ACUTE EFFECTS OF UPPER EXTREMITY STATIC STRETCHING AND DYNAMIC WARM-UP PROTOCOLS ON RANGE OF MOTION, STRENGTH, AND POWER OUTPUT

by

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INTRODUCTION: Overhead throwing athletes develop muscular and capsular tightness of the posterior shoulder and an altered arc of motion in their dominant shoulder due to repetitive overhead throwing. Stretching has been suggested as a way to improve soft tissue flexibility and reduce the risk of shoulder pathology associated with posterior shoulder tightness (PST). Baseball players commonly perform upper extremity acute static stretching exercises during warm-up to increase glenohumeral (GH) range of motion (ROM), prevent injury, and enhance performance. However, previous literature has demonstrated that acute static stretching may be detrimental to performance. The purpose of this study was (1) to compare upper extremity static stretching and dynamic warm-up protocols and (2) determine the most appropriate protocol to increase GH ROM, decrease PST, and maintain GH strength and power.

METHODS: Upper extremity static and dynamic protocols were compared in 15 healthy and physically active males using a within-subject, repeated measures, and counterbalanced design. GH internal rotation (IR) and external rotation (ER) ROM, PST, and GH isokinetic concentric strength and power were measured before and after each protocol. Post-test assessments occurred over four time intervals (post-0, post-5, post-15, and post-30 minutes).

RESULTS: The results of this study demonstrated no significant test x time interactions between the static and dynamic protocols at any time interval for any of the dependent variables. However, a significant main effect occurred where GH IR ROM group mean significantly increased at the post-0 ($p=<0.001$), post-5 ($p=0.004$), post-15 ($p=0.017$), and post-30 ($p=0.050$) time intervals compared to the pre-test measurement. GH ER ROM group mean also significantly increased at the post-5 ($p=0.003$), post-15 ($p=0.003$), and post-30 ($p=0.017$) time intervals compared to the pre-test measurement.

CONCLUSIONS: This study did not identify a stretching or warm-up protocol that increased or decreased muscular force output. However, both protocols acutely increased GH IR and ER ROM for up to 30 minutes, suggesting that static stretching and dynamic warm-up may be similarly effective at increasing ROM. Clinicians and researchers must continue to work together to guide future research and determine the most effective stretching or warm-up protocol to maximize upper extremity performance.

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PREFACE

I would like to take this opportunity to acknowledge and express my sincere gratitude to several individuals and entities, which without their guidance and support, the completion of this thesis would not be possible. First, to my thesis committee, Dr. John Abt; Dr. Timothy Sell; Dr. Kevin Conley; and Mr. David Tumbas—no words are sufficient to express my appreciation for the support each of you have so graciously provided and the contributions you have each made to this project. Through your mentorship, each of you have inspired me to go above and beyond a level of academia and scholarship that I ever imagined was achievable. A special thanks is warranted to Mr. Tumbas for offering his unique expertise and for serving as an external examiner. To my doctoral mentor, Mr. Anthony House—your time, energy, enthusiasm and dedication have been instrumental in the completion of this project and I am forever indebted to you for all of your contributions, including but certainly not limited to, your assistance with data collection and subject recruitment. To Mrs. Candice Goerger and Dr. Joseph Myers—your time, support, and encouragement stimulated the development of this project and I am appreciative of all of your contributions. To the School of Health & Rehabilitation Sciences, whose financial support provided through the SHRS Research Development Fund undoubtedly contributed to the success of this project—your assistance is greatly appreciated. To those associated with the Neuromuscular Research Laboratory, including Dr. Scott Lephart and all staff members—I am extremely grateful for your consideration, patience, and overall support of my project; my experiences in the NMRL have been rewarding on many levels and I am thankful to have had such a wonderful opportunity to conduct my research. To Dr. Ellen Cohn, thank you for your continual enthusiasm directed towards my research and for being supportive every step of the way. A special thanks also goes to Dr. David Hornyak of the University Honors College for granting me the opportunity to be apart of the B.Phil community. To my second family, the University of Pittsburgh Athletic Training Education Program, including Kevin Conley, Amy Aggelou, faculty, staff, and students—I would like to express my extended gratitude for your continual support and for offering me countless opportunities to learn, to grow, and to contribute to the exciting field of athletic training. And last but certainly not least, to my family—your love and support of my dreams and aspirations have been my motivation and inspiration to succeed. Thank you to all who have contributed to this project in one way or another.

1.0 INTRODUCTION

Flexibility is an important objective of athletic conditioning to promote safe and effective movements in sports.[1, 2] Athletes commonly perform stretching exercises to improve soft tissue flexibility and joint ROM.[3] Stretching has received anecdotal support from coaches, clinicians, and athletes for many years and has become a universal component of the athletic warm-up preceding physical activity.[4-7] Moreover, stretching is frequently incorporated into the athletic warm-up of overhead throwing athletes. Baseball players perform upper body acute stretching exercises for reasons of increasing shoulder ROM,[8-11] preventing injury,[2, 8, 12] and improving throwing performance.[2, 11-13] Recently, acute stretching has been under extensive investigation by researchers attempting to validate its reported benefits and overall effectiveness.

The importance of flexibility has been suggested to be greater in sports requiring large, functional ranges of motion and may therefore have additional significance in the sport of baseball.[6, 14] The overhead throwing motion in baseball is a highly dynamic skill requiring a delicate balance of strength and flexibility for optimal performance, particularly at the shoulder complex.[15, 16] The shoulder acts as a catapult during overhead delivery and utilizes large ranges of motion to generate explosive forces to propel the baseball forward.[17, 18] Elite pitchers can generate humeral angular velocities in excess of $7{,}000° \cdot \text{sec}^{-1}$ during acceleration, translating to ball speeds of 90 miles per hour or higher.[18, 19] During overhead delivery, elite pitchers may reach approximately 180° of maximal ER.[16, 17] Stretching exercises may promote soft tissue flexibility to allow the large shoulder ranges of motion essential for overhead throwing.

Shoulder mobility has previously been associated with throwing performance.[18, 20] Optimal throwing performance requires plentiful mobility at the shoulder without sacrificing stability, a concept identified as the “thrower’s paradox.”[21] In theory, increased GH flexibility may enhance overhead throwing speed and accuracy by promoting muscular synchrony and allowing mechanical efficiency.[16, 20, 22] Moreover, impaired throwing performance and increased injury risk have been associated with muscular and capsular tightness of the posterior shoulder.[16, 18] Russek et al[23] suggested that the appropriate amount of flexibility to promote optimal performance and decreased injury risk occurs on a continuum between the pathologic extremes of ankylosis and hypermobility.[23]

Baseball players are part of a unique population of overhead athletes often presenting with soft tissue adaptations and flexibility imbalances in the throwing shoulder.[24] Large volumes of high velocity throwing challenge the physiological limits of the GH joint and greatly stress its supporting structures, including the rotator cuff musculature, GH ligaments, glenoid labrum, and joint capsules.[16, 25, 26] Repetitive overhead throwing and subsequent microtrauma to the GH static and dynamic supporting structures are thought to play a role in several physiological adaptations seen in overhead athletes.[27-29] Upon clinical examination, overhead throwing athletes present with several GH soft tissue adaptations in the dominant (throwing) arm.[27, 30]

The most evident and consistent adaptation in the throwing athlete is an altered arc of motion in the dominant arm compared to the non-dominant (non-throwing) arm.[30] It is clearly demonstrated in the literature[22, 27, 29-38] that baseball pitchers and position players at many levels of competition display an increase in GH joint ER ROM, identified in the literature as an external rotation gain (ERG), and a subsequent decrease in GH joint internal rotation (IR) ROM, identified in the literature as a glenohumeral internal rotation deficit (GIRD). Brown et al[30] found as much as a 9° increase and a 15° decrease in ER and IR, respectively, when comparing dominant and non-dominant arms of professional baseball pitchers.

Relative laxity developed between the anterior and posterior capsules in response to subtle, repetitive microtrauma may contribute to the appearance of an altered arc of GH joint ROM.[17] Attenuation of the anterior capsule and anterior-inferior GH ligamentous complex from tensile loads during late cocking may contribute to an ERG.[39] The throwing arm can be externally rotated as much as 160° to 180° during late cocking, placing excessive tensile stresses on the anterior capsuloligamentous complex and thereby contributing to increased ER ROM over time.[16, 31, 39] Attenuation and acquired laxity of the anterior capsule has been observed in veteran pitchers.[25]

Adaptive tightening and contracture of the posteroinferior capsule from cumulative microtraumas during deceleration may be responsible for the loss of IR seen in the dominant arm of throwing athletes.[16, 25, 27, 40, 41] Deceleration is the most demanding phase of overhead throwing because the dynamic stabilizers must withstand extreme joint distraction forces created during acceleration to dissipate residual energy not transferred to the baseball.[16, 17] Violent eccentric contractions of the posterior rotator cuff musculature generate joint compression forces in excess of 1,000 N during deceleration, which may cause scarring and thickening of the posterior shoulder, and ultimately leading to a decrease in posterior shoulder flexibility and loss of IR ROM.[17, 25, 27] The adaptive tightening of the muscular and capsular tissues of the posterior shoulder associated with repetitive overhead throwing has been identified in the literature as posterior shoulder tightness (PST).[27]

It is theorized that a relative laxity between the anterior and posterior capsules may be the adaptive response of the body to balance the need for greater mobility as well as provide the stability needed to withstand anterior shear joint forces during throwing.[35] Still, some authors believe true anterior instability occurs only in the most veteran pitchers, and furthermore an ERG occurs with or without anterior capsular laxity.[25] Burkhart et al[25] concluded that PST is the ultimate culprit and is the first adaptation in a cascading series of events leading to the "dead arm." They defined this as any degree of shoulder pathology causing an inability to throw at previous levels of speed or accuracy.[25] It was proposed that PST causes hyperexternal rotation (ERG) by creating a "tethering effect" shifting the humeral-glenoid contact point posterosuperiorly, thus allowing additional clearance of the greater tuberosity before it contacts the glenoid.[25] The posterosuperior shift of the contact point secondarily creates a functional pseudolaxity and "cam effect" of the anterioinferior capsule allowing an increase in ER ROM.[25] The relationship between PST and GIRD has also been established, wherein a loss of IR ROM is the result of a tightened posterior capsule.[25, 27, 41]

Some empirical evidence also suggests that bony adaptations may co-exist with soft tissue adaptations and contribute to an altered arc of GH joint ROM.[31, 35, 36] One study demonstrated that baseball players exhibited increased humeral retroversion of 10° of the throwing arm upon radiographic examination.[36] Increased humeral retroversion was not apparent in the non-dominant arm.[31] Humeral retroversion has been defined in the literature as the acute angle, in a medial and posterior direction, between the axis of the elbow joint and the axis through the center of the humeral head.[36] Osseous changes have been thought to develop only during skeletal growth prior to epiphyseal closure, and may be caused by opposing muscular forces repeatedly occurring about the proximal humerus during overhead throwing.[31] Increased humeral retroversion may contribute to an altered arc of motion by allowing the articulating surfaces between the humeral head and glenoid to remain in contact for a longer period of time before becoming restrained by the anterior capsule.[36]

