for glenohumeral internal rotation ROM *between* the three conditions (p = .36). However, due to the large differences witnessed in the changes in internal rotation range of motion from pre-test to post-test between the three conditions, a one-way ANOVA was used to determine if there were any significance differences from pre-test to post-test between the three conditions. The results of the one-way ANOVA using the differences in glenohumeral internal rotation ROM from pre-test to post-test showed that there was a significant main effect (p = .0001) and a Tukey's post-hoc test showed that the changes in glenohumeral internal rotation ROM were significantly greater in SS (4.74°; p = .01; d = 1.19) and SMR+SS (6.31°; p = .001; d = 1.43) when compared to SMR (Figure 7). However,

there was no significant difference in changes in glenohumeral internal rotation ROM between SS and SMR+SS (1.57°; p = .55). There was a significant interaction effect (p = .01) between time and condition for glenohumeral internal rotation ROM. This interaction shows that as the condition changes there is a significant difference in glenohumeral internal rotation ROM from pre-test to post-test. All within and between condition internal rotation ROM measures showed good reliability with ICCs of well over .75 (Table 3). Paired samples statistics for glenohumeral internal rotation ROM can be seen in Table 4. Paired samples test for glenohumeral internal rotation ROM can be seen in Table 5. Pairwise comparison statistics for glenohumeral internal rotation ROM can be seen in Table 6.

Table 2

Descriptive Statistics for Participants

n	Age (years)	Playing Experience (years)	Height (cm)	Mass (kg)	Throw IR (deg)	Non-throw IR (deg)	IR diff (deg)	IR diff (p value)
12	36.92 ±11.17	28.42 ±10.93	177.42 ±6.30	87.58 ±18.39	19.10 ±5.19	43.96 ±5.35	-25.63 ±3.88	**0.0001**

Table 3

Intra-Class Correlation Coefficients (ICC) for Dependent Variables

	ICC		ICC		ICC
SMR IR pre	0.99	SS IR pre	0.99	SMR+SS IR pre	0.95
SMR IR post	0.99	SS IR post	0.96	SMR+SS IR post	0.99
SMR ISO pre	0.98	SS ISO pre	0.99	SMR+SS ISO pre	0.96
SMR ISO post	0.95	SS ISO post	0.94	SMR+SS ISO post	0.97
SMR VELO pre	0.99	SS VELO pre	0.99	SMR+SS VELO pre	0.98
SMR VELO post	0.99	SS VELO post	1.00	SMR+SS VELO post	0.99
SMR Infra MVCs	0.99	SS Infra MVCs	0.99	SMR+SS Infra MVCs	0.93
SMR Pec MVCs	0.99	SS Pec MVCs	0.98	SMR+SS Pec MVCs	0.99
SMR Lat MVCs	0.97	SS Lat MVCs	0.98	SMR+SS Lat MVCs	0.97
SMR Infra pre	0.99	SS Infra pre	0.99	SMR+SS Infra pre	0.93
SMR Infra post	0.99	SS Infra post	1.00	SMR+SS Infra post	0.98
SMR Pec pre	0.99	SS Pec pre	0.98	SMR+SS Pec pre	0.99
SMR Pec post	0.98	SS Pec post	0.86	SMR+SS Pec post	0.97
SMR Lat pre	0.98	SS Lat pre	0.99	SMR+SS Lat pre	0.98
SMR Lat post	0.97	SS Lat post	0.99	SMR+SS Lat post	0.88

Table 4

Paired Samples Statistics for Glenohumeral Internal Rotation Range of Motion (deg)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SMRIRpre	20.3108	12	4.66021	1.34529
	SMRIRpost	24.1475	12	5.29486	1.52849
Pair 2	SSIRpre	20.0417	12	5.17224	1.49310
	SSIRpost	28.6192	12	6.79294	1.96095
Pair 3	SMRSSIRpre	20.2092	12	3.92566	1.13324
	SMRSSIRpost	30.3567	12	7.21365	2.08240

Table 5

Paired Samples Test for Glenohumeral Internal Rotation Range of Motion

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	SMRIRpre - SMRIRpost	-3.83667	1.41230	.40770	-4.73400	-2.93933	-9.411	11	.000
Pair 2	SSIRpre - SSIRpost	-8.57750	4.48518	1.29476	-11.42725	-5.72775	-6.625	11	.000
Pair 3	SMRSSIRpre - SMRSSIRpost	-10.14750	4.93899	1.42576	-13.28558	-7.00942	-7.117	11	.000

Table 6

Pairwise Comparison Statistics for Glenohumeral Internal Rotation Range of Motion

Pairwise Comparisons

Measure: MEASURE_1

(I) ROM		Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b] Lower Bound	Upper Bound
SMR	SS	-4.651*	1.291	.012	-8.292	-1.010
	SMR+SS	-6.333*	1.218	.001	-9.768	-2.898
SS	SMR	4.651*	1.291	.012	1.010	8.292
	SMR+SS	-1.683	1.557	.909	-6.073	2.708
SMR+SS	SMR	6.333*	1.218	.001	2.898	9.768
	SS	1.683	1.557	.909	-2.708	6.073

Based on estimated marginal means

*. The mean difference is significant at the .05 level.

b. Adjustment for multiple comparisons: Bonferroni.

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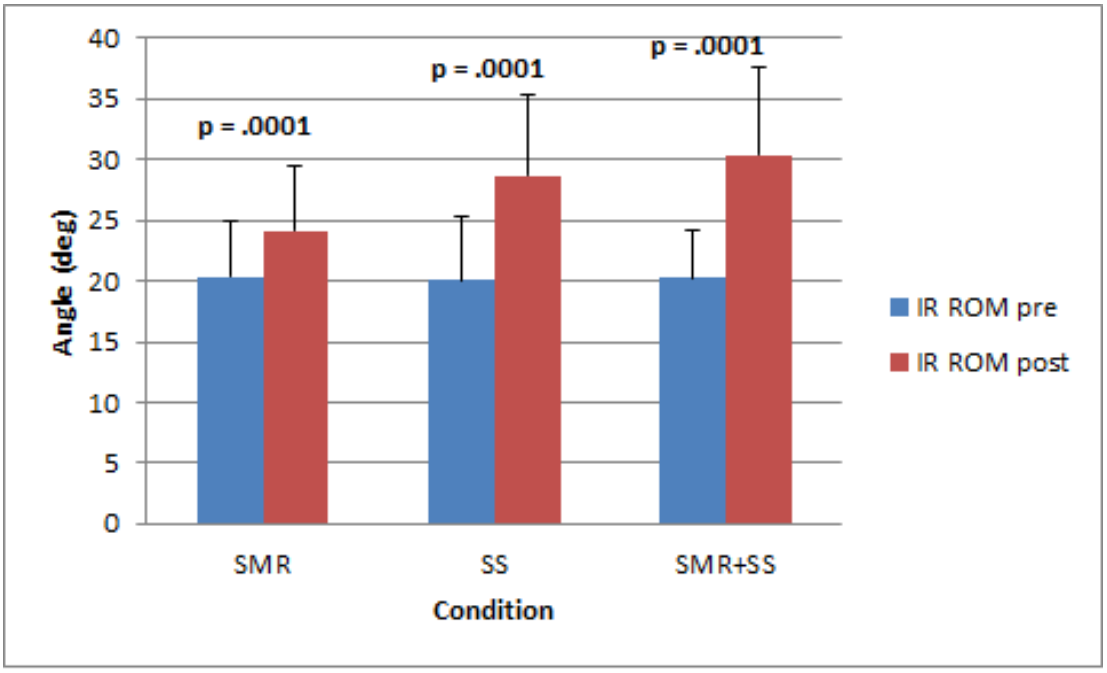

Figure 6. Pre-test to post-test changes in glenohumeral internal rotation range of motion within conditions.

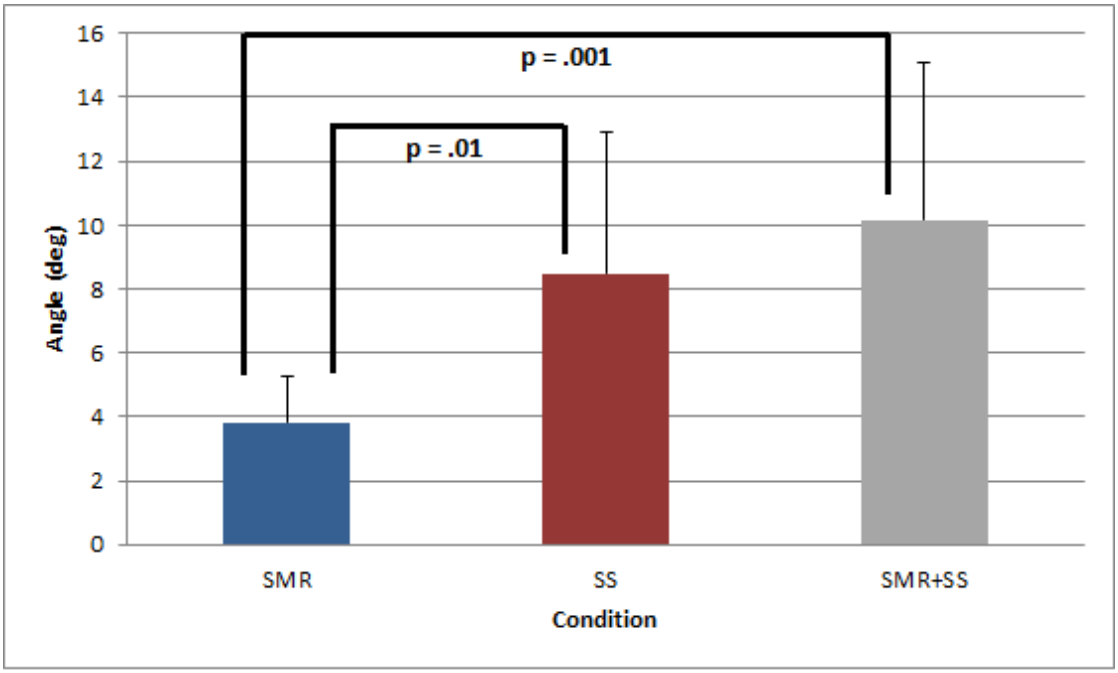

Figure 7. Changes in glenohumeral internal rotation range of motion between conditions.

Glenohumeral External Rotation Isometric Strength

For pre-test to post-test *within* condition measures, SMR produced a significant increase in glenohumeral isometric external rotation strength by 4.54 N ± 5.77 (p = .02; d =.22) (Figure 8). There were no significant differences in glenohumeral isometric external rotation strength following SS (1.27 N ± 13.84; p = .76) or SMR+SS (-1.18 N ± 10.87; p = .71). There were no significant differences in glenohumeral isometric external rotation strength *between* the three conditions (p = .41). All within and between condition glenohumeral isometric external rotation strength measures showed good reliability with ICCs of well over .75 (Table 3). Paired samples statistics for glenohumeral external rotation isometric strength can be seen in Table 7. Paired samples test for glenohumeral external rotation isometric strength can be seen in Table 8. Pairwise comparison statistics for glenohumeral external rotation isometric strength can be seen in Table 9.

Table 7

Paired Samples Statistics for Glenohumeral External Rotation Isometric Strength (N)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SMRisopre	101.6208	12	18.61039	5.37236
	SMRisopost	106.1575	12	21.69196	6.26193
Pair 2	SSisopre	103.4800	12	24.72813	7.13839
	SSisopost	104.7525	12	20.27291	5.85229
Pair 3	SMRSSisopre	104.1883	12	16.19161	4.67412
	SMRSSisopost	103.0083	12	20.27724	5.85353

Table 8

Paired Samples Test for Glenohumeral External Rotation Isometric Strength

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	SMRisopre - SMRisopost	-4.53667	5.77143	1.66607	-8.20366	-.86968	-2.723	11	.020
Pair 2	SSisopre - SSisopost	-1.27250	13.83860	3.99486	-10.06512	7.52012	-.319	11	.756
Pair 3	SMRSSisopre - SMRSSisopost	1.18000	10.86889	3.13758	-5.72576	8.08576	.376	11	.714

Table 9

Pairwise Comparison Statistics for Glenohumeral External Rotation Isometric Strength

Pairwise Comparisons

Measure: MEASURE_1

(I) ISO		Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
SMR	SS	3.307	4.597	1.000	-9.657	16.270
	SMR+SS	5.759	3.378	.349	-3.768	15.286
SS	SMR	-3.307	4.597	1.000	-16.270	9.657
	SMR+SS	2.453	4.655	1.000	-10.674	15.579
SMR+SS	SMR	-5.759	3.378	.349	-15.286	3.768
	SS	-2.453	4.655	1.000	-15.579	10.674

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

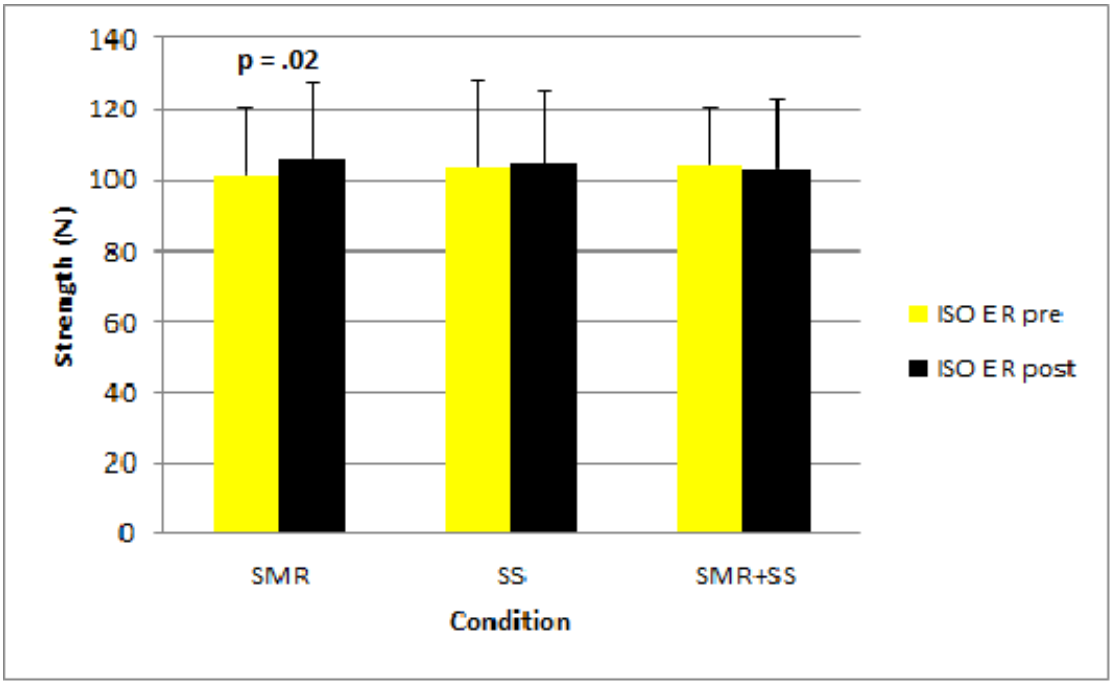

Figure 8. Pre-test to post-test changes in glenohumeral isometric external rotation strength within conditions.

Motor Unit Recruitment of Infraspinatus during Isometric Strength Testing

For pre-test to post-test *within* condition measures, mean infraspinatus normalized EMG magnitudes during isometric shoulder external rotation significantly increased by 6.30% ± 7.31 ($p = .01$; $d = 0.86$) in the SS and by 7.52% ± 9.23 ($p = .02$; $d = 0.82$) in the SMR+SS condition (Figure 9). There were no significant differences in infraspinatus normalized EMG magnitudes in the SMR condition (.18%, ± 10.97; $p = .96$). There were no significant differences in the changes in mean infraspinatus normalized EMG magnitudes *between* the three conditions ($p = .14$). All within and between condition infraspinatus motor unit recruitment measures showed good reliability with ICCs of well over .75 (Table 3). Paired samples statistics for infraspinatus motor unit recruitment can be seen in Table 10. Paired samples test for infraspinatus motor unit

recruitment can be seen in Table 11. Pairwise comparison statistics for infraspinatus motor unit recruitment can be seen in Table 12.

Table 10

Paired Samples Statistics for Infraspinatus Motor Unit Recruitment (Mean % of MVC)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SMRinfrapre	100.0000	12	0.00000	0.00000
	SMRinfrapost	100.1800	12	10.96616	3.16566
Pair 2	SSinfrapre	100.0000	12	0.00000	0.00000
	SSinfrapost	106.3017	12	7.30749	2.10949
Pair 3	SMRSSinfrapre	100.0000	12	0.00000	0.00000
	SMRSSinfrapost	107.5183	12	9.22849	2.66404

Table 11

Paired Samples Test for Infraspinatus Motor Unit Recruitment

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	SMRinfrapre - SMRinfrapost	-.18000	10.96616	3.16566	-7.14757	6.78757	-.057	11	.956
Pair 2	SSinfrapre - SSinfrapost	-6.30167	7.30749	2.10949	-10.94463	-1.65871	-2.987	11	.012
Pair 3	SMRSSinfrapre - SMRSSinfrapost	-7.51833	9.22849	2.66404	-13.38184	-1.65483	-2.822	11	.017

Table 12

Pairwise Comparison Statistics for Infraspinatus Motor Unit Recruitment

Pairwise Comparisons

Measure: MEASURE_1

(I) INFRA		Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
SMR	SS	-6.122	3.303	.273	-15.437	3.193
	SMR+SS	-7.338	4.752	.452	-20.740	6.063
SS	SMR	6.122	3.303	.273	-3.193	15.437
	SMR+SS	-1.217	3.078	1.000	-9.896	7.462
SMR+SS	SMR	7.338	4.752	.452	-6.063	20.740
	SS	1.217	3.078	1.000	-7.462	9.896