Several studies reported consistency in the total arc of motion in the dominant arm compared to the non-dominant arm despite a clear alteration in the arc of motion.[29, 31, 35, 36] The total arc of motion is measured as the arc from maximum IR to maximum ER, and is approximately 180°.[29] It has been suggested that only a posterior shift in ROM occurs in an adaptive physiological response to the high demands placed on the shoulder during repetitive overhead activity.[31] Recent studies[31, 35, 36] attributing increased humeral retroversion as the cause of an altered arc of motion have demonstrated consistent total arcs of motion between the dominant and non-dominant limbs in baseball pitchers. The authors of these studies believed an altered arc of motion is due largely to increased humeral retroversion and is simply a physiological response to repetitive overhead activity.[31, 35, 36]

The proposed cam effect theory may also explain an altered arc of motion, but this theory has been associated with PST and the dead arm syndrome.[25] The total arc of motion can be disrupted when excessive PST develops and total losses in IR ROM exceed total gains in ER ROM.[25, 27] Impaired throwing performance and injury have been associated with excessive PST and GIRD.[25, 27, 40, 41] Arthroscopic examination of a group of disabled throwers with excessive GIRD demonstrated significant contractures and thickenings of the posterior band of the inferior GH ligament. Based on published findings, a linear relationship is thought to exist in that approximately 4° of GIRD is acquired for every 1 cm of PST.[41] This ratio has been observed in baseball players diagnosed with pathologic internal impingement[27] and subacromial impingement.[41]

Despite the lack of evidence in prospective clinical studies, PST may lead to shoulder and elbow pathologies in overhead athletes such as subacromial impingement,[41-44] ulnar collateral ligament sprains, SLAP lesions,[25] and pathologic internal impingement.[27] The posterior capsular structures play an important role in allowing and controlling normal arthrokinematics of the shoulder during functional activities.[40, 44, 45] The static GH ligaments and joint capsules prevent excessive humeral translation, while the rotator cuff acts dynamically to compress the humeral head and keep it centered on the glenoid.[21] Contracture of the posterior shoulder creates abnormal arthrokinematics during shoulder elevation by causing an anterior and superior migration of the humeral head, possibly contributing to subacromial impingement.[40] Tyler et al[41] also proposed that asymmetrical PST causes anterior-superior migration of the humeral head during shoulder elevation. Abnormal arthrokinematics from a contracted posterior capsule may cause impingement as the humeral head is pinched into the coracoacromial arch.[40]

Arthrokinematics have been theorized to return to normal if GIRD is less than or equal to ERG.[25] Ticker et al[40] reported a 37° decrease of GIRD and a subsequent return to normal arthrokinematics following posterior capsular release and post-operative rehabilitation in patients with chronic GIRD and impingement syndrome. Maintaining shoulder flexibility may also promote normal arthrokinematics and decrease PST and GIRD.[25, 27, 41, 46] Daily stretching of the posteroinferior capsule has been shown to decrease GIRD and decrease the incidence of injury in major league baseball pitchers.[25]

Maintaining a balanced total arc of motion between the throwing and non-throwing arms may reduce injury risk in baseball players.[25, 27] Therefore, 1° of IR ROM may be lost for every degree of ER ROM gained without imposing a predisposition for injury.[27] GIRD, in fact, becomes problematic when a disruption in the total arc of motion occurs and the IR loss far exceeds the gain in ER.[25, 46] Lintner et al[33] found that IR stretching restores the total arc of the dominant arm by decreasing the level of GIRD. Results from this study indicated that GIRD is neither mandatory nor permanent, and individuals will respond to stretching. [33] Furthermore, Burkhart et al[25] stated that 90% of all throwers with symptomatic GIRD would be successful in restoring IR to an acceptable level following a posteroinferior capsular stretching program. An ‘acceptable level’ has been defined as exhibiting either less than 20° of GIRD or having an IR loss less than 10% of the total arc of motion of the non-throwing shoulder.[25]

Based on overwhelming evidence[22, 27, 29-38] that baseball players will inevitably develop physiological adaptations from repetitive throwing, several authors[26, 27, 31, 33, 41] support the intervention of a prophylactic stretching program to prevent upper extremity injury. Previous authors have validated and recommended the use of daily stretching for baseball players to manage posterior shoulder flexibility and prevent injury. Major league baseball pitchers restored a total arc of motion and decreased the incidence of injury following a daily posteroinferior capsular stretching program over a one-year period.[25] Pain relief was also a reported benefit of posterior shoulder stretching.[27]

While the effects of acute stretching on reducing injury rates are not completely agreed upon, several authors have reported that acute stretching may also help reduce the incidence of musculoskeletal injury by allowing normal kinematics and joint mechanics.[7, 14, 47, 48] Similar increases in flexibility occur following both acute and daily stretching programs.[6] Acute stretching may decrease the onset of injury in throwing athletes if it can help maintain posterior shoulder flexibility and restore a total arc of motion. Acute stretching may also be important in promoting muscular synchrony, increasing throwing efficiency, and allowing better throwing mechanics.[18-20] Baseball players may therefore decrease injury risk and improve throwing performance by performing acute stretching exercises prior to competition or practice.

Stretching is a common practice among athletes of all ages, sports, and competitive levels for reasons of increasing flexibility and joint ROM, enhancing performance, and preventing injury.[6, 14, 49-51] Static stretching is one of the safest and most commonly performed stretching methods to improve flexibility.[10] Static stretching involves moving a limb to the end range of its motion and holding the limb in the stretched position for a period of time, usually between 10 and 60 seconds per set.[6]

Research has demonstrated significant improvements in short-term flexibility and ROM following acute static stretching exercises.[6, 52] A 2007 systematic review[6] identified 27 published reports demonstrating significant increases in joint flexibility following acute stretching at the knee, hip, trunk, shoulder, and ankle joints. Also, the authors found that a single 15 to 30 second static stretch of a muscle group was enough to significantly increase short-term flexibility.[6] Duration of increased flexibility may last anywhere from 6 up to 90 minutes following acute stretching, due to the large variations in stretching protocols studied.[9, 53] The literature supports the use of acute static stretching to produce increases in tissue flexibility and joint ROM.[6]

The increased ROM associated with acute stretching is attributed to decreases in the viscoelastic properties of the musculotendinous unit (MTU), decreases in muscle activity, and increases in stretch tolerance.[6, 54, 55] Viscoelasticity is an intrinsic mechanical property of tissues giving them the ability to undergo elastic and plastic deformation when a stretch torque is applied.[1, 4] Stretching is believed to decrease the stiffness of the MTU through decreases in tissue viscoelasticity.[56]

Acute stretching is also believed to enhance muscular performance and has been widely incorporated in the athletic warm-up for many years based on the intuition that increased tissue flexibility will allow skeletal musculature to work more efficiently.[2, 12, 48, 50, 57] Current literature has recently demonstrated that acute bouts of prolonged static stretching may actually decrease athletic performance in lower extremity activities.[58, 59] Numerous reports have shown that static stretching performed prior to activity temporarily decreased lower extremity strength[8, 12, 58-65] and power.[51, 62, 66-69] Fowles et al[59] reported a 28% decrease in maximum voluntary isometric contraction in the plantarflexors following a 30 minute passive stretch, with negative effects lasting up to an hour following stretching. Other studies have demonstrated that acute static stretching decreased vertical jump performance,[67-69] increased sprint time,[70] and reduced lower extremity agility, balance, and reaction time.[47]

Two underlying physiological mechanisms thought to be responsible for decreases in the force generating capability of skeletal muscle have been identified in previous studies.[47, 52, 59, 71] Acute reductions in the maximal force-generating capability of skeletal muscle have been attributed to both mechanical and neural factors.[55, 59] Increases in muscle length following prolonged stretching may decrease the neural activation and reflex sensitivity of skeletal muscle due to changes in proprioceptive feedback of specialized stretch receptors found throughout the MTU.[8, 58-60, 65] Stretching has also been shown to reduce muscle stiffness and increase compliance of the MTU.[8, 12, 55, 56, 60, 63, 66, 71, 72] Increased compliance may decrease rate of force development by increasing the time required to take up slack within the tendon.[4, 59]

Fowles et al[59] found significantly decreased muscle activation and significant decreases in muscle stiffness following passive stretching of the plantarflexors for 30 minutes. Maximum voluntary isometric strength of the plantarflexors was also significantly reduced up to one hour following stretching.[59] Yet, many studies reporting performance deficits from acute static stretching were criticized to have limited applicability to sports due to the large volumes and durations of stretching protocols used.[58, 59] A single muscle group was stretched anywhere between 100 seconds and 30 minutes, which is unlikely to be performed during an athletic warm-up.[50] Sports stretching has been defined by one group of authors[54] as that in which is typical of athletes to perform before participation in sporting events, or about 5 to 10 minutes of stretching.

Studies using static stretching protocols with a 30-second stretch of a single muscle group reported no difference in leg extension power compared to a control group.[50] Several other authors found that a 5-10 minute static stretching protocol did not decrease lower extremity strength[47, 56, 65, 73] or power.[7, 48, 57, 65, 73] In one study,[71] changes in viscoelastic properties and neurological activation of skeletal muscle did occur during a single 30-second static stretch, but were restored immediately after stretching. Static-stretching induced deficits in force generation may therefore be intimately related the volume, duration, and intensity of the stretching protocol performed.[50, 65]

Based on current research there is inconclusive evidence to neither endorse nor discontinue the use of acute static stretching to achieve its believed benefits despite its commonality in the athletic warm-up.[6] Modest bouts of static stretching may not be as harmful to performance as first thought.[50] One group still suggested athletes should not consider even 30 seconds of static stretching.[50] Likewise, no studies have reported improvements in muscular performance following acute static stretching, which is a primary reason for performing acute stretching.[74]

Recently dynamic warm-ups have been gaining interest in the literature for their potential performance benefits.[14] Dynamic warm-ups have been shown to significantly increase power and agility when compared to static stretching.[5, 14, 50, 70, 75, 76] Several studies have provided support for dynamic warm-ups for their ability to produce acute increases in muscular performance in lower extremity activities including vertical jumping,[76] sprinting,[70] leg extension power,[50] and agility drills.[14]

Dynamic warm-ups consist of functional sports-specific movements with increasing intensities and these may enhance muscular performance through several physiological mechanisms.[14] Dynamic activities may improve neuromuscular function due to an increase in core temperature, muscle temperature, and blood flow to the muscles.[14, 77] Increased muscle temperature can decrease muscle and joint stiffness, increase nerve impulse transmission, alter the force/velocity relationship, and increase glycogenolysis, glycolysis, and high-energy phosphate degradation.[78] Other reports of the physiological benefits of dynamic warm-ups which may contribute to enhanced performance include increased proprioception and joint position sense, neuromuscular stimulation of sport-specific motor units, and increased oxygen uptake.[14]

The implications of these findings suggest that prior to activity, dynamic warm-ups may be more beneficial than static stretching at enhancing lower extremity performance, and thus more research is needed to confirm this in upper extremity activities.[5, 14, 50, 70, 75, 76] Short-term increases in flexibility following dynamic warm-up have not been clearly demonstrated, but one study[79] suggested that passive stretching is more effective than dynamic stretching of the hamstring.

The current clinical justification for many stretching routines are based largely on individual experiences of clinicians, coaches and athletes rather than based on scientific evidence.[14] For years individuals have been performing static stretching in the athletic warm-up based on the intuition that it will help enhance muscular performance and reduce the risk of injury.[2, 12] Currently, the literature is inconclusive about the acute effects of stretching on sports performance and injury prevention.[6, 74] Stretching has been shown to be successful at restoring IR ROM and decreasing the risk of injury in elite baseball players.[25, 33] However, a simultaneous decrease in muscular performance following acute stretching would contradict the goals of sports medicine professionals and athletes to promote maximal performance. Thus, identifying an appropriate acute warm-up protocol that improves flexibility while still maintaining ball velocity is vital.

This will be the first study to examine and compare the acute effects of static stretching and dynamic warm-up on strength and power output in the upper extremity. This study will determine the most effective warm-up to increase GH ROM, decrease PST, and maintain strength and power. Our hypothesis is that the static stretching and dynamic warm-up protocols in this study will each generate differences in GH ROM, PST, strength, and power measurements. The results of this study will provide valuable information for athletic trainers, strength and conditioning professionals, coaches, and athletes relative to designing the most effective warm-up for baseball players.

Clinically, the lack of research in this area may lead to inappropriate stretching techniques that result in decreased athletic performance and the potential for injury. Empirical validation will aid clinicians and respective sports medicine professionals in selecting the most appropriate parameters for the athletic warm-up. The effects of static stretching and dynamic warm-up protocols on GH ROM and force output undoubtedly needs to be evaluated to ensure that baseball players are maximizing their abilities and minimizing their risk of injury. In a growing trend towards teaching evidence-based sports medicine, there exists a need for a general consensus on warm-up protocols in baseball players.

Specific Aim 1: To examine the acute effects of upper extremity static stretching and dynamic warm-up protocols in 15 healthy and physically active individuals on GH IR and ER ROM. This will be accomplished by taking measurements with a digital inclinometer on the throwing shoulder before and after each stretching protocol.

Hypothesis 1a: GH IR and ER ROM will increase following both the static stretching and dynamic warm-up protocols.

Hypothesis 1b: A static stretching protocol will cause the most change in GH IR and ER ROM.

Specific Aim 2: To examine the acute effects of upper extremity static stretching and dynamic warm-up protocols in 15 healthy and physically active individuals on PST. This will be accomplished by taking measurements with a digital inclinometer on the throwing shoulder before and after each stretching protocol.

Hypothesis 2a: PST will decrease following both the static stretching and dynamic warm-up protocols.

Hypothesis 2b: A static stretching protocol will cause the most change in PST.

Specific Aim 3: To examine the acute effects of upper extremity static stretching and dynamic warm-up protocols in 15 healthy and physically active individuals on GH IR and ER strength (measured as peak torque/body weight [PT/BW]). This will be accomplished by taking measurements with an isokinetic dynamometer at a speed of 60 deg/sec before and after each stretching protocol.

Hypothesis 3a: No significant decreases in GH IR and ER strength will occur following the static stretching protocol used in this study.

Hypothesis 3b: A significant increase in GH IR and ER strength will be found following the dynamic warm-up protocol.

Specific Aim 4: To examine the acute effects of upper extremity static stretching and dynamic warm-up protocols in 15 healthy and physically active individuals on GH IR and ER power output (measured as average power [AP]). This will be accomplished by taking measurements with an isokinetic dynamometer at a speed of 60 deg/sec before and after each stretching protocol.

Hypothesis 4a: No significant decreases in GH IR and ER power output will occur following the static stretching protocol used in this study.

Hypothesis 4b: A significant increase in GH IR and ER power output will be found following the dynamic warm-up protocol.

Specific Aim 5: To examine the duration of the acute stretching effects of upper extremity static stretching and dynamic warm-up protocols in 15 healthy and physically active individuals. This will be accomplished by measuring the changes in ROM, PST, PT/BW, and AP over four time intervals to determine the lasting effects of each protocol. The dependent variables (ROM, PST, PT/BW, and AP) will be assessed immediately, 5-, 15-, and 30-minutes following the static stretching and dynamic warm-up protocols.

Hypothesis 5: All dependent variables will return to at least 75% of that of pre-testing measurements 30 minutes after completion of both protocols.

TABLE 1: Dependent Variables

Type of Test	Dependent Variable
ROM	Internal Rotation Humeral ROM (deg) External Rotation Humeral ROM (deg)
PST	Supine cross-body horizontal adduction test (deg)
Power	Internal Rotation Average Power (W) External Rotation Average Power (W)
Strength	Internal Rotation Peak Torque/Body Weight External Rotation Peak Torque/Body Weight

TABLE 2: Independent Variables

Protocol	Time Interval (minutes)				
	Pre-test	0	5	15	30
Static					
Dynamic					

2.0 MATERIALS & METHODS

2.1 SUBJECTS

Data were collected on a sample population of fifteen healthy and physically active males. "Active" was defined as currently participating in physical activity three sessions per week with a minimum of 30 minutes per session or a total of 90 minutes per week. Age, height, and mass for all subjects is summarized in **TABLE 3**.

TABLE 3: Subject Demographics

	Mean	SD
Age (yrs)	21.67	1.58
Height (cm)	176.07	6.11
Mass (kg)	83.07	9.07

2.2 INSTRUMENTATION

All ROM measurements were performed on a standard examination plinth. A digital inclinometer (Saunders Group, Chaska, MN) was used to assess GH IR ROM, GH ER ROM, and PST. A calibrated Biodex System 3 Isokinetic Dynamometer (Biodex Medical, Shirley, NY) was used to measure GH IR and ER concentric strength and power. Yellow (extralight) Theraband tubing (Hygenic Corporation, Akron, OH) was used during the dynamic protocol to provide light resistance throughout the exercise. A digital metronome was used to control the tempo of repetitions during the dynamic warm-up exercises between subjects.

2.3 PROCEDURE

All testing took place in the University of Pittsburgh's Neuromuscular Research Laboratory. Each subject read and signed an informed consent form approved by the University of Pittsburgh Institutional Review Board upon arrival to the laboratory and before any testing was performed.

The study was a repeated-measures, within-subject research design. Each subject reported to the laboratory on two non-consecutive days to complete testing. Subjects performed either the static stretching or dynamic warm-up protocol on their first visit to the laboratory. Testing was counterbalanced to assure every subject performed each protocol over two sessions. Each testing session lasted approximately one hour. A minimum of 48 hours was enforced between each testing session to control for potential stretching carry-over effects, fatigue, or muscle soreness. Subjects were told not to perform any strenuous upper body activity during the testing window. All subjects completed both testing sessions within one week of each other.

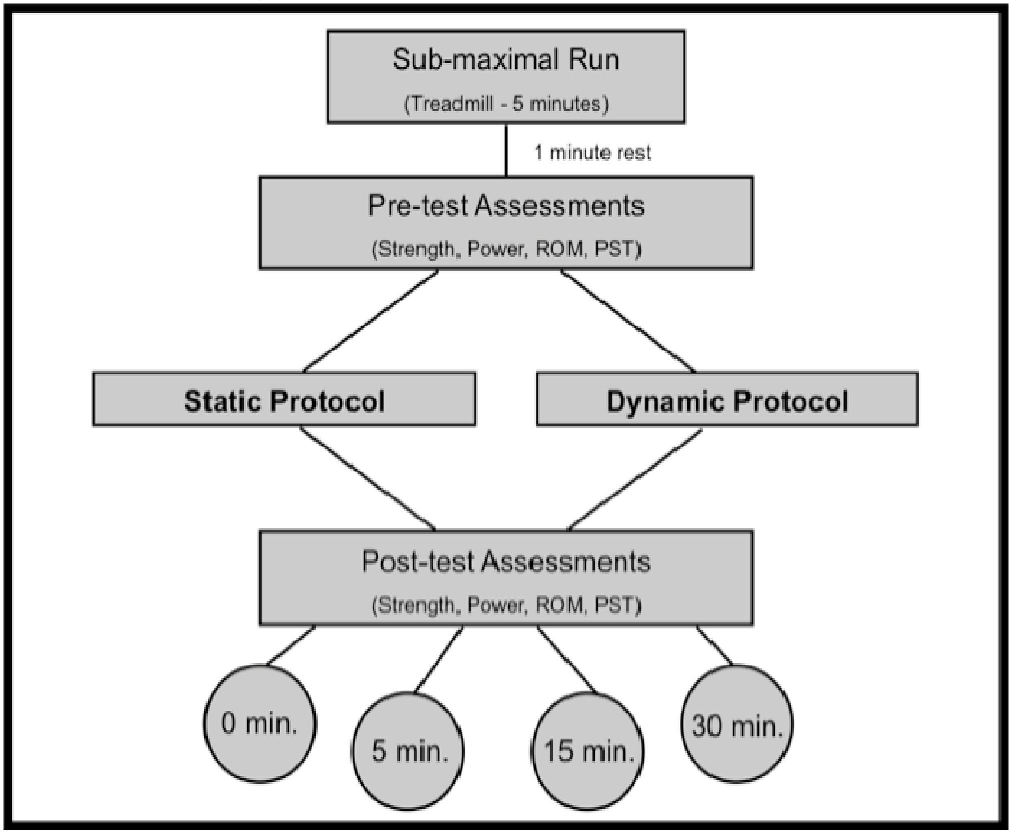
The procedure was thoroughly explained prior to testing, and each subject was given the opportunity to ask questions before and throughout the procedure. A schematic of the testing procedure is shown in **FIGURE 1**. The experimental protocol was performed following a brief jog and baseline measurements of all dependent variables listed in **TABLE 1**. Upon completion of the protocol, the same dependent variables were reassessed at the four time intervals— 0, 5, 15, and 30 minutes.

The same two examiners performed all measurements throughout data collection to ensure consistency. One examiner was strictly assigned to be the positioning/testing examiner and the other was assigned as the measuring/recording examiner. Intrasession and intersession reliability data were previously collected in the University of Pittsburgh's Neuromuscular Research Laboratory and are shown in **TABLE 4**.

TABLE 4: Intrasession & Intersession Reliability

	Intrasession		Intersession	
	ICC	**SEM**	**ICC**	**SEM**
Internal Rotation ROM	0.973	2.068	0.983	1.678
External Rotation ROM	0.978	1.706	0.932	3.161
Supine PST	0.957	2.212	0.766	4.972

FIGURE 1: Testing Procedure



2.3.1 Sub-maximal Aerobic Warm-up

A five-minute sub-maximal aerobic warm-up was performed on a treadmill to prepare each participant for activity. Subjects were asked to select a self-preferred jogging speed which they could comfortably maintain for the five minute duration.