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

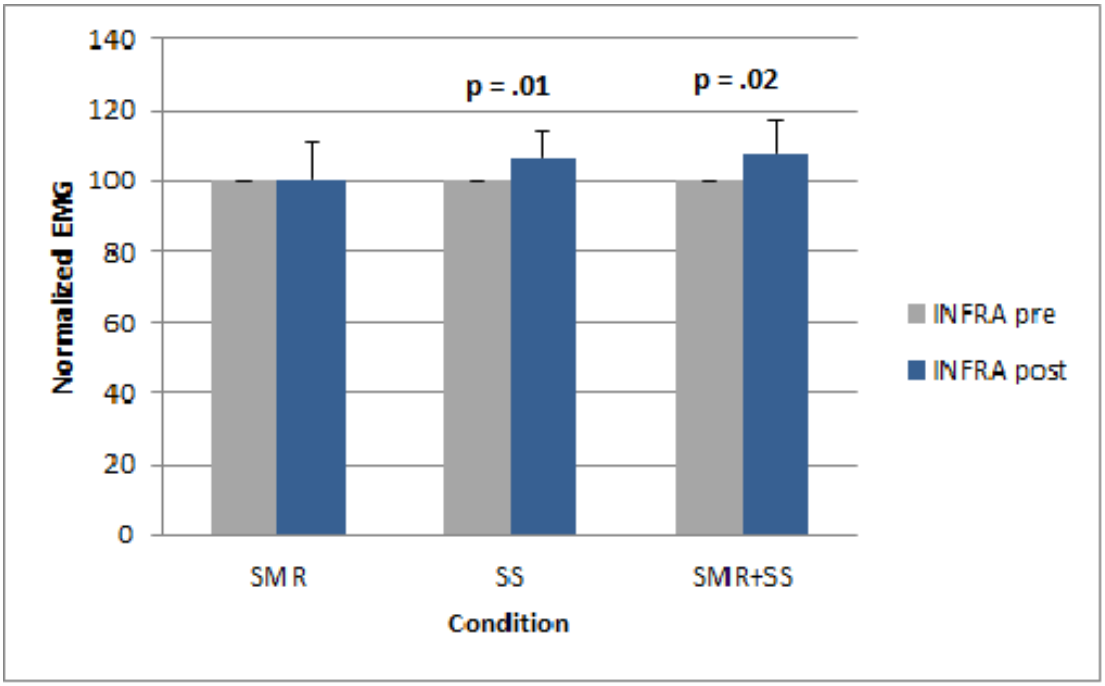

Figure 9. Pre-test to post-test changes in infraspinatus motor unit recruitment during isometric shoulder external rotation within conditions.

Motor Unit Recruitment of Pectoralis Major during Isometric Strength Testing

For pre-test to post-test *within* condition measures, mean pectoralis major normalized EMG magnitudes during isometric shoulder external rotation significantly decreased in the SMR+SS condition by 5.90% ± 7.98 ($p = .03$; $d = 0.62$) (Figure 10). There were no significant differences in mean pectoralis major normalized EMG magnitudes in the SMR (-2.95% ± 5.05; $p = .07$) or SS conditions (0.10% ± 2.00; $p = .87$). There was a significant differences in the changes in mean pectoralis major normalized EMG magnitudes *between* the three conditions ($p = .03$), however, there was no significance found following a pairwise comparison. All within and between condition pectoralis major motor unit recruitment measures showed good reliability with ICCs of well over .75 (Table 3). Paired samples statistics for pectoralis major motor unit recruitment can be seen in Table 13. Paired samples test for pectoralis major motor unit recruitment can be seen in Table 14. Pairwise comparison statistics for pectoralis major motor unit recruitment can be seen in Table 15.

Table 13

Paired Samples Statistics for Pectoralis Major Motor Unit Recruitment (Mean % of MVC)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SMRpecpre	9.2808	12	7.22702	2.08626
	SMRpecpost	6.3292	12	3.19393	.92201
Pair 2	SSpecpre	7.0350	12	5.07839	1.46600
	SSpecpost	7.1333	12	5.19387	1.49934
Pair 3	SMRSSpecpre	12.3292	12	10.81485	3.12198
	SMRSSpecpost	6.4250	12	3.82798	1.10504

Table 14

Paired Samples Test for Pectoralis Major Motor Unit Recruitment

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	SMRpecpre - SMRpecpost	2.95167	5.05225	1.45846	-.25838	6.16171	2.024	11	.068
Pair 2	SSpecpre - SSpecpost	-.09833	1.99939	.57718	-1.36869	1.17202	-.170	11	.868
Pair 3	SMRSSpecpre - SMRSSpecpost	5.90417	7.97514	2.30222	.83700	10.97133	2.565	11	.026

Table 15

Pairwise Comparison Statistics for Pectoralis Major Motor Unit Recruitment

Pairwise Comparisons

Measure: MEASURE_1

(I) PEC		Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
SMR	SS	-3.052	1.657	.278	-7.725	1.621
	SMR+SS	2.953	1.932	.464	-2.497	8.402
SS	SMR	3.052	1.657	.278	-1.621	7.725
	SMR+SS	6.004	2.415	.091	-.806	12.814
SMR+SS	SMR	-2.953	1.932	.464	-8.402	2.497
	SS	-6.004	2.415	.091	-12.814	.806

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

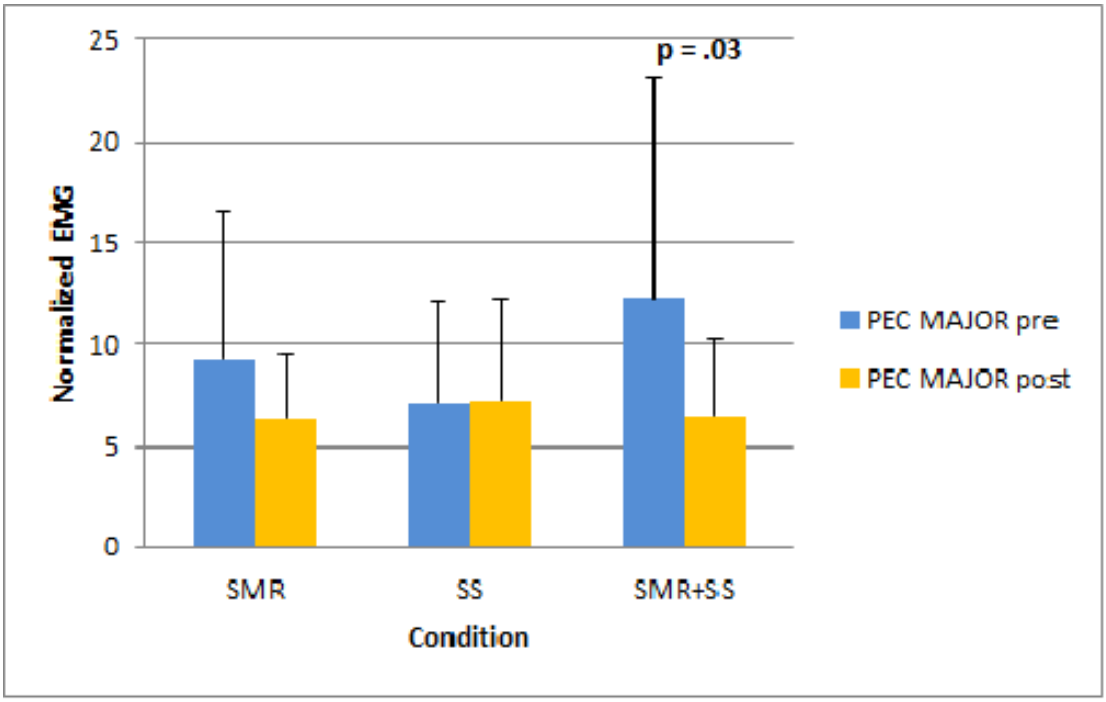

Figure 10. Pre-test to post-test changes in pectoralis major motor unit recruitment during isometric shoulder external rotation within conditions.

Motor Unit Recruitment of Latissimus Dorsi during Isometric Strength Testing

For pre-test to post-test *within* condition measures, mean latissimus dorsi normalized EMG magnitudes during isometric shoulder external rotation significantly decreased by 11.88% ± 17.28 ($p = .04$; $d = 0.80$) following SMR+SS (Figure 11). There were no significant differences in mean latissimus dorsi normalized EMG magnitudes following the three conditions of SMR (-4.60% ± 16.95; $p = .37$) or SS (-0.98% ± 11.69; $p = .78$). There were no significant differences in the changes in mean latissimus dorsi normalized EMG magnitudes *between* the three conditions ($p = .27$). All within and between condition latissimus dorsi motor unit recruitment measures showed good reliability with ICCs of well over.75 (Table 3). Paired samples statistics for latissimus dorsi motor unit recruitment can be seen in Table 16. Paired

samples test for latissimus dorsi motor unit recruitment can be seen in Table 17. Pairwise comparison statistics for latissimus dorsi motor unit recruitment can be seen in Table 18.

Table 16

Paired Samples Statistics for Latissimus Dorsi Motor Unit Recruitment (Mean % of MVC)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SMRlatpre	23.7600	12	13.10901	3.78425
	SMRlatpost	19.1575	12	18.58794	5.36588
Pair 2	SSlatpre	19.6950	12	10.63770	3.07084
	SSlatpost	18.7133	12	14.39265	4.15480
Pair 3	SMRSSlatpre	25.7233	12	16.72023	4.82671
	SMRSSlatpost	13.8392	12	4.94067	1.42625

Table 17

Paired Samples Test for Latissimus Dorsi Motor Unit Recruitment

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	SMRlatpre - SMRlatpost	4.60250	16.95386	4.89416	-6.16947	15.37447	.940	11	.367
Pair 2	SSlatpre - SSlatpost	.98167	11.68995	3.37460	-6.44577	8.40911	.291	11	.777
Pair 3	SMRSSlatpre - SMRSSlatpost	11.88417	17.27556	4.98702	.90780	22.86053	2.383	11	.036

Table 18

Pairwise Comparison Statistics for Latissimus Dorsi Motor Unit Recruitment

Pairwise Comparisons

Measure: MEASURE_1

(I) LAT		Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a]	
					Lower Bound	Upper Bound
SMR	SS	-3.621	6.814	1.000	-22.837	15.595
	SMR+SS	7.273	7.171	.997	-12.950	27.495
SS	SMR	3.621	6.814	1.000	-15.595	22.837
	SMR+SS	10.893	5.758	.255	-5.346	27.132
SMR+SS	SMR	-7.273	7.171	.997	-27.495	12.950
	SS	-10.893	5.758	.255	-27.132	5.346