2.3.2 Glenohumeral Internal & External Rotation Range of Motion Assessment

GH IR and ER ROM assessments are illustrated in **FIGURE 2** and **FIGURE 3**, respectively. Subjects were asked to remove their shirts during testing to allow accessibility to the shoulder bony anatomy. Using a surgical pen, the measuring examiner placed marks on the olecranon process of the elbow and the ulnar styloid process of the wrist to properly align the digital inclinometer during measurement. All measurements were taken with the participant positioned supine on the plinth with the arm at 90º of GH abduction and 90º of elbow flexion. A small towel roll was placed under the humerus to maintain its position in the frontal plane. One examiner positioned the arm and stabilized the scapula while the other examiner measured and recorded the angle of GH ROM with a digital inclinometer. Scapular stabilization was achieved by applying a posteriorly directed force against the subject's coracoid process and clavicle with the heel of the hand.[80]

The testing examiner passively rotated the limb to end range of rotation while the measuring examiner aligned the digital inclinometer with the forearm to record the humeral rotation angles. ROM endpoints were based on descriptions by Awan et al,[80] which were defined by subject comfort and by capsular end-feel. A total of three measurements were taken for each position on the dominant arm. The mean value for GH IR and ER ROM were recorded for statistical analysis.

FIGURE 2: Glenohumeral Internal Rotation Range of Motion Assessment

FIGURE 3: Glenohumeral External Rotation Range of Motion Assessment

2.3.3 Posterior Shoulder Tightness Assessment

PST was assessed using the supine method **(FIGURE 4)** previously described by Myers et al[27] which is known to have good reliability and validity.[28] Each subject was positioned supine on the plinth with the shirt removed. The measuring examiner placed marks using a surgical pen on the deltoid tuberosity of the humerus and the lateral epicondyle of the elbow to properly align the inclinometer during measurement. The testing examiner stood on the side of the shoulder being tested and asked the subject to lift the tested shoulder off the table. The testing examiner pressed his hand against the lateral border of the scapula to stabilize it in a retracted position. The humerus was elevated to 90º of abduction in neutral rotation and was passively horizontally adducted while the scapula remained fully retracted. Similar endpoints were used as described previously in ROM assessment. At the end ROM the recording examiner recorded the angle formed between the humerus and the horizontal plane from the superior aspect of the shoulder with the digital inclinometer. A total of three measurements were taken and the average value was recorded for statistical analysis.

FIGURE 4: Posterior Shoulder Tightness Assessment

2.3.4 Glenohumeral Internal & External Rotation Strength & Power Assessment

Concentric strength and power output of the shoulder internal and external rotators was measured using an isokinetic dynamometer **(FIGURE 5)**. The Biodex was calibrated prior to testing and proper set up and testing procedures were performed as previously described by

Perrin et al.[81] Participants were tested in a seated modified neutral position in the scapular plane (10º abduction and 30º flexion) and standardized to the active ROM of each subject. Subjects were allowed to perform sub-maximal repetitions prior to testing for appropriate familiarization with isokinetic testing. During testing, each subject performed five maximal repetitions at a velocity of 60° · sec^{-1}. Peak torque normalized to body weight (PT/BW) and average power (AP) were collected from the Biodex software and used for statistical analysis.

FIGURE 5: Glenohumeral Isokinetic Strength & Power Assessment

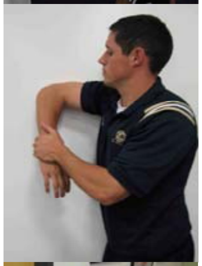
2.3.5 Static Stretching Protocol

The static stretching protocol consisted of six active stretches, which globally targeted the soft tissues surrounding the shoulder, and is shown in **FIGURE 6**. The stretches selected for this protocol were based on the recommendations from several athletic trainers who worked with the sport of baseball. This protocol attempted to accurately resemble the on-the-field stretches currently being performed by baseball players prior to practices or games. The static stretches selected for this study have been previously described in the literature.[15, 82] Using a stopwatch, two 20-second sets were performed for each of the six stretching exercises. A rest period of 15 seconds followed each stretch. The total stretch protocol lasted six minutes, three minutes of which was active stretching. Subjects were instructed to increase the stretch to a point of discomfort, but not pain, and hold for the full 20-second duration.

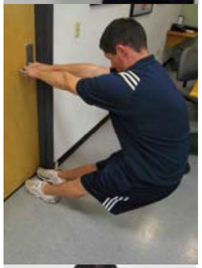
FIGURE 6: Static Stretching Protocol

Deltoid / Posterior Shoulder Stretch: The stretch began with the subject standing with the dominant shoulder and lateral border of their scapula against a wall. The dominant shoulder was flexed to 80-90° and a passive horizontal adduction force was applied by the non-dominant arm to the dominant elbow. The end position was flexion of the dominant elbow and the dominant hand reaching behind the opposite shoulder. By leaning against the wall, the lateral border of the scapula remained against the wall to prevent the scapula from following the humerus across the body.[82]

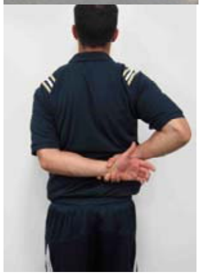
Pec Major / Anterior Capsule Stretch: The stretch began with the subject standing and facing a wall support. With the dominant shoulder flexed to 90° and the dominant elbow in full extension, the palm of the dominant hand made contact against the wall. The patient then rotated their trunk away from their dominant limb while maintaining shoulder and elbow joint angles.[82]



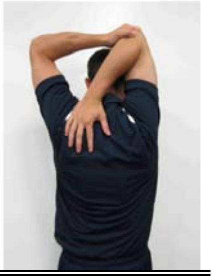
Standing Sleeper Stretch: The stretch began with the subject standing with their dominant shoulder against a wall support and flexed at 90° and elbow also in 90° of flexion. The subject then leaned against the wall applying pressure to the lateral border of their scapula. The head and neck remained in neutral position, looking straight ahead. The scapula remained pressed against the wall while the dominant shoulder was moved into IR by slowly pressing the forearm down with the non-dominant hand.[15]



Rhomboid / Posterior Shoulder Stretch: The stretch began with the subject facing the edge of a door. The feet were placed on each side of the door, the hands on the doorknobs, and the knees in full extension. The subject then proceeded to let the hips drop downward and backward. The elbows remained fully extended with the shoulders flexed at 90° as the body moved backward. Subjects were told to relax the arms so that the body weight stretched the rhomboids.[82]



Supraspinatus / Superior Capsule Stretch: The stretch began with the subject standing with the dominant arm behind the body with the elbow flexed to 90°. The subject then grasped the dominant hand with the non-dominant hand and pulled the dominant arm toward the non-dominant side.[82]



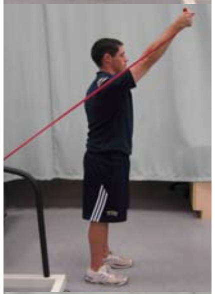
Triceps / Inferior Capsule Stretch: The stretch began with the subject standing with the dominant arm overhead. The subject then flexed the elbow so that the forearm was placed behind the head perpendicular to the ground. The subject then pulled downward on the elbow of the dominant arm with the hand of the non-dominant arm.[82]

2.3.6 Dynamic Warm-up Protocol

The dynamic warm-up protocol consisted of six exercises **(FIGURE 7)** previously described by Myers et al.[83] They evaluated several on-the-field warm-up exercises for throwing athletes using resistance tubing.[83] The current protocol utilized yellow Theraband tubing to provide light resistance continuously through a dynamic ROM. Each subject performed continuous movements throughout the duration of each exercise with no visible slack in the band. The metronome standardized the tempo of each exercise to two seconds per repetition for a total of 10 repetitions. The duration and rest periods of the dynamic protocol were identical to the static stretching protocol described previously.

FIGURE 7: Dynamic Warm-up Protocol

Shoulder Extension: Standing facing towards the stable base with the elbow extended and the forearm in a neutral position (thumb pointing upward), the exercise began with the subject's shoulder at 90° of forward flexion. The exercise consisted of moving the shoulder toward maximum extension and then returning to the starting position while maintaining both elbow extension and the forearm-neutral position. The rubber tubing was secured to a stable base at a height equal to the height of each subject's fingertips with the arm fully flexed in a standing position (high fixation position).[83]



Shoulder Flexion: Standing facing away from the stable base with the elbow extended and the forearm in a neutral position (thumb pointing upward), the exercise began with the shoulder fully extended. The exercise consisted of moving the shoulder toward maximum flexion and then returning to the starting position, while maintaining both elbow extension and the forearm-neutral position. The rubber tubing was secured to a stable base at a height equal to the height of each subject's fingertips from the ground while standing in anatomical position (low fixation position).[83]

Scapular Punch: Standing facing away from the stable base the starting position for this exercise was with the elbow fully flexed, forearm in neutral position, and the scapula fully retracted. The exercise consisted of flexing the shoulder to approximately 100°, extending the elbow, and fully protracting the scapula while punching forward and then returning to the starting position. The rubber tubing was secured to a stable base at a height equal to the height of each subject's elbow from the ground when standing in anatomical position (middle fixation position).[83]

Throwing Acceleration: Standing facing away from the stable base with the shoulder abducted and the elbow flexed to 90°, the exercise began with the subject's shoulder in full external rotation. The exercise consisted of moving the arm across the body (similar to the acceleration phase of throwing [D2 flexion pattern]) and then returning to the starting position. The rubber tubing was secured to a stable base at a height equal to the height of each subject's fingertips with the arm fully flexed in a standing position (high fixation position).[83]

Throwing Deceleration: Standing facing towards the stable base the exercise began with each subject's shoulder at 30° of flexion. The exercise consisted of pulling the tubing back so the shoulder moved into full extension and scapular retraction. At full shoulder extension, the shoulder was moved to 90° each of shoulder external rotation, shoulder abduction, and elbow flexion. The exercise was finished with the subject eccentrically controlling the tubing as the arm returned to the starting position of 30° of shoulder flexion. The rubber tubing was secured to a stable base at a height equal to the height of each subject's fingertips from the ground while standing in anatomical position (low fixation position).[83]

ER @ 90° of Abduction: Standing facing towards the stable base with both the shoulder abducted and elbow flexed to 90°, the exercise began with the subject's shoulder in full internal rotation. The exercise consisted of moving the shoulder into full external rotation and then returning to the starting position while maintaining the shoulder-abduction and elbow-flexion positions. The rubber tubing was secured to a stable base at a height equal to the height of each subject's fingertips from the ground while standing in anatomical position (low fixation position).[83]

2.4 DATA REDUCTION

SPSS version 16.0 was used for statistical analysis. Statistical analysis comparisons were made between experimental protocols and intervals of dependent variable assessments using repeated-measure ANOVA models. Two within-subjects, repeated-measure ANOVAs were performed on the IR ROM, ER ROM, PST, PT, and AP data to determine acute effects of each protocol. A Bonferroni post-hoc test was also performed on variables with significant differences. Statistical significance was determined using a 0.05 alpha level.

3.0 RESULTS

3.1 ACUTE EFFECTS OF INTERNAL ROTATION RANGE OF MOTION

IR ROM data for the static and dynamic protocols are presented in **TABLE 5**. No significant test x time interaction for IR ROM was found between the static and dynamic protocols at any time interval **(FIGURE 8)**. However, a significant main effect was found where the GH IR ROM group means significantly increased at the post-0, post-5, post-15, and post-30 time intervals compared to the pre-test measurement. **(FIGURE 9)**. No differences existed between the post-test measurements.