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

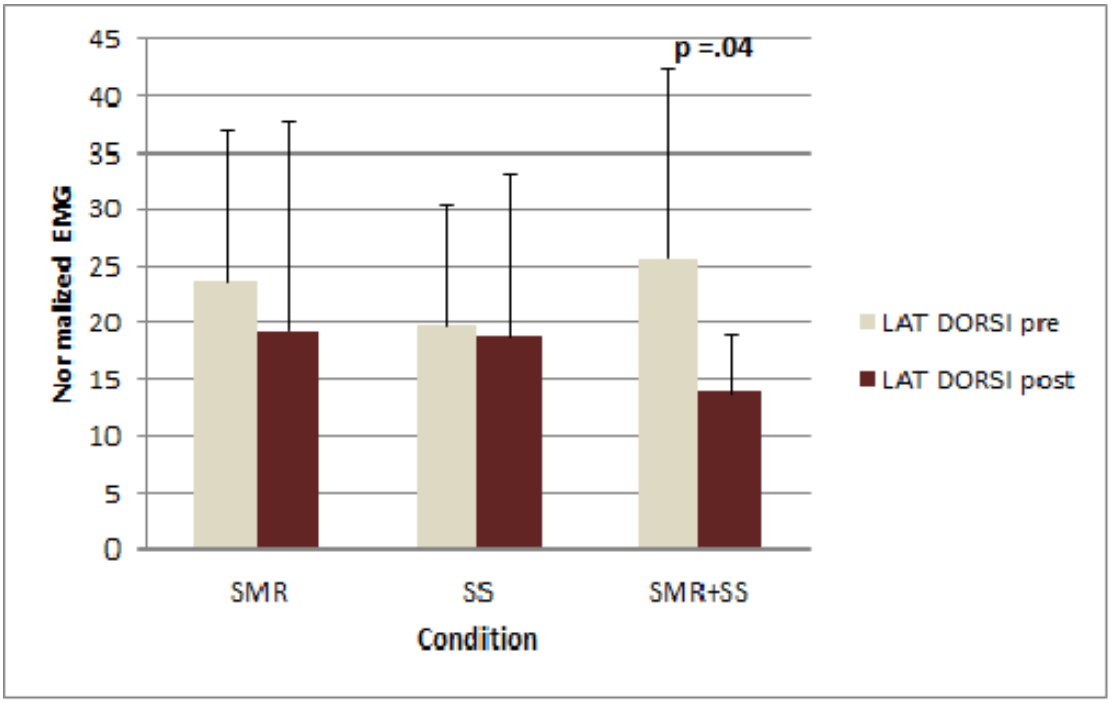

Figure 11. Pre-test to post-test changes in latissimus dorsi motor unit recruitment during isometric shoulder external rotation within conditions.

Overhead Throwing Velocity

For pre-test to post-test *within* condition measures, overhead throwing velocity significantly increased by 0.35 m/s ± 0.41 m/s (p = .01; d = 0.11) in the SMR condition (Figure 12). There were no significant differences in overhead throwing velocity in the SS (0.24 m/s ± 0.64; p = .23) or SMR+SS (0.11 m/s ± 0.32; p = .25) conditions. There were no significant differences in the changes in overhead throwing velocity *between* the three conditions (p = .33). All within and between condition overhead throwing velocity measures showed good reliability with ICCs of well over .75 (Table 3). Paired samples statistics for overhead throwing velocity can be seen in Table 19. Paired samples test for overhead throwing velocity can be seen in Table 20. Pairwise comparison statistics for overhead throwing velocity can be seen in Table 21.

Table 19

Paired Samples Statistics for Overhead Throwing Velocity (m/sec)

Paired Samples Statistics

		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	SMRvelopre	22.4262	12	3.04756	.87976
	SMRvelopost	22.7737	12	2.88841	.83381
Pair 2	SSvelopre	22.7489	12	2.48262	.71667
	SSvelopost	22.9847	12	2.98023	.86032
Pair 3	SMRSSvelopre	22.5816	12	2.69123	.77689
	SMRSSvelopost	22.6944	12	2.65756	.76717

Table 20

Paired Samples Test for Overhead Throwing Velocity

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	SMRvelopre - SMRvelopost	-.34741	.40853	.11793	-.60697	-.08784	-2.946	11	.013
Pair 2	SSvelopre - SSvelopost	-.23579	.63953	.18462	-.64213	.17055	-1.277	11	.228
Pair 3	SMRSSvelopre - SMRSSvelopost	-.11280	.32101	.09267	-.31676	.09116	-1.217	11	.249

Table 21

Pairwise Comparison Statistics for Overhead Throwing Velocity

Pairwise Comparisons

Measure: MEASURE_1

(I) VELO		Mean Difference (I-J)	Std. Error	Sig.[a]	95% Confidence Interval for Difference[a] Lower Bound	Upper Bound
SMR	SS	.096	.246	1.000	-.598	.789
	SMR+SS	.307	.165	.271	-.159	.773
SS	SMR	-.096	.246	1.000	-.789	.598
	SMR+SS	.211	.197	.921	-.345	.768
SMR+SS	SMR	-.307	.165	.271	-.773	.159
	SS	-.211	.197	.921	-.768	.345

Based on estimated marginal means

a. Adjustment for multiple comparisons: Bonferroni.

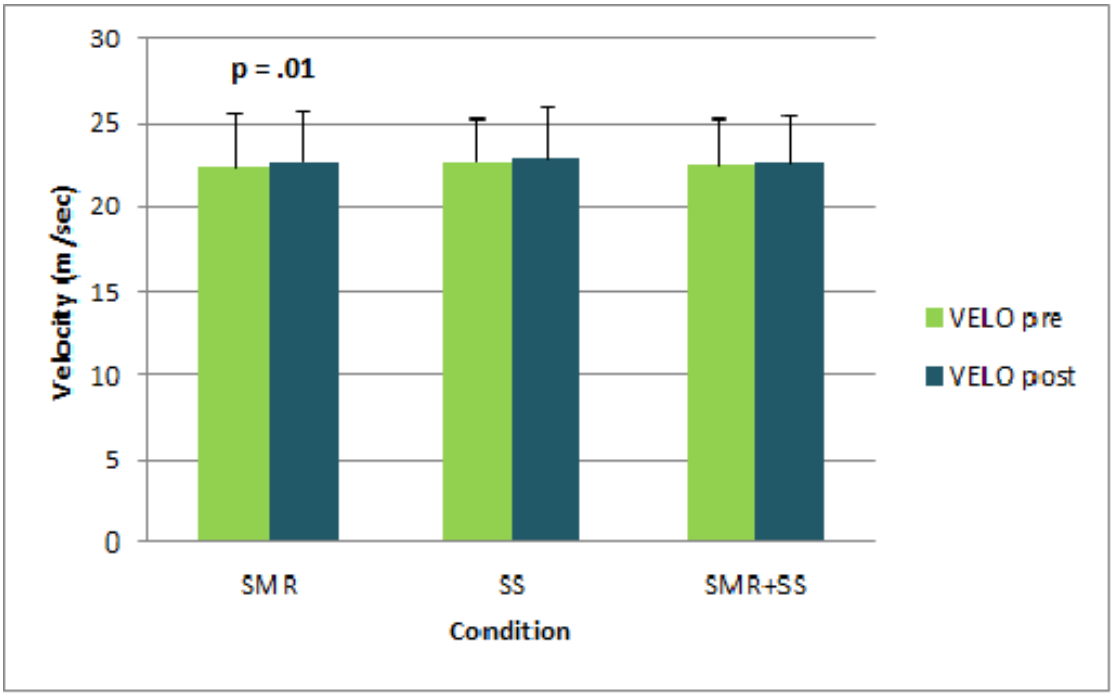

Figure 12. Pre-test to post-test changes in overhead throwing velocity within condition

Chapter V

DISCUSSION

The sample of male softball players in this study presented with a significant difference of 25.63° less glenohumeral internal rotation ROM in their throwing shoulders when compared to their non-throwing shoulders. This substantial decrease in ROM is clinically significant considering individuals exhibiting GIRD of greater than or equal to 20° appear to be at a greater risk for shoulder injury and surgery (Wilk et al., 2011). The decrease in ROM in these participants is consistent with prior research that witnessed a decrease in dominant arm glenohumeral internal rotation ROM in overhead athletes such as baseball pitchers (Downer & Sauers, 2005; Hurd et al., 201; Laudner, Moline, & Meister, 2010; Reagan et al., 2000), baseball position players (Laudner, Moline, & Meister, 2010), volleyball players (Thomas, Swanik, Swanik, & Huxel, 2009), tennis players (Ellenbecker, Roetert, Piorkowski, & Schulz, 1996), overhead cricket bowlers (Giles & Musa, 2008), and handball players (Almeida et al., 2013). This movement impairment of the shoulder can be attributed to soft tissue adaptations (Litner, Mayol, Uzodinma, Jones, & Labossiere, 2007; Myers et al. 2007) and/or osseous changes of the humeral head (Chant, Litchfield, Griffin, & Thain, 2007; Crockett et al., 2002; Litner, Mayol, Uzodinma, Jones, & Labossiere, 2007; Reagan et al., 2002) caused by the repetitive overhead movements required in the athletic activities mentioned above, specifically the deceleration and follow-through phases. However, as previously mentioned, osseous changes are not capable of being corrected by a clinician interventions, so any changes in ROM following the interventions

used in this study can be attributed to acute positive changes in soft tissue structures, such as the posterior glenohumeral capsule, muscles (i.e. shoulder external rotators) and connective tissue.

Effects of the Intervention on Glenohumeral Internal Rotation Range of Motion

Static stretching has long been utilized as an intervention for improving ROM with the purpose of decreasing risk of injury. However, recently self-myofascial release has become a popular technique used by strength and conditioning professionals during the pre-activity warm-up period to assist in muscle relaxation and soft tissue pliability. Though to date, there has been very little research performed on the acute effects of self-myofascial release on range on motion. In their text, Clark and Lucett (2011) recommend performing self-myofascial release on tender areas in the muscle tissue that would result in the relaxation of the overactive, structurally shortened muscles, a phenomenon known as autogenic inhibition. Clark and Lucett (2011) recommend performing static stretching for these same muscles immediately following self-myofascial release to lengthen the muscle and connective tissues, while decreasing muscle spindle activity and motor unit excitability. While there has been very little research on the acute effects of performing self-myofascial release alone, there has been no research published on the acute effects of the combination of self-myofascial release and static stretching on ROM. Therefore the main purpose of this study was to research the acute effects of self-myofascial release, static stretching, and the combination of self-myofascial release and static stretching on glenohumeral internal rotation ROM in male softball players with GIRD. In turn, improvements in glenohumeral internal rotation rotation ROM can then be believed to lead to a decreased risk of injury commonly seen in individuals with GIRD.

Performing self-myofascial release with a standard lacrosse ball on the most tender area in the infraspinatus muscle for 2 sets of 60 seconds with 30 seconds between sets significantly increased glenohumeral internal rotation ROM by 3.84° ($p = .0001$) with a moderate effect size ($d = 0.77$). Prior research by MacDonald et al. (2013), in which this same protocol was used through performing foam rolling on the quadriceps muscles resulted in significant increases of 10° in knee flexion ROM two minutes following the intervention and 8° after 10 minutes ($p < .001$). Research by Sullivan, Silvey, Button, and Behm (2013) found that foam rolling of the hamstring muscles using a low-volume of self-myofascial release when compared to the current study and MacDonald et al. (2013) (i.e. 1-2 sets of 5-10 sec) still resulted in significant main effect increase of 4.3% in sit-and-reach test measures ($p = .0001$). The increases in range of motion are believed to be a response to the biomechanical loading of soft tissue and neural reflex modifications through stimulation of GTOs and inhibition of the muscle spindles, a phenomenon known as autogenic inhibition (Remvig, Ellis, & Patijn, 2008). Although more research is necessary on the acute effects of self-myofascial release on ROM, this study along with the two published peer-reviewed studies show that self-myofascial release can positively affect ROM and in turn, may assist in decreasing risk of injury. According to the results of this study, the hypothesis of glenohumeral internal rotation ROM would be significantly different following a bout of self-myofascial release was supported by the significant increase in ROM witnessed.

Static stretching is very commonly prescribed to individuals with GIRD to improve glenohumeral internal rotation ROM and decrease risk of injury. The two static stretches predominately prescribed are the sleeper stretch and the cross-body stretch. There has been a substantial amount of research that has shown that the application of these stretches over time (e.g. 4-6 weeks) in individuals with GIRD can significantly improve glenohumeral internal

rotation ROM (Kibler & Chandler, 2003; Litner, Mayol, Uzodinma, Jones, & Labossiere, 2007; Maenhout, Van Eessel, Van Dyck, Vanraes, &Cools, 2012; Manske, Meschke, Porter, Smith, & Reiman, 2010; Tyler, Nicholas, Lee, Mullaney, & McHugh, 2010). However, there have only been two known studies that have looked at the acute effects of these static stretches on glenohumeral internal rotation ROM. A study by Laudner, Sipes, and Wilson (2008) found that 3 sets of 30 seconds with 30 seconds rest of an assisted sleeper stretch can significantly increase glenohumeral internal rotation ROM (3.1°; $p = .003$; $d = .32$) in NCAA Division I baseball players. In 2010, Oyama, Goerger, Goerger, Lephart, and Myers examined the acute effects of three different self-applied static stretches (3 sets of 30 sec with 30 sec rest) including a cross-body stretch against the wall, sleeper stretch standing against the wall with the shoulder flexed to 90°, and a sleeper stretch standing against the wall with the shoulder flexed to 45° on glenohumeral internal rotation ROM in collegiate baseball pitchers. The results showed that the cross-body stretch against the wall, sleeper stretch standing against the wall with the shoulder flexed to 90°, and a sleeper stretch standing against the wall with the shoulder flexed to 45° significantly improved internal rotation ROM by 4.4°, 3.8°, and 4.6° respectively.

For the current study, the results show that performing 3 sets of 30 seconds with 30 seconds rest between sets of the sleeper and cross-body stretches resulted in a significant increase of 8.58° ($p = .0001$) with a large effect size ($d = 1.40$). Following the same protocol as Laudner, Sipes, and Wilson (2008) and Oyama, Goerger, Goerger, Lephart, and Myers (2008), the increases in internal rotation ROM were approximately two times the increases in these studies. This large difference in results may have been due to utilizing two stretches, as opposed to one in the previously mentioned studies. Also, a large variance in discomfort thresholds associated with the stretches may have played a part. Some participants were witnessed to have

higher thresholds, which resulted in greater ROM gained during the stretches and therefore greater increases in ROM. In addition, compared to the assisted stretching used in Laudner, Sipes, and Wilson (2008), the participants in this study performed the stretches on themselves, which may result in a further ROM gained while stretching when compared to partner-assisted stretches. Also, the participants performed the stretches in a side-lying position which provides greater stability to the scapula allowed the subject more leverage to apply a further stretch when compared to the standing position used in Oyama, Goerger, Goerger, Lephart, and Myers (2008). Nevertheless, this large increase in ROM can be assumed to result in a decreased risk of injury associated with GIRD. The increase of 8.58° was significantly greater ($p = .01$) than self-myofascial release alone (3.54°) and can be considered a superior technique for acutely improving glenohumeral internal rotation ROM. According to the results of this study, the hypothesis of glenohumeral internal rotation ROM would be significantly different following a bout of static stretching was supported by the significant increase in ROM witnessed.

As previously mentioned, despite the recommendation of performing self-myofascial release and static stretching together (Clark & Lucett, 2011), there have been no published research on the effects of the combination of these two interventions on ROM. However, the rationale behind this recommendation most likely comes from the logic that combining the two interventions, which have been shown to significantly improve ROM, would result in an even greater improvement than either intervention performed alone and thus a greater decrease in injury risk. This is the first study to test this reasoning and determine if the combination of self-myofascial release and static stretching is superior to self-myofascial release and static stretching alone for improving glenohumeral internal rotation ROM. According to the results, performing a combination of self-myofascial release and static stretching increased glenohumeral internal

rotation ROM by 10.15° with a large effect size (d = 1.62). Therefore, the hypothesis of glenohumeral internal rotation ROM would be significantly different following a bout of a combination of self-myofascial release and static stretching was supported by the significant increase witnessed. The increase in ROM following the combination of self-myofascial release and static stretching was significantly greater than self-myofascial release alone by 6.31° (p = .001) with a high effect size (d = 1.43). Although the increase in ROM following combination of self-myofascial release and static stretching was greater than static stretching alone by 1.57°, it was not considered statistically significant (p = .91). Therefore, the combination of self-myofascial release and static stretching can be considered superior to performing self-myofascial release alone, but not static stretching alone. The significant increase in ROM with the combination of self-myofascial release and static stretching can be attributed to the addition of static stretching to the intervention. Due to the small difference in the increase in ROM between the combination of self-myofascial release and static stretching and static stretching alone, it may not be beneficial to dedicate the additional time to performing the volume of self-myofascial release employed in this study if pre-activity warm-up time is limited. On the other hand, if the athlete does have the additional warm-up time available, the inclusion of self-myofascial release to static stretching may be beneficial over time and may pose additional benefits, although more research in this area is warranted. According to the results of the study, the hypothesis that changes in glenohumeral internal rotation ROM would not be significantly different between self-myofascial release, static stretching, and the combination of self-myofascial release and static stretching cannot be supported due to the significant differences found between static stretching and self-myofascial release; and the combination of self-myofascial release and static stretching and self-myofascial release alone.

Effects of the Intervention on Strength, Motor Unit Recruitment, and Throwing Velocity

To date, here have only been three studies investigating the effects of self-myofascial release on strength, motor unit recruitment, and power. (Healey, et al., 2013; MacDonald et al., 2013; Sullivan, Silvey, Button, & Behm, 2013). However, all of the studies looked at the effects on lower-body performance. In contrast, there has been a substantial amount of research examining the effects of static stretching on these same variables in both the upper- and lower-body (Beedle, Rytter, Healy, & Ward, 2008; Faigenbaum et al., 2006; Hagg, Wright, Guillette, and Greany, 2010; Kay & Blazevich, 2012; Knudson, Noffal, Bahamonde, Bauer, & Blackwell, 2004; Rubini, Costa, & Gomes, 2007; Torres et al., 2008). Though to date, there has been no research published on the effects of the combination of self-myofascial release and static stretching on strength, motor unit recruitment, or power. Therefore, the secondary purpose of this study was to determine if pre-activity a) self-myofascial release, b) static stretching, and c) the combination of self-myofascial release and static stretching acutely affect glenohumeral external rotation isometric strength, motor unit recruitment of the external and internal shoulder rotators, or overhead throwing velocity. This is of significant importance due to the fact that if any these three conditions negatively affect any of these variables, athletic performance will also negatively be affected. Consequently, these conditions will then be less likely to be recommended prior to any athletic activity requiring these performance variables, even though ROM may be improved.