TABLE 5: Glenohumeral Joint Internal Rotation Range of Motion Measurements

	Pre-test		**Post-0**		**Post-5**		**Post-15**		**Post-30**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
IR (deg)										
Static	60.2	10.5	66.4	10.4	65.1	10.4	65.7	10.7	64.2	11.5
Dynamic	59.3	8.8	63.3	9.1	64.0	9.4	62.1	10.1	62.4	9.6
Group Mean	59.8	9.7	64.8	9.8	64.5	9.9	63.9	10.4	63.3	10.5
Difference			+5.0		+4.7		+4.1		+3.4	
p-value			<0.001*		0.004*		0.017*		0.050*	

*Significant main effect of protocols

FIGURE 8: Glenohumeral Joint Internal Rotation Range of Motion Measurements

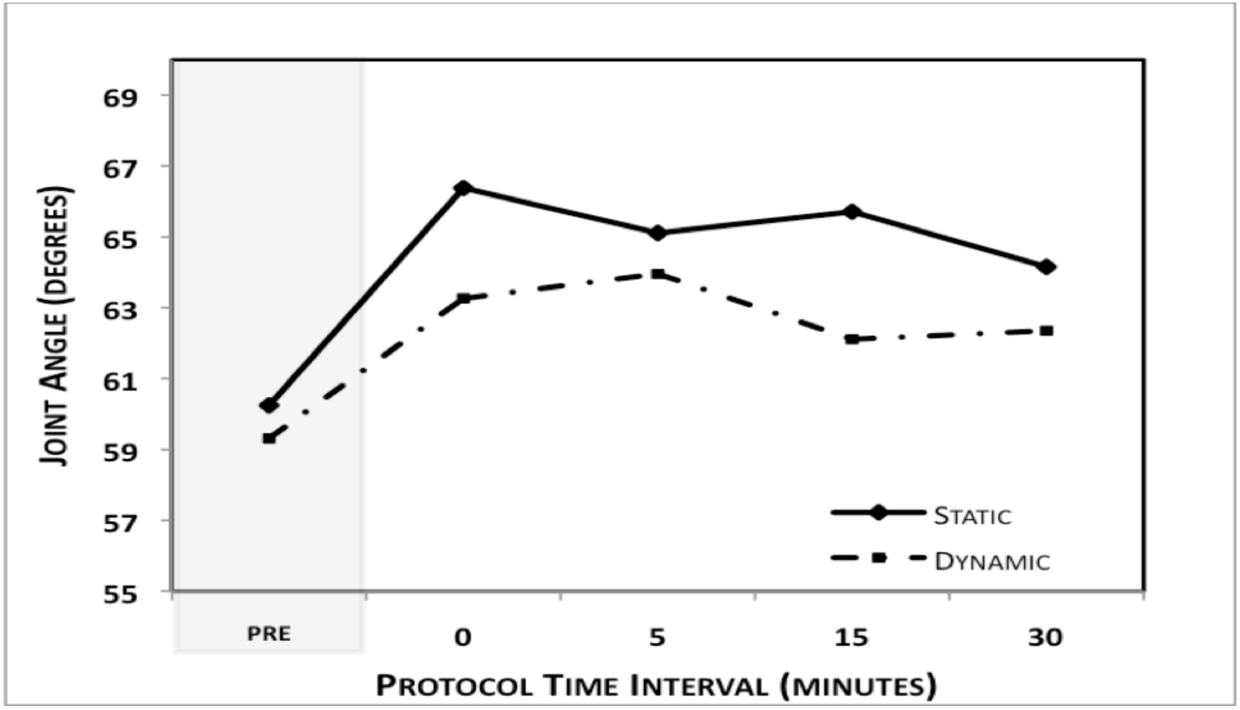
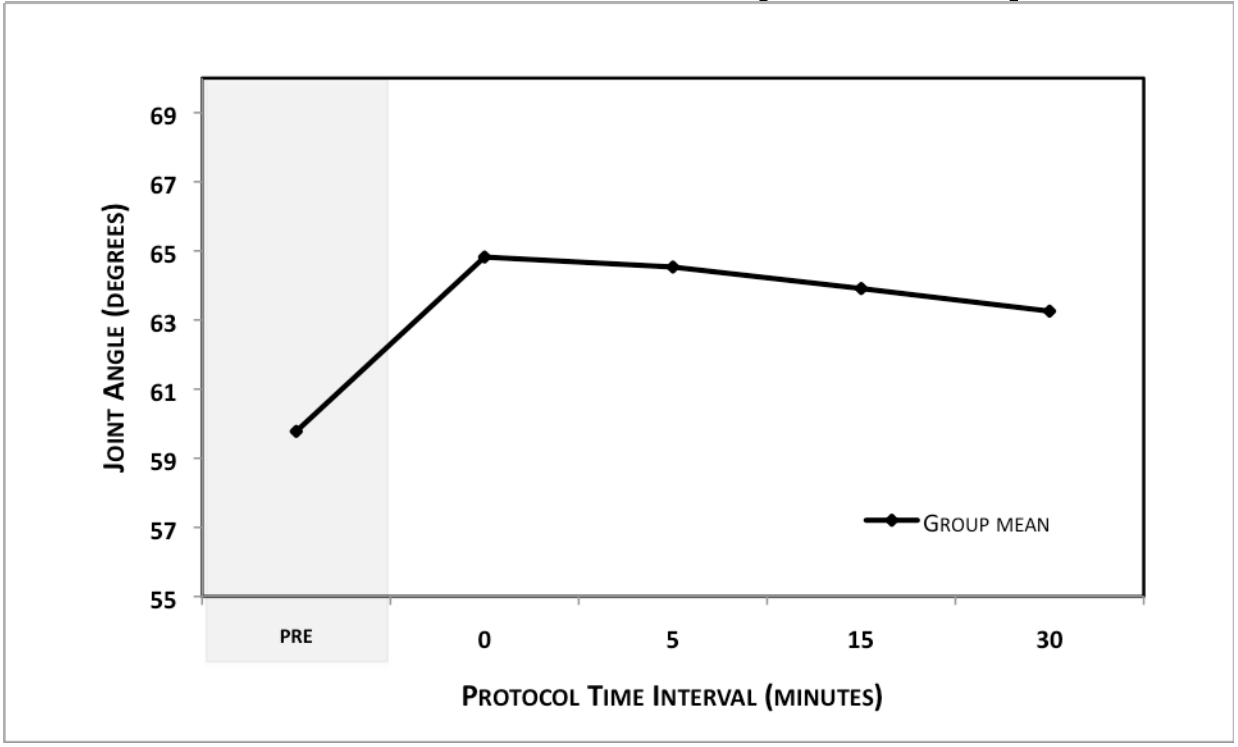


FIGURE 9: Glenohumeral Joint Internal Rotation Range of Motion Group Mean



3.2 ACUTE EFFECTS OF EXTERNAL ROTATION RANGE OF MOTION

ER ROM data for the static and dynamic protocols are presented in **TABLE 6**. No significant test x time interaction for ER ROM was found between the static and dynamic protocols at any time interval **(FIGURE 10)**. However, a significant main effect occurred where the GH ER ROM group mean was significantly increased at the post-5, post-15, and post-30 time intervals compared to the pre-test measurement. **(FIGURE 11)**. No differences existed between the post-test measurements.

TABLE 6: Glenohumeral Joint External Rotation Range of Motion Measurements

	Pre-test		**Post-0**		**Post-5**		**Post-15**		**Post-30**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
ER (deg)										
Static	121.4	14.9	124.2	13.1	126.2	12.2	126.9	12.1	123.8	12.6
Dynamic	120.5	10.7	124.8	11.5	127.1	11.4	125.5	11.8	126.0	12.6
Group Mean	121.0	12.8	124.5	12.3	126.7	11.8	126.2	11.9	124.9	12.6
Difference			+3.5		+5.6		+5.2		+3.9	
p-value			0.115		0.003*		0.003*		0.017*	

*Significant main effect of protocols

FIGURE 10: Glenohumeral Joint External Rotation Range of Motion Measurements

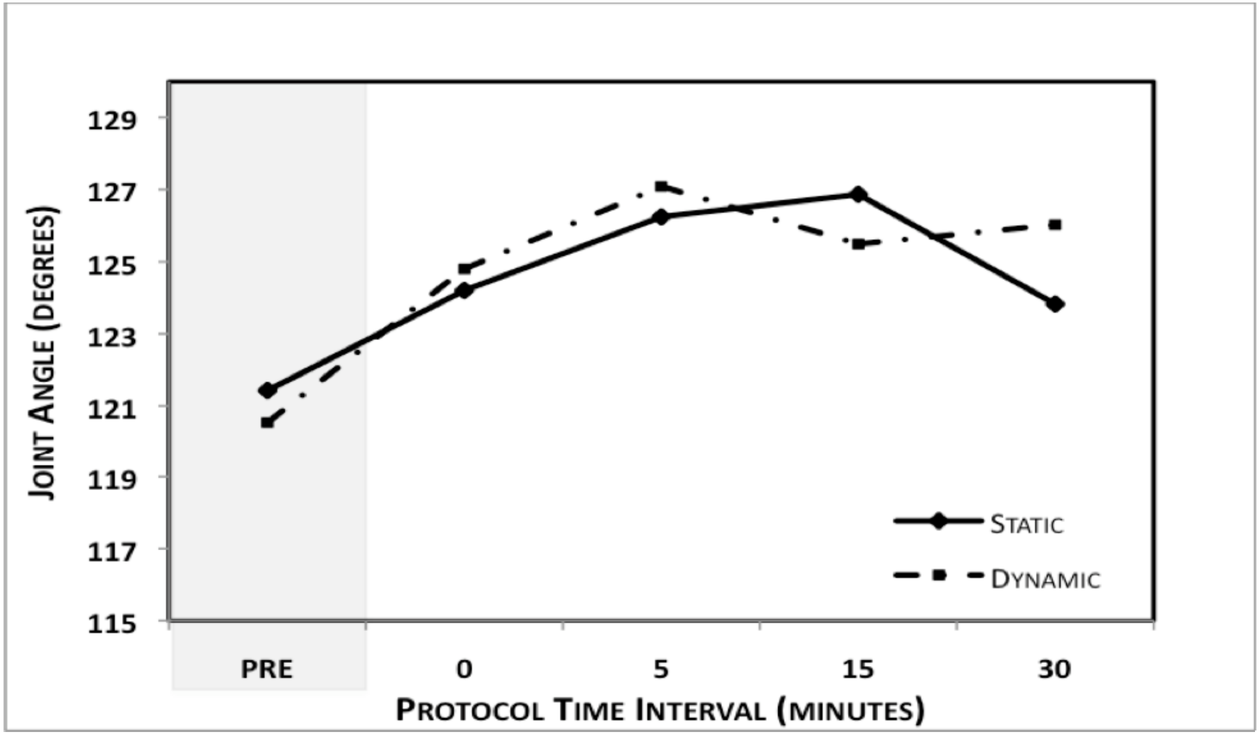
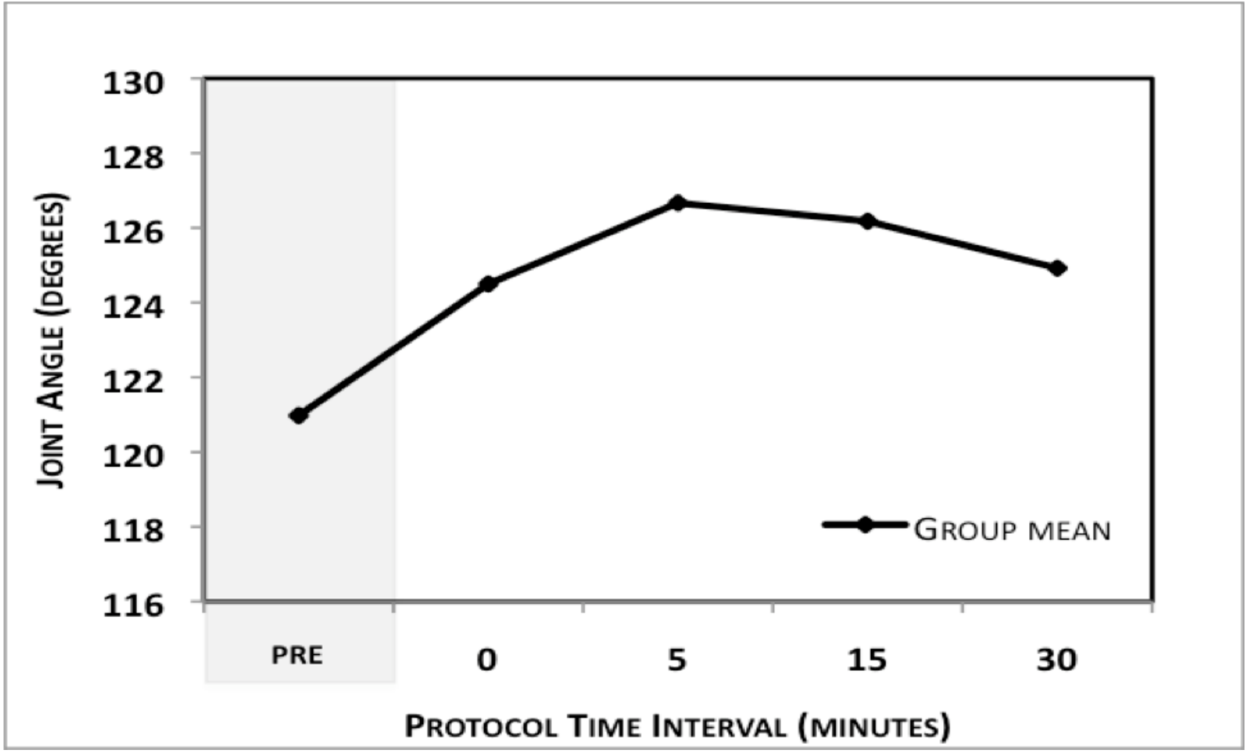


FIGURE 11: Glenohumeral Joint External Rotation Range of Motion Group Mean



3.3 ACUTE EFFECTS OF POSTERIOR SHOULDER TIGHTNESS

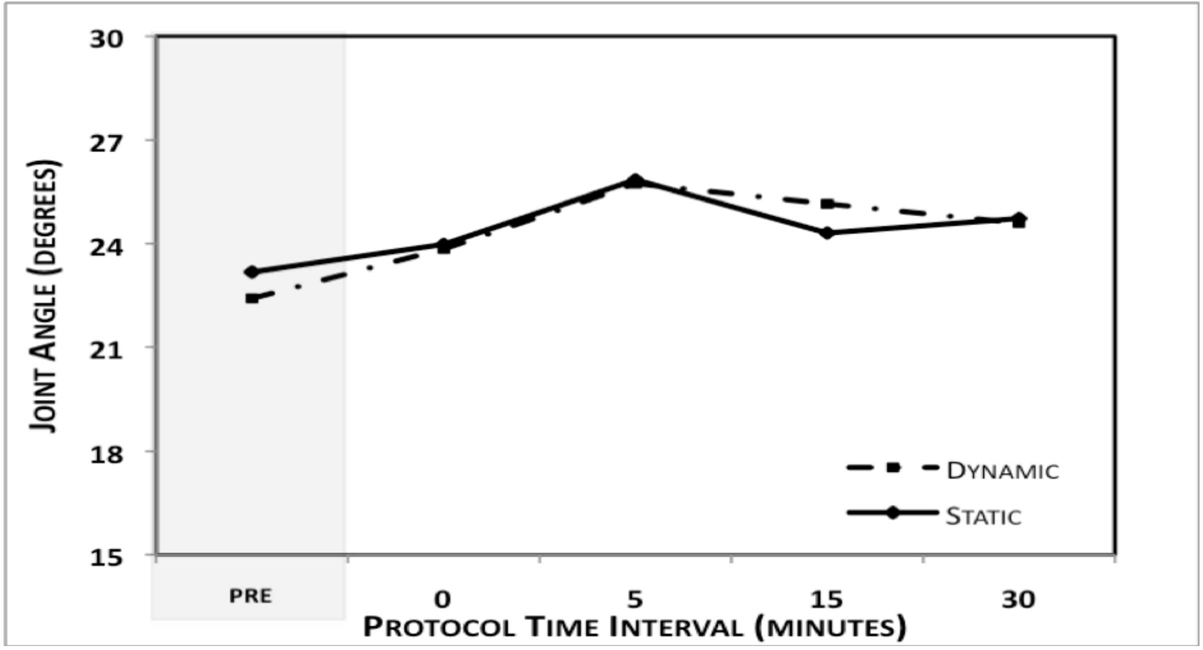
PST data for the static and dynamic protocols are presented in **TABLE 7**. No significant test x time interaction for PST was found between the static and dynamic protocols **(FIGURE 12)**. However, PST was significantly increased at the post-5 time interval compared to the pre-test measurement.

TABLE 7: Posterior Shoulder Tightness Measurements

	Pre-test		Post-0		Post-5		Post-15		Post-30	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
PST (deg)										
Static	23.2	6.5	24.0	7.6	25.8	8.4	24.3	7.8	24.7	8.3
Dynamic	22.4	7.2	23.8	8.3	25.7	7.5	25.2	7.1	24.6	7.6
Group Mean	22.8	6.8	23.9	8.0	25.8	8.0	24.7	7.4	24.7	8.0
Difference			+1.1		+2.9		+1.9		+1.8	
p-value			1.000		0.016*		0.097		0.172	

*Significant main effect of protocols

FIGURE 12: Posterior Shoulder Tightness Measurements



3.4 ACUTE EFFECTS OF INTERNAL & EXTERNAL ROTATION STRENGTH

GH IR and ER isokinetic concentric strength data for the protocols are presented in **TABLE 8** and **TABLE 9**, respectively. No significant test x time interaction for IR or ER isokinetic strength was found between the static and dynamic protocols **(FIGURES 13 and 14)**. Isokinetic strength was not significantly different at any time interval following the protocols.

TABLE 8: Glenohumeral Internal Rotation Isokinetic Concentric Strength Measurements

	Pre-test		**Post-0**		**Post-5**		**Post-15**		**Post-30**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
IR (PT/BW)										
Static	67.55	11.98	69.27	11.14	70.81	11.33	70.72	12.39	73.03	12.31
Dynamic	68.76	10.77	67.52	10.31	69.37	9.43	71.03	10.77	71.91	11.25
Group Mean	68.16	11.38	68.40	10.73	70.09	10.38	70.87	11.58	72.47	11.78
Difference			+0.24		+0.1.93		+0.27		+0.43	
P-value			1.000		1.000		1.000		0.123	

TABLE 9: Glenohumeral External Rotation Isokinetic Concentric Strength Measurements

	Pre-test		**Post-0**		**Post-5**		**Post-15**		**Post-30**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
ER (PT/BW)										
Static	48.21	5.91	48.30	6.41	47.78	6.38	47.77	5.16	47.85	5.48
Dynamic	48.75	7.59	46.71	5.76	46.30	5.06	45.99	5.37	44.89	5.29
Group Mean	48.48	6.75	47.51	6.09	47.04	5.72	46.88	5.26	46.37	5.38
Difference			-0.97		-1.43		-1.60		-2.10	
P-value			1.000		0.319		0.672		0.185	

FIGURE 13: Glenohumeral Internal Rotation Isokinetic Concentric Strength Measurements

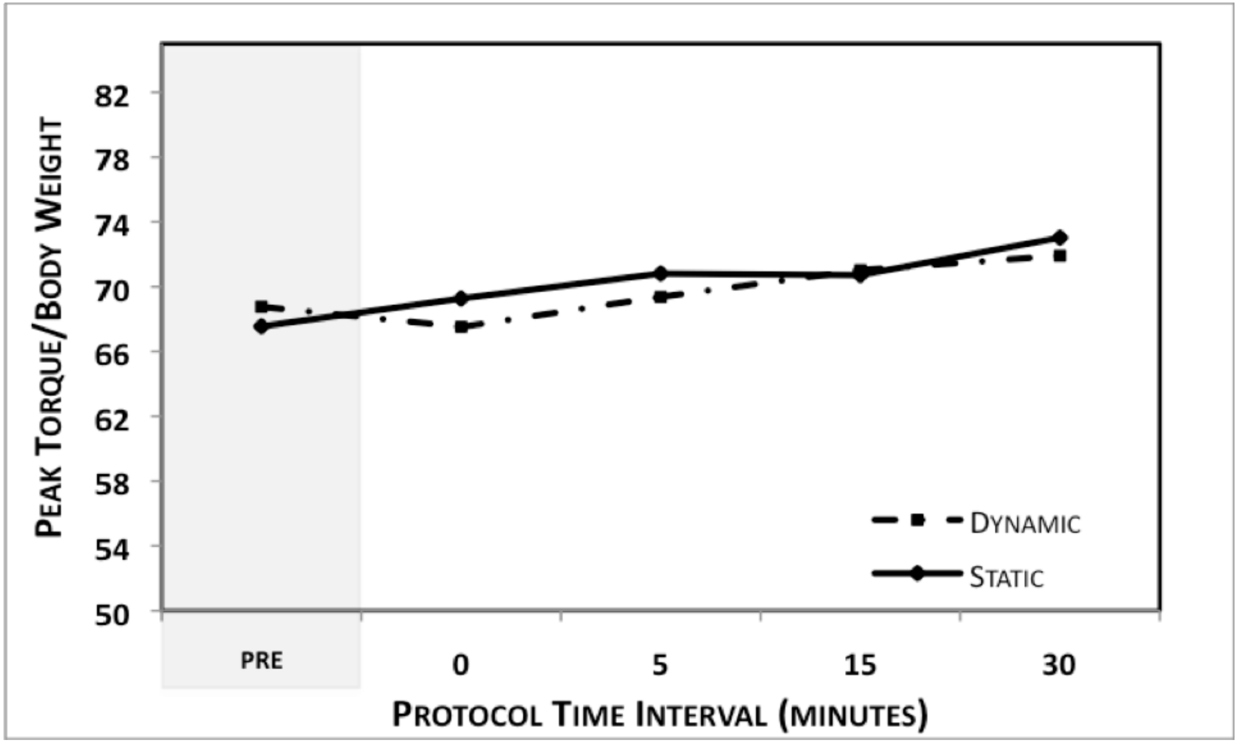
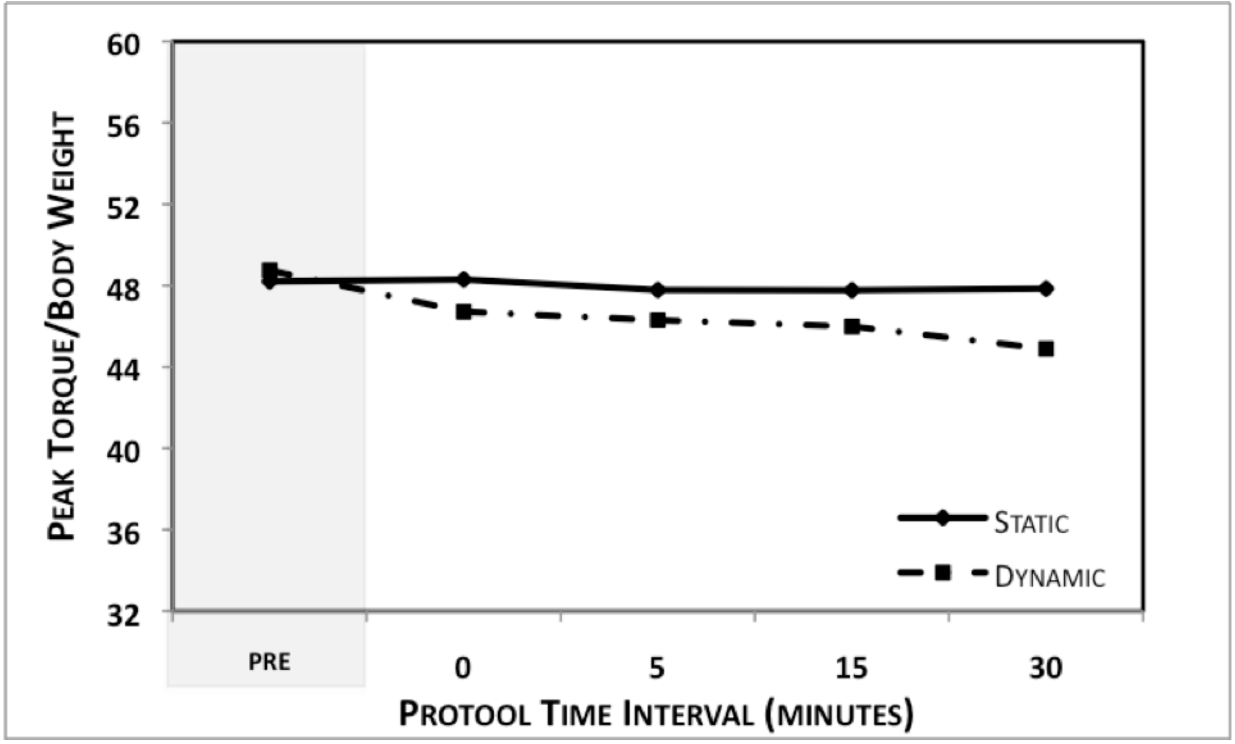