According to the results, 2 sets of 60 seconds with 30 seconds rest of self-myofascial release produced a significant increase in glenohumeral external rotation isometric strength by 4.54 N ($p = .02$), however, the effect size was low ($d = 0.22$). Although the increase in isometric strength was small, strength did not decrease, which a positive outcome is considering

glenohumeral internal rotation ROM was significantly improved. Research by MacDonald et al. (2013) also found that foam rolling did not have a significant effect on maximal knee extensor contraction force following the same protocol followed in this study. Similarly, Healey et al. (2013) found that foam rolling exercises for the lower-body resulted in no significant difference in isometric squatting force against a stationary Smith machine squat bar. In addition, Sullivan, Silvey, Button, and Behm (2013) found that rolling of the hamstring did not significantly affect isometric force of the hamstrings. This is the first study to examine the effects of self-myofascial release on upper-body strength performance. From the results of this study and previous research cited, it can be concluded that the hypothesis of external rotation maximal isometric strength would not be significantly different following a bout of self-myofascial release was supported by the small, but significant increase in isometric strength witnessed.

As previously mentioned, pre-activity static stretching has been shown to negatively affect lower-body strength performance, however, this has not been witnessed in the upper-body. Due to the relatively low amount of studies researching the acute effects of static stretching on upper-body performance, there has been no firm conclusion on why the effects of stretching are different between the upper- and lower-body (Kay & Blazevich, 2012; Torres et al., 2008). Therefore, more research is warranted on the acute effects of static stretching on upper-body performance. According to the results, 3 sets of 30 seconds with 30 seconds rest of the sleeper stretch and cross-body stretch did not significantly affect glenohumeral external rotation isometric strength ($p = .76$). These results are similar to research by Beedle, Rytter, Healy, and Ward (2008), which found that 3 sets of 15 seconds static stretches for the chest, shoulders and triceps with 15 seconds rest did not significantly affect 1RM bench press performance. In addition, Torres et al. (2008) found that 2 sets of 15 second static stretches for the shoulders and

arms did not significantly affect isometric bench press strength. The results of the current study show that static stretching can significantly improve glenohumeral internal rotation ROM without having a significant enough effect structurally or neurologically to negatively affect external rotation isometric strength performance. According to the results of this study, the hypothesis of external rotation maximal isometric strength would not be significantly different following a bout of static stretching was supported.

This is the first study to examine the effects of the combination of self-myofascial release and static stretching on strength performance. According to the results, there were no significant differences in glenohumeral isometric external rotation strength following the combination of self-myofascial release and static stretching ($p = .71$). This is a positive finding considering that the combination of self-myofascial release and static stretching resulted in the greatest increase in internal rotation ROM (10.15°), but did not negatively affect isometric strength. This may be due to the fact that the increase in glenohumeral internal rotation ROM following the combination of self-myofascial release and static stretching was not so significant to negatively affect the length-tension relationship of the muscle resulting in a decrease in strength isometric strength performance (Rubini, Costa, & Gomes, 2007). According to the results of this study, the hypothesis of external rotation maximal isometric strength would not be significantly different following a bout of the combination of self-myofascial release and static stretching was supported.

It is believed that by applying myofascial pressure to tender areas in the tissue, GTO along with other interstitial receptors and Ruffini endings throughout the fascia, respond to tension thus inhibiting the muscle spindles and allowing the muscle to relax and become more pliable and able to be lengthened (Schleip, 2003). Consequently, it has been theorized that this

mechanoreceptor inhibition may result in a decrease in motor unit activation capability and strength/power performance. However, research by MacDonald et al. (2013) has shown that pre-activity self-myofascial release significantly improves knee flexion ROM without significantly affecting knee extensor motor unit activation. Similarly, Sullivan, Silvey, Button, and Behm (2013) found that self-myofascial release improved sit-and-reach ROM without significantly affecting hamstring motor unit activation. The current study is the first study to examine the effect of self myofascial release on upper-body motor unit recruitment. In addition to looking at the effects of self-myofascial release on the motor unit recruitment of the infraspinatus muscle during glenohumeral external rotation isometric testing, the study also simultaneously examined motor unit recruitment of the pectoralis major and latissimus dorsi to research possible effects of myofascial release on antagonist muscles. When a muscle is structurally shortened or overactive, it can alter the reciprocal inhibition (i.e. relaxation) of its antagonist counterparts during contraction. In this case, the overactivity of external rotator infraspinatus muscle may lead to a co-contraction of the internal rotators (pectoralis major and latissimus dorsi) during glenuhumeral isometric external rotation.

According to the results, there was a no significant change (.18%; $p = .96$) in mean EMG magnitude of the infraspinatus during glenohumeral external rotation isometric strength testing following self-myofascial release. Although not statistically significant, there was however, a 2.95% ($p = .07$) decrease in pectoralis major EMG magnitudes and a 4.60% ($p = .37$) decrease in latissimus dorsi EMG magnitudes during glenohumeral external rotation. These results show that self-myofacial release did not significantly affect motor unit recruitment of the agonist infraspinatus muscle, but slightly decreased motor unit recruitment of the antagonist pectoralis major and latissimus dorsi muscles. These results may be due to improved reciprocal inhibition

allowing for decreased neural innervation and co-contraction of the antagonist muscles (i.e. pectoralis major and latissimus dorsi) (Page, Frank, & Lardner, 2010). Therefore, the hypothesis that motor unit recruitment of the glenohumeral external rotator (infraspinatus) and internal rotators (pectoralis major and latissimus dorsi) during maximal isometric external rotation would not be significantly different following a bout of self-myofascial release was supported.

Static stretching has been shown to decrease motor unit recruitment, though this effect has been shown predominately in the lower-body. On the other hand, the effect on motor unit recruitment may be a result of a dose-response effect. In other words, research has shown that a higher volume of stretching (e.g. 4 sets of 30 seconds of four different stretches) is correlated with negative effects on motor unit recruitment (Cramer et al., 2005; Cronwell, Nelson, & Sidaway, 2002; Marek et al., 2005), whereas a lower volume (e.g. 1-4 sets of one 30 second stretch) does not result in a negative effect (Herda, Cramer, Ryan, McHugh, & Stout, 2008; Hough, Ross, and Howatson; 2009; Miyahara, Naito, Ogura, Katamoto, & Aoki, 2013). The neural mechanism of decreased motor unit activation associated with greater static stretching volume may be due to a reduced activity of the large diameter afferents, resulting in the reduced sensitivity of the muscle spindles to stretch (Avela, Kyröläinen, & Komi, 1999). A protocol of 3 sets of 30 seconds of two stretches (i.e. sleeper and cross-body) was used in this study and could be considered a moderate volume of stretching. According to the results, infraspinatus EMG magnitudes during isometric shoulder external rotation significantly increased by 6.30% ($p = .01$) following static stretching with a high effect size ($d = 0.86$). However, there were no significant differences in pectoralis major (0.10%; $p = .87$) or latissimus dorsi (-0.98%; $p = .78$) EMG magnitudes. Theoretically, this increase in infraspinatus motor unit recruitment may be due to a more optimal filament positioning and length-tension relationship as a result of an 8.58°

increase in internal rotation ROM. When the muscle has a short initial length, the filaments in each sarcomere are already overlapping, which in turn limits the amount of tension the muscle can develop (Sahrmann, 2002). The prior research mentioned above did not measure initial ROM to determine if the muscles being tested were structurally shortened or tight. If the researchers would have tested the intervention on muscles that were shown to be in a shortened or tight positon, their results may have shown an increase in motor unit recruitment. According to the results, the hypothesis that motor unit recruitment of the glenohumeral external rotator (infraspinatus) and internal rotators (pectoralis major and latissimus dorsi) during maximal isometric external rotation would not be significantly different following a bout of static stretching is not supported due to the significant increase in infraspinatus motor unit recruitment. However, this increase infraspinatus motor unit recruitment would not lead to a decrease in strength and may actually improve performance, which can be viewed as a positive result.

To date, there has been no research published on the effects of the combination of self-myofascial release and static stretching on motor unit recruitment. According to the results, infraspinatus EMG magnitudes during isometric shoulder external rotation significantly increased by 7.52% ($p = .02$) following the combination of self-myofascial release and static stretching, with a high effect size ($d = 0.82$). On the contrary, pectoralis major EMG magnitudes significantly decreased by 5.90% ($p = .03$) with a moderate effect size ($d = 0.62$) and latissimus dorsi EMG magnitudes significantly decreased by 11.88% ($p = .04$) with moderate-to-high effect size ($d = 0.80$). The improvement in infraspinatus motor unit recruitment may be the product of positively altered filament positioning and length-tension relationship resulting in a greater ability to produce tension (Sahrmann, 2002). In contrast, the decrease in pectoralis major and latissimus dorsi motor unit recruitment may be due to improved reciprocal inhibition allowing

for decreased neuron innervation and co-contraction of the antagonist muscles (Page, Frank, & Lardner, 2010). These results are extremely noteworthy considering the muscle performing the work had a greater activation of motor units following the intervention, while the opposing muscles had a decreased activation or co-contraction. This consequence is important to achieving proper arthokinematics, structural alignment, muscular strength and endurance, and motor coordination through means of optimal reciprocal inhibition between agonist and antagonist muscles (Clark & Lucett, 2011). According to the results, the hypothesis of motor unit recruitment of the glenohumeral external rotator (infraspinatus) and internal rotators (pectoralis major and latissimus dorsi) during maximal isometric external rotation would not be significantly different following a bout of a combination of self-myofascial release and static stretching cannot be supported due to the changes witnessed.

Only one of the studies on self-myofascial release looked at its effect on variables of muscular power and explosiveness. Healey et al. (2013) found that foam rolling had no significant effect on vertical jump for height, vertical jump for power, or pro agility test. Overhead velocity was used in this study to determine effects on power and explosiveness. According to the results of this study, overhead throwing velocity significantly increased by 0.35 m/s ($p = .01$; $d = 0.11$). This increase may have been statistically significant, however, due to the small effect size this increase may not be considered meaningful in terms of practical application. Nonetheless, the hypothesis of overhead throwing velocity would not be significantly different following a bout of self-myofascial release cannot be supported due to the significant increase in throwing velocity.

Research has shown that static stretching can negatively affect power and explosiveness in the lower-body, but not in the upper-body. Faigenbaum et al. (2006) showed that 2 sets of 30

second stretches with 5 seconds rest for the upper-body had no significantly affect seated medicine ball chest throw distance. Knudson, Noffal, Bahamonde, Bauer, and Blackwell (2004) found that the combination of a traditional tennis warm-up period and 2 sets of static stretches with 10 second rest for the upper and lower-body did not significantly affect tennis serve velocity and serve percentage in adult tennis players. Research by Hagg, Wright, Guillette, and Greany (2010) found that 1 set of 30 second static stretching for the muscles of the throwing shoulder following an active warm-up had no significant impact on average throwing velocity, maximum throwing velocity, or throwing accuracy. Similarly, the results of this study showed that static stretching had no significant effect on overhead throwing velocity (0.24 m/s; $p = .23$), despite the 8.58° increase in internal rotation ROM. According to the results, the hypothesis of overhead throwing velocity would not be significantly different following a bout of static stretching can be supported.

This is the first study to examine the effect of the combination of self-myofascial release and static stretching on power and explosiveness. According to the results, there were no significant differences in overhead throwing velocity following the combination of self-myofascial release and static stretching (0.11 m/s; $p = .25$), even with the greatest increase in internal rotation ROM of 10.15°. Therefore, the hypotheses of overhead throwing velocity would not be significantly different following a bout of a combination of self-myofascial release and static stretching is supported. In addition, the hypothesis of changes in external rotation isometric strength, motor unit recruitment, and overhead throwing velocity would not be significantly different between the three conditions was support due to no significant differences found between the three conditions in any of the performance variables.

Summary

Glenohumeral internal rotation ROM was significantly increased in all three conditions of self-myofascial release, static stretching, and the combination of self-myofascial release and static stretching. However, static stretching and the combination of self-myofascial release and static stretching exhibited significantly greater increases than self-myofascial release alone. Though there was no significant difference between static stretching and the combination of self-myofascial release and static stretching. These positive results may be due to mechanical adaptations such as improved length and elasticity of soft tissue and increased length-tension relationships; as well as neurological adaptations such as decreased contractile activity and motor neuron excitability, improved autogenic inhibition, and increased muscle relaxation and pliability. These increases in glenohumeral internal rotation ROM should result in a decreased risk of shoulder injuries associated with overhead activities.

Even with the significant increases in glenohumeral internal rotation ROM, glenohumeral external rotation maximal isometric strength and maximal overhead throwing velocity were not negatively affected by any of three conditions. The conditions resulted in improved ROM, but not to the point of decreased neuromuscular efficiency resulting in impaired performance. Motor unit recruitment of infraspinatus (agonist) increased following static stretching and the combination of self-myofascial release and static stretching. These positive results imply improved motor unit recruitment of the muscle producing the work, acute mechanoreceptor and proprioceptive responses, and positively altered muscular length-tension relationship and plasticity. In addition, motor unit recruitment of pectoralis major and latissimus dosi (antagonists) decreased following the combination of self-myofascial release and static

stretching. These positive results imply decreased motor units recruited, positively altered reciprocal inhibition, and decreased co-contraction of the antagonist muscles.

Limitations of the Study

First, due to the scope of the researcher, the sample was limited to individuals without diagnosed shoulder pathologies. Many individuals who have GIRD experience pain and are commonly diagnosed with a specific shoulder pathology such as anterior instability, rotator cuff pathologies, shoulder impingement, labral lesions, and scapular dyskinesis (Braun, Kokmeyer, & Millett, 2009; Kolber, Hanney, & Benevento, 2012). Secondly, due to the lack of availability of isokinetic equipment, strength had to be tested isometrically with a handheld dynamometer. This type of strength testing does not measure muscular forces produced concentrically and eccentrically at the shoulder at a high velocity comparable to overhead throwing. Thirdly, with the pre- and post-intervention testing order of strength and then power, there may have been shoulder fatigue throughout testing that could have affected subsequent testing performance results. However, the testing order used was the most logical to the researcher. Lastly, the effects of the intervention were not tested at multiple intervals following the intervention (e.g. 10 and 20 minutes) to examine if the effects begin to diminish over time. In overhead sports like baseball and softball, the athlete may not throw for extended periods of time during a game (e.g. multiple innings) and if the athlete is inactive during these periods, the positive effects of the intervention may be reversible.

Chapter VI

CONCLUSIONS

Practical Applications

The field of strength and conditioning is always in search of new strategies to assist in keeping athletes injury-free and performing their best on the field or court. Over the last decade, the technique of self-myofascial release has increased in popularity due to its proposed benefit of increased ROM, which is presumed to be correlated with a decreased risk of injury. In addition, some associations like the National Academy of Sports Medicine (NASM), promote performing pre-activity self-myofascial release immediately followed by static stretching to result in an even greater increase in ROM and thus, a further decrease in injury risk (Clark & Lucett, 2011). However, the combination of these two pre-activity injury prevention strategies has not been researched and therefore cannot be considered evidence-based practice. Moreover, the inclusion of static stretching into the pre-activity warm-up period has been shown to decrease performance in activities requiring maximal strength and power, at least in the lower-body. Therefore, the purposes of this study were to a) examine the effects of self-myofascial release, static stretching, and the combination of self-myofascial release and static stretching on glenohumeral internal rotation ROM and b) to determine if an of the three conditions affect strength, motor unit recruitment, and/or power performance.

The results of this study show that all three conditions significantly improve glenohumeral internal rotation ROM in overhead athletes with GIRD, however, static stretching and the combination of self-myofascial release and static stretching improved ROM significantly

more than self-myofascial release alone. Although the static stretching and the combination of self-myofascial release and static stretching resulted in a greater increase in ROM when compared to static stretching alone, the difference between the two was not statistically significant. Therefore, if the athlete has a limited amount of time to dedicate to the pre-activity warm-up period (i.e. 3-4 minutes), it can be presumed that performing static stretching alone may suffice for improving ROM, at least when it comes to short-term benefits.

Along with the effects on ROM, this study examined the effects of the three conditions on performance variables of glenohumeral external rotation isometric strength, motor unit recruitment of the infraspinatus (agonist), pectoralis major (antagonist) and latissimus dorsi (antagonist) during external rotation isometric strength testing, and overhead throwing velocity. None of the three conditions of self-myofascial release, static stretching, or the combination of self-myofascial release and static stretching resulted in a decrease in any of the performance variables. However, the combination of self-myofascial release and static stretching resulted in the most significant increase in motor unit recruitment of the infraspinatus (agonist) and decreases in pectoralis major and latissimus dorsi motor unit recruitment during external rotation isometric strength testing. This improvement in motor unit recruitment and glenohumeral internal rotation ROM following the combination of self-myofascial release and static stretching would theoretically result in the greatest decrease in injury risk and may be accompanied by improved strength through greater motor unit activation of the agonist muscle and deactivation of the antagonists. Therefore, if the athlete has the time available that is needed to perform the combination of self-myofascial release and static stretching (i.e.7-8 minutes), it is recommended to use this strategy during the pre-activity warm-up period.

Suggestions for Further Research

Due to the scope of practice of the researcher, participants with no prior diagnosed shoulder pathologies were used in this study. Since many individuals with GIRD experience pain and have been diagnosed with specific pathologies, future research should examine the effects of self-myofascial release and the combination of self-myofascial release and static stretching in this sample to determine possible outcomes in relation to these diagnoses. Attributable to the lack of isokinetic equipment, the current study utilized a handheld dynamometer to measure the effects of the conditions on glenohumeral external rotation isometric strength. Future research is warranted using isokinetic equipment for measuring dynamic glenohumeral external rotation strength at high velocities comparable to the arm cocking phase of overhead throwing, which would be more specific to the biomechanical movement of the sport.

Research has shown that acute improvements in ROM from static stretching may be lost in as little as 3 minute (DePino, Webright, & Arnold, 2000) and as many as 15 minutes (de Weijer, Gorniak, & Shamus, 2003) after cessation of the stretching. However, both of these studies examined the length of the effect from static stretching in the hamstring muscles. Future research is necessary to determine the length of the effect of self-myofascial release, static stretching, and the combination of self-myofascial release and static stretching in the upper-body muscles, specifically the glenohumeral rotators. This research is especially critical in relation to athletes in sports such as baseball and softball, where the athletes may not perform explosive, dynamic movements like throwing for extended periods of time (e.g. multiple innings). The acute improvements in ROM may be reversible after a certain period of time (e.g. 3-15 minutes) and consequently the injury prevention benefits may be lost. The results would assist strength and conditioning professionals to identify how frequently athletes in these sports should perform

static stretching during games to retain the improvement in ROM and possible performance benefits. The current study examined the acute effects of the conditions on ROM and performance, however, further research is needed examining the effects of performing these conditions over time in strength and conditioning program (e.g. 6 weeks). Therefore, future research examining the incorporation of self-myofascial release and the combination of self-myofascial release and static stretching into a strength and conditioning program would be valuable in determining the chronic effects of these injury prevention strategies.