FIGURE 14: Glenohumeral External Rotation Isokinetic Concentric Strength Measurements



3.5 ACUTE EFFECTS OF INTERNAL & EXTERNAL ROTATION POWER

GH isokinetic IR and ER concentric power data for the protocols are presented in **TABLE 10** and **TABLE 11**, respectively. No significant test x time interaction for IR or ER isokinetic power was found between the static and dynamic protocols **(FIGURES 15 and 16)**. However, ER isokinetic power was significantly decreased at the post-30 time interval compared to the pre-test measurement.

TABLE 10: Glenohumeral Internal Rotation Isokinetic Concentric Power Measurements

	Pre-test		**Post-0**		**Post-5**		**Post-15**		**Post-30**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
IR (AP)										
Static	41.05	11.02	41.89	11.71	42.34	11.17	43.19	12.24	44.47	12.80
Dynamic	40.18	8.49	39.67	7.34	39.75	6.22	40.04	6.74	40.16	7.13
Group Mean	40.62	9.76	40.78	9.53	41.05	8.69	41.62	9.49	42.32	9.96
Difference			+0.16		+0.43		+1.00		+1.70	
P-value			1.000		1.000		1.000		1.000	

TABLE 11: Glenohumeral External Rotation Isokinetic Concentric Power Measurements

	Pre-test		**Post-0**		**Post-5**		**Post-15**		**Post-30**	
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
IR (AP)										
Static	30.84	7.41	30.41	6.59	30.31	6.95	30.01	6.54	30.00	7.26
Dynamic	30.29	4.45	29.60	4.09	28.45	3.52	28.45	3.04	27.14	3.04
Group Mean	30.57	5.93	30.00	5.34	29.38	5.24	29.23	4.79	28.57	5.15
Difference			-0.56		-1.18		-1.33		-1.99	
P-value			1.000		0.425		0.597		0.049*	

*Significant main effect of protocols

FIGURE 15: Internal Rotation Isokinetic Concentric Power

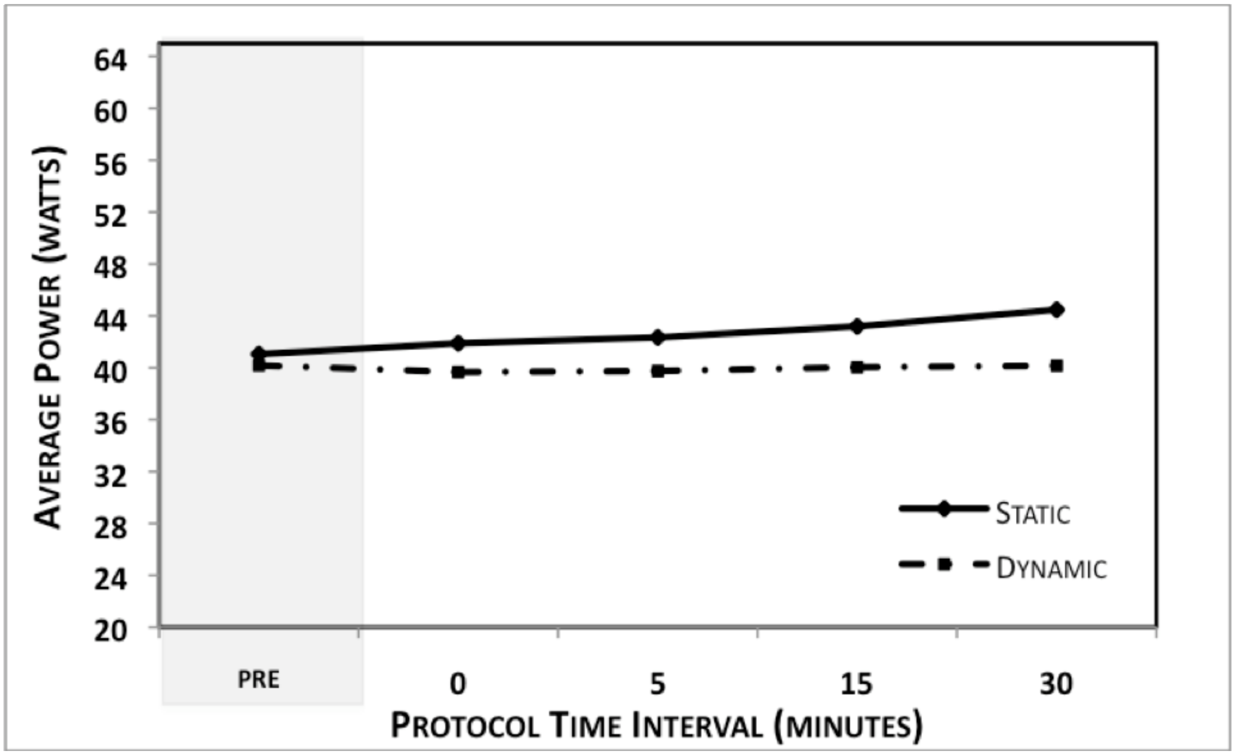
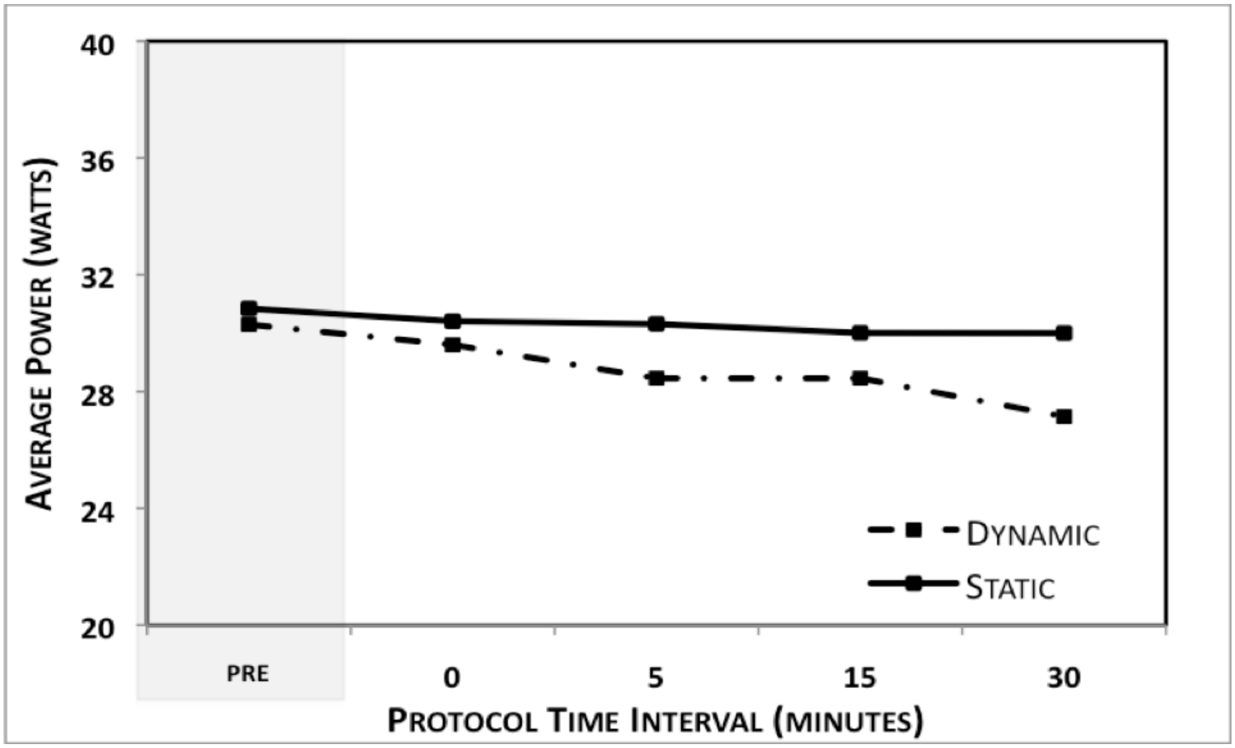


FIGURE 16: External Rotation Isokinetic Concentric Power



3.6 DURATIONAL EFFECTS OF PROTOCOLS

Percent return to baseline (%RTB) for all dependent variables is presented in **TABLE 12.** All dependent variables returned to at least 75% of baseline values at 30 minutes following the protocols.