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Appendix A

Recruitment Flyer

You are invited to participate in a research study entitled:

"Acute effects of self-myofacial release and static stretching on shoulder range of motion and performance in overhead athletes with glenohumeral internal rotation deficit: A pilot study"

Conducted by: Ryan R. Fairall

Repetitive overhead throwing required in playing softball can lead to tightness of the muscles and tendons of the back of the shoulder which has been linked to shoulder injury. The purpose of this study is to examine the effects of two injury prevention strategies (self-myofascial release and static stretching) on shoulder range of motion and also shoulder performance (strength, muscle activity, and throwing speed).

Your participation would require 1.5-2 hours on three separate testing sessions with approximately one-week between testing sessions. To be included, you must show at least 20 degrees less range of motion in your throwing shoulder compared to your non-throwing shoulder (will be measured by researcher). You must also be a male between 18 and 40 years of age.

You will be tested initially on range of motion and performance, then perform one of the three conditions (static stretching, self-myofascial release, and the combination of self-myofascial release), and then be immediately re-tested on range of motion and performance.

Your participation in this study is completely voluntary. By participating in this study, you will learn specific injury prevention exercises that may help to improve your shoulder range of motion and assist in lowering your risk of shoulder injury.

If you are interested, please contact the principal investigator:

Ryan R. Fairall
Phone: (917)744-6685
Email: ryan.fairall@student.shu.edu

Appendix B

Subject-Informed Consent Form

Researcher's Affiliation
The research project entitled, "Acute effects of self-myofacial release and static stretching on shoulder range of motion and performance in overhead athletes with glenohumeral internal rotation deficit: A pilot study" is being conducted by Ryan R. Fairall who is a certified strength and conditioning specialist and PhD Candidate in the Graduate Program in Health Sciences at Seton Hall University with all the necessary qualification to assess and test all participants during this research study.

Purpose
The purpose of this study is to examine the acute effects of a) self-myofascial release, b) static stretching, and c) a combination of self-myofascial release and static stretching on shoulder external rotation range of motion and shoulder performance in overhead athletes with decrease shoulder range of motion.

Procedures
Participants will be recreational male softball players ages 18-40 exhibiting at least 20° less shoulder internal rotation range of motion in their throwing shoulder when compared to their non-throwing shoulder. participants' participation will require 1.5-2 hours on three separate testing sessions with approximately one-week between testing sessions. Participants will be tested initially on range of motion and performance (i.e. strength, muscle activity, and throwing velocity), perform one of the three interventions (i.e. static stretching, self-myofascial release, and the combination of self-myofascial release), and then be immediately re-tested on range of motion and performance.

Participants will perform three different interventions (i.e. self-myofascial release, static stretching, and a combination of self-myofascial release and static stretching) on three separate days. Participants will perform self-myofascial release in the side-lying position through the use of a lacrosse ball for 2 sets of 60 seconds on the most tender area in the back of the shoulder with 30 seconds rest between sets. Participants will perform two static stretches in the side-lying position known as the sleeper stretch and cross-body stretch for 3 sets of 30 seconds to the point of mild discomfort with 30 seconds between sets. The participants will perform the combination of self-myofascial release and static stretching in the described order.

All measurements will be taken before and after each intervention. Participants will be measured for shoulder internal rotation range of motion in the side-lying position while the researcher passively takes the subject's shoulder into internal rotation. Participants will be measured for peak shoulder external rotation isometric strength while lying face down as the subject is instructed to rotate the shoulder maximally against the resistance of the researcher. Participants will be measured for muscle activity using an electromyography (EMG) system during the peak shoulder external rotation isometric strength testing. Prior to EMG electrode placement, the skin over the muscle will be shaved if needed and then cleaned with the use of a rubbing alcohol pad. Following ten warm-up throws, mean and peak overhead throwing velocity will be measured during five maximal overhead throws using a standard softball to a net located approximately ten meters in front of the subject.

Instrumentation
Participants will perform the self-myofascial release technique through the use of a standard-sized Under Armour lacrosse ball. There will be no instrumentation needed to perform the static stretching techniques. Glenohumeral internal rotation range of motion will be measured using a handheld Baseline digital inclinometer. Peak glenohumeral external rotation range of motion will be measured using a MicroFET$_2$ handheld digital dynamometer. Muscle activity of the shoulder muscles will be measured using a Delsys electromyography (EMG) system. Mean and peak overhead throwing velocity will be tested using a Bushnell radar gun. Participants will be throwing a standard 11" Clincher softball.

Voluntary Nature
The participants' participation in this study is voluntary. He/she may refuse to participate, or discontinue participating at any time without penalty.

Confidentiality
The following procedures will be followed in an effort to keep personal information confidential in this study: the subject's identity will be held confidential: i.e. the subject's identity will be coded by a number instead of his/her name. The linking information is kept separate in a locked file and identifiers will be destroyed when the study is complete. All data will be kept in a locked file cabinet in the office of the principle investigator.

The principle investigator, the members of the research team, and the Institutional Review Board Committee will be the only people with access to these research records.

Risks & Discomforts
There is a minimal risk to the subject for participation in this study. Participants may feel mild tenderness and discomfort in the muscle while performing self-myofascial release and static stretching, however this tenderness will subside after performing the exercises.

Benefits
There is no direct benefit for participating in this study. However, participants will be introduced to specific injury prevention exercises that may assist in improving range of motion and decreasing injury risk.

Costs, Reimbursements, and Treatment in the Event of Injury
The subject will not be responsible for any of the costs or expenses associated with this study. Additionally, the subject will not be compensated for participation in this study.

The Department of Health and Human Services requires that participants be advised as to the availability of medical treatment if a physical injury should result from research procedures. No special medical arrangements have been made regarding the subject's participation in this project

In the event the subject believes that he/she has suffered any injury as a result of the participation in the research program, please contact the Chairperson of the Institutional Review Board (phone number 973-313-6314) who will review the matter with the subject, and identify any other resources that may be available.

Contact Information
If the subject has any questions related to the study, they may contact Ryan R. Fairall/Principle Investigator. He may be reached ryan.fairall@student.shu.edu or (917)744-6685. Any questions that participants may have regarding their rights as research participants may be directed to the IRB Director, Dr. Ruzicka at (973) 313-6314. The IRB office is located at Presidents Hall on the SHU campus.

All participants will be given a copy of the signed and dated informed consent form.

_____ _____
Print Name Date

_____ _____
Signature Date

Appendix C

Eligibility to Participate Flow Sheet

Subject
1. Age: _____

2. Years of playing experience: _____

3. Do you currently have shoulder pain in your throwing shoulder that would not allow you to participate in this study? Yes/No

4. Have you even been diagnosed with any specific shoulder injury in your throwing shoulder by a physician? Yes/No
If so, what was the injury?
_____

5. Have you ever had surgery on your throwing shoulder? Yes/No
If so, what type of surgery was it?
_____
When was the surgery performed?
_____

6. Have you ever been diagnosed or experiencing any of following:

- Malignancy Yes/No
- Osteoporosis Yes/No
- Osteomyelitis (infection of bone tissue) Yes/No
- Phlebitis (infection of superficial veins) Yes/No
- Cellulitis (infection of soft tissue) Yes/No
- Acute Rheumatoid arthritis Yes/No
- Blood clot Yes/No
- Aneurysm Yes/No
- Anticoagulant therapy Yes/No
- Bursitis Yes/No
- Sutures Yes/No
- Congestive heart failure Yes/No
- Bleeding disorders Yes/No
- Goiter (enlarged thyroid) Yes/No
- Eczema or other skin lesions Yes/No
- Hypersensitive skin conditions Yes/No
- Open wounds Yes/No
- Healing fractures Yes/No
- Obstructive edema Yes/No
- Advanced diabetes Yes/No
- Hematoma or systematic or localized infection Yes/No
- Febrile state Yes/No
- Advanced degenerative changes Yes/No
- Organ failure Yes/No

Appendix D

Data Collection Form

Pre-Intervention Testing
Date:_____

Intervention:_____

Subject Number: _____

1. EMG MVICs (3-seconds)

Infraspinatus mean mV

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

Pectoralis Major mean mV

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

Latisimmus Dorsi mean mV

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

2. Glenohumeral Internal Rotation Range of Motion (degrees)

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

3. Peak Glenohumeral External Rotation Isometric Strength (kg)

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

4. Motor Unit Activity (mean and peak mV)

Infraspinatus mean mV

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

Pectoralis Major mean mV

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

Latisimmus Dorsi mean mV

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

5. Overhead Throwing Velocity (km/hour)

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

Post-Intervention Testing
Date:_____

Intervention:_____

Subject Number: _____

1. Glenohumeral Internal Rotation Range of Motion (degrees)

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

2. Peak Glenohumeral External Rotation Isometric Strength (kg)

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

3. Motor Unit Activity (mean and peak mV)

Infraspinatus mean mV

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

Pectoralis Major mean mV

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

Latisimmus Dorsi	mean mV
Trial 1:	
Trial 2:	
Trial 3:	
Mean:	

4. Overhead Throwing Velocity (km/hour)

Trial 1:	
Trial 2:	
Trial 3:	
Mean:	