TABLE 12: Dependent Variable Percent Return to Baseline (%RTB)

	Pre-test		**Post-30**		**%RTB**
	Mean	**SD**	**Mean**	**SD**	
Dependent Variable					
IR ROM (deg)	59.8	9.7	63.3	10.5	105.8%
ER ROM (deg)	121.0	12.8	124.9	12.6	103.3%
PST (deg)	22.8	6.8	24.7	8.0	108.2%
IR Strength (PT/BW)	68.2	11.4	72.5	11.8	106.3%
ER Strength (PT/BW)	48.5	6.7	46.4	5.4	95.7%
IR Power (AP)	40.6	9.8	42.3	10.0	104.2%
ER Power (AP)	30.6	5.9	28.6	5.1	93.5%

4.0 DISCUSSION

The purpose of this study was to evaluate upper body static stretching and dynamic warm-up protocols and determine the most effective intervention to acutely increase glenohumeral ROM, decrease PST, and maintain strength and power. While traditional methods of acute static stretching are effective at increasing soft tissue flexibility, they may be detrimental to muscular performance by decreasing the force-generating capability of skeletal muscle. For the overhead throwing athlete, decreased force output and throwing velocity might outweigh the potential injury prevention benefits of static stretching associated with decreases in PST and GIRD and restoration of a total arc of motion at the shoulder. Dynamic warm-up was hypothesized to be a more appropriate method to enhance muscular performance by stimulating a physiological response of the active tissues. The static stretching and dynamic warm-up protocols in this study were therefore expected to generate differences in ROM, PST, and force output. However, this study demonstrated no significant differences between the static and dynamic protocols. Neither protocol enhanced nor diminished muscular performance, but both protocols were similarly effective at producing significant acute increases in glenohumeral IR and ER ROM for at least 30 minutes following stretching.

4.1 ACUTE CHANGES IN FLEXIBILITY

The results of this study demonstrated significant increases in GH IR and ER ROM following the static stretching and dynamic warm-up protocols, but no significant differences were found between the protocols. It was hypothesized that GH IR and ER ROM would significantly increase following both protocols, and that the static stretching would produce the greatest increase in ROM.

Static stretching may increase flexibility through facilitated decreases in tissue viscoelasticity, decreases in muscle stiffness, decreases in muscle activation, and increases in stretch tolerance.[6, 54, 55] Viscoelasticity is an intrinsic property of biological tissues giving characteristics of elasticity and viscosity when a stretch torque is applied.[1] Stress relaxation occurs when a passive force is applied to soft tissues, producing a variation in the load-deformation curve.[56, 84] Tissue stiffness is defined mathematically as the change in force per change in length of a tissue, and allows tissues to resist a change in length.[85] Tissue stiffness is reduced when the force required to change the length of that tissue is reduced.[85]

Specialized stretch receptors located throughout the MTU also contribute to muscle relaxation and increased muscle length following stretching.[84] In addition to intrinsic collagenous make-up of soft tissues, reflexive neural control also contributes to muscle stiffness. Muscle spindles function as part of a continual feedback loop known as the stretch reflex and act to prevent excessive stretching of the MTU.[84, 86] Stretching may decrease neural feedback and promote increased muscle length by inhibiting the stretch reflex and activating the golgi tendon organs located within the tendon. Electromyographical studies have quantified decreases in muscle activation following acute stretching exercises in which the muscle was placed in a lengthened position.[59, 62]

The results of the current study confirm previous reports that acute static stretching is effective at producing transient increases in joint range of motion. Previous studies demonstrated that a single 15- or 30-second stretch significantly improves range of motion at any major joint.[3, 6] Shorter duration stretches were as effective as longer duration stretches at improving range of motion and the acute ROM effects of static stretching may last between 6 and 90 minutes.[6] The results of this study demonstrated significant increases in IR and ER ROM up to 30 minutes after the initial stretch period. The static stretching protocol used in the current study consisted of six upper extremity stretching exercises aimed at globally stretching the shoulder. Each exercise was performed twice for a period of 20 seconds and for a total of three minutes of active stretching.

Interestingly, the dynamic warm-up protocol used in this study resulted in similar increases in ROM as the static stretching protocol, and thus our hypothesis was not confirmed. Limited research has quantified comparisons between static and dynamic protocols on acute flexibility, but one study found that passive stretching was more effective than dynamic stretching to improve hamstring flexibility.[79] The dynamic warm-up used in this study consisted of active movements performed throughout the full range of motion using light resistance tubing. These exercises were unlikely to have reached the plastic threshold of the stress-strain curve, but the dynamic warm-up may have increased muscle temperature and blood flow to the active tissues producing increased elasticity and decreased muscle stiffness.[14] Previous studies have suggested muscle temperature is directly correlated to tissue flexibility.[87] While not directly measured in this study, increased local tissue temperature and blood flow may have contributed to the increased flexibility following the dynamic warm-up protocol.[14]

The results of this study demonstrated no significant decreases in PST between the static stretching or dynamic warm-up protocols, but PST was significantly reduced at the 5 minute time interval following stretching. It was hypothesized that PST would significantly decrease following both protocols, and moreover that the static stretching protocol would create the greatest decrease in PST.

In this study, significance did not occur immediately after stretching, but a significant decrease in PST occurred at the 5-minute time interval. Our hypothesis was not supported, thus, it seems logical in retrospect that the protocols in this study were not effective in greatly reducing PST. The static stretching protocol was designed to globally stretch and activate important shoulder musculature and did not solely focus on the posterior shoulder as previous studies have. One study demonstrated a significant mean decrease in PST (3.39° ± 3.99) following three sets of 30-second static stretches of the posterior shoulder.[15]

4.2 ACUTE CHANGES IN FORCE OUTPUT

The results of this study demonstrated no significant changes in GH IR and ER strength and power following the static stretching or dynamic warm-up protocols. We hypothesized there would be no changes in strength or power following the static stretching protocol, but it was thought strength and power would significantly increase following the dynamic warm-up protocol.

Previous studies have demonstrated that various static stretching routines can cause decreases in the force-generating capability of skeletal muscle.[58, 59] Static stretching increases MTU compliance which may decrease tissue stiffness and allow for increased tissue flexibility.[56] Tissue stiffness is defined as ratio of change in force to change in length.[87] Decreased muscle stiffness may increase tissue length, but subsequently decrease the force available for contraction.[59] Increases in muscle length may also decrease neural activation of muscles through altered proprioceptive feedback of specialized mechanoreceptors found in the MTU.[47, 87] Mechanical and neurological mechanisms are both attributed to decreased force output following acute static stretching.

Strength and power deficits have ranged from 5 to 30% in previous studies and negative effects have lasted up to an hour.[58, 59, 61] Vertical jump and sprint performance were impaired following acute static stretching.[69, 70] In some studies, stretches were held for periods ranging from 90 seconds per muscle group up to one hour per muscle group.[50, 58, 59] In terms of practicality to sport, stretching a single muscle group for 15-30 seconds is more realistic, and also produces similar flexibility increases as longer duration stretches.[3, 50]

Yamaguchi et al[3, 50] demonstrated that static stretching for 30 seconds neither improves nor reduces leg extension power. The results of this study supported the hypothesis that our static stretching protocol would not cause changes in shoulder strength and power. Each stretching exercise in the current study intentionally targeted different tissues about the shoulder to globally stretch the shoulder. Additionally, each stretch was only held for 20 seconds, compared to previous studies using longer duration stretches.[58, 59]

The dynamic warm-up protocol in this study was not sufficient to improve internal rotation strength or power. Several studies have found improvements in muscular power following dynamic warm-up exercises.[14, 50, 76] Increased core and muscle temperature, increased blood flow to active tissues, increased firing and activation of motor units, and other physiological mechanisms have been proposed to explain the positive benefits of dynamic warm-ups.[14] The design of the current study did not allow measurement of any physiological factors, but the rubber tubing exercises used in this study may not have stimulated a significant physiological response necessary to enhance muscular performance. It is also possible that the rubber tubing exercises in this study produced a fatigue effect significant enough to outweigh the performance benefits of a physiological response but not enough to significantly decrease muscular performance beyond baseline measurements.

4.3 CLINICAL SIGNIFICANCE

Our data suggests that either the static or dynamic protocol used in this study is sufficient to provide a short-term increase in GH joint ROM for at least 30 minutes. This may be important to overhead throwing athletes to allow a temporary increase in total arc of motion before performing in a game or practice. Clinicians must be aware that baseball athletes may need to stretch between innings to sustain increases in joint ROM because practices and games generally last longer than 30 minutes. While our results did not directly demonstrate increases in strength or power following stretching or warm-up, a larger arc of motion may be biomechanically advantageous to overhead throwing performance. A larger arc of motion at the shoulder increases the time over which muscular forces are applied to the baseball prior to ball release. The subsequent increase in the baseball's impulse results in a greater change in momentum of the ball and ultimately a greater ball velocity. Static stretching should therefore continue to be included in the daily habits of throwing athletes to maintain a large arc of motion, but should be performed after activity during the cool-down to avoid any potential performance impairments. Daily stretching is also important to manage GIRD and PST and prevent injuries associated with decreased flexibility of the posterior shoulder. Meanwhile, clinicians and researchers must continue to work together to develop upper extremity dynamic warm-up protocols to enhance muscular performance.

4.4 LIMITATIONS

One limitation of this study is the generalizability of functional testing performance (i.e. isokinetic dynamometry) to actual sport performance. Although we did not observe any strength or power deficits using isokinetic dynamometry, there is a limitation in direct applicability to throwing performance. Elite pitchers can generate humeral angular velocities in excess of 7,000° $\cdot \text{sec}^{-1}$ during acceleration. Isokinetic dynamometry is limited in this sense because it cannot recreate the extreme velocities reached during overhead throwing. The most appropriate measure to assess true throwing performance would be to measure ball velocity or throwing distance. However, careful consideration must also be given to control for confounding variables that may occur in non-laboratory settings.

Another limitation of this study is the potential interaction of confounding factors due to a repeated-measures design. Subjects may have been introduced to a repeated dynamic mechanism during testing as a result of performing alternating measurements of IR and ER isokinetic strength and range of motion assessments. Strength testing may have contributed to elevated levels of GH joint ROM observed immediately and up to 30 minutes following stretching.

4.5 FUTURE DIRECTIONS

Future research is still needed to determine the most effective stretching or warm-up protocol to maximize throwing performance. This was the first study to compare static stretching and dynamic warm-up on ROM and force output in the upper extremity. The majority of the research evaluating stretching and warm-up protocols has been performed on the lower extremity. While the dynamic warm-up protocol in this study was not effective at increasing upper extremity strength and power, previous studies have shown dynamic warm-up to be effective at enhancing lower extremity muscular performance, including vertical jumping and sprinting. Future studies should continue to evaluate upper extremity dynamic warm-up protocols and explore physiological responses that have been theorized to enhance performance. Once physiological mechanisms are better understood, researchers can then develop more effective warm-up protocols capable of enhancing athletic performance. Future research may also choose to include overhead throwing athletes who exhibit PST and GIRD to examine if any differences arise in response to stretching and warm-up compared to non-overhead athletes.

4.6 CONCLUSIONS

This study did not identify a stretching or warm-up protocol that increased muscular force output, but it did demonstrate that both protocols acutely increased GH IR ROM and ER ROM up to 30 minutes. The static stretching and dynamic warm-up protocols in this study are easily performed on-the-field and still may be beneficial to baseball athletes to reduce the risk of throwing-related injury.

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