How Do Different Upper Body Stretches Affect Range of Motion of the Shoulder and the Speed of a Lacrosse Shot?

By
Chelsea Esser
April 3, 2023



Allegheny College
Department of Biology

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A Senior Comprehensive Project in Partial Fulfillment of the Requirements for a Bachelor of Science Degree from Allegheny College

I hereby recognize and pledge to fulfill my responsibilities as defined in the Honor Code and to maintain the integrity of both myself and the College community as a whole.

Chelsea Esser

Pledge

Approval by the Senior Thesis Committee:

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Dr. 1st Reader

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Dr. 2nd Reader

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I want to start off and thank Dr. Lisa Whitenack for all of her help throughout the various stages of this project. She was so understanding and patient with me as I found my way throughout this process. From FS101 to now, Dr. Whitenack has been one of my biggest supporters.

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Abstract

In the competitive world of athletics, individuals or teams are constantly competing to be the best and believe things like training routines, nutrition, and attitude will get them to the top. Part of those training routines usually include some sort of stretching routine, but what constitutes a good and beneficial routine? The purpose of this research is to find out which type static, dynamic or both - will lead to the greatest shoulder range of motion (ROM) and fastest lacrosse shot. The Allegheny College Women's and Men's Lacrosse team was given three stretching routines to complete for four days at a time and in a different order. ROM and velocity were measured at the beginning of data collection and at the end of each stretching regimen. Flexion was the only range of motion position that was significantly different, as the baseline measurement was higher than the post-static stretching measurement. Extension, internal rotation and external rotation, along with the lacrosse shot velocity were not significantly different across stretching regimes. The insignificance of the stretching routines and their corresponding ROM and velocity measurements suggest that individuals can perform whichever type of stretching they prefer and obtain the same results.

Introduction

Flexibility is known to enhance joint range of motion (ROM) and strengthen muscular performance (Haag et al., 2010). Strength and conditioning coaches are constantly implementing stretching routines for their athletes, which tend to include a large number of static movements (Haag et al., 2010). Stretching is considered to be a vital part of an athlete's pre-workout regimen, but what type of stretching is the best? In a population of people that are constantly competing to be the best of the best, there needs to be a stretching routine associated with certain goals they are trying to achieve, such as more range of motion or more force production.

Muscle Anatomy

Skeletal muscle is able to contract and stretch to whatever the individuals' stretching capacity is. These abilities are due to how muscle is made up of many subunits called muscle fibers, which are muscle cells (Fox & Rompolski, 2022). Each of these cells are encased in sarcolemma, a plasma membrane, and those then have a thin layer called endomysium around them (Figure 1) (Fox & Rompolski, 2022). Muscle fibers are made up of much smaller fibers,

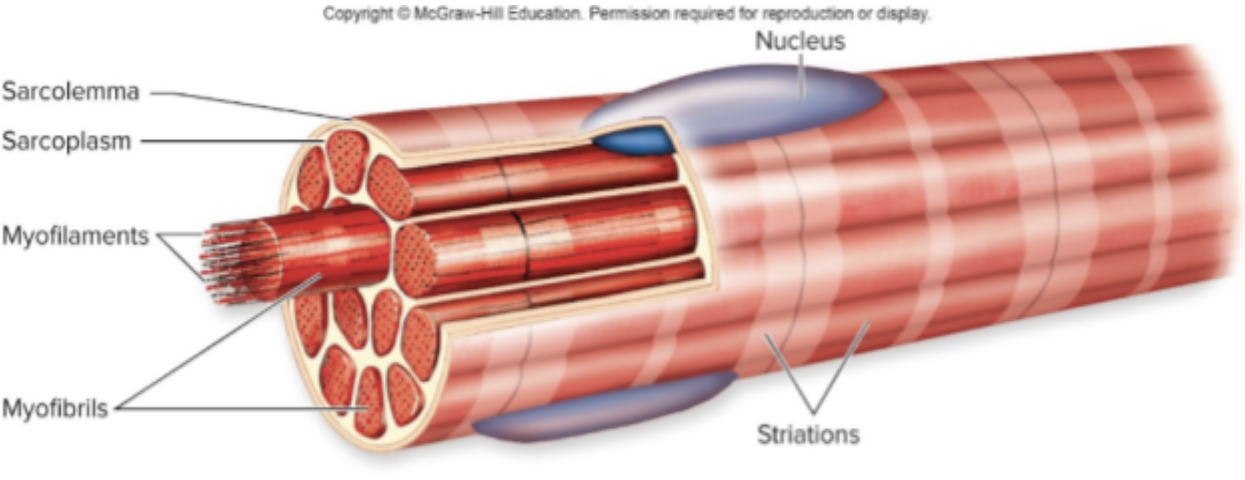


Figure 1. Skeletal muscle fiber and it's various structures. Fox, Stuart Ira, and Krista Lee Rompolski. "Chapter 12: Muscle." *Human Physiology*, 16th ed., McGraw Hill LLC, New York, NY, 2022, pp. 358–397.

which are known as myofibrils (Fox & Rompolski, 2022). The structures are then made up of myofilaments, both thick and thin which are made of myosin and actin proteins, respectively (Fox & Rompolski, 2022). There are many different building blocks in muscle, which are all involved in applying the effects of stretching to the body.

Stretching the Muscle

Once the stretch is initiated by the individual, the sarcomere is the first structure to be affected. A sarcomere is the smallest functional contractile unit in muscle (Herzog, 2022). The sarcomeres in all of the muscle fibers will begin to contract, which leads to the gap between the thick (actin) and thin (myosin) filaments of the myofilaments to increase (Figure 2). The muscle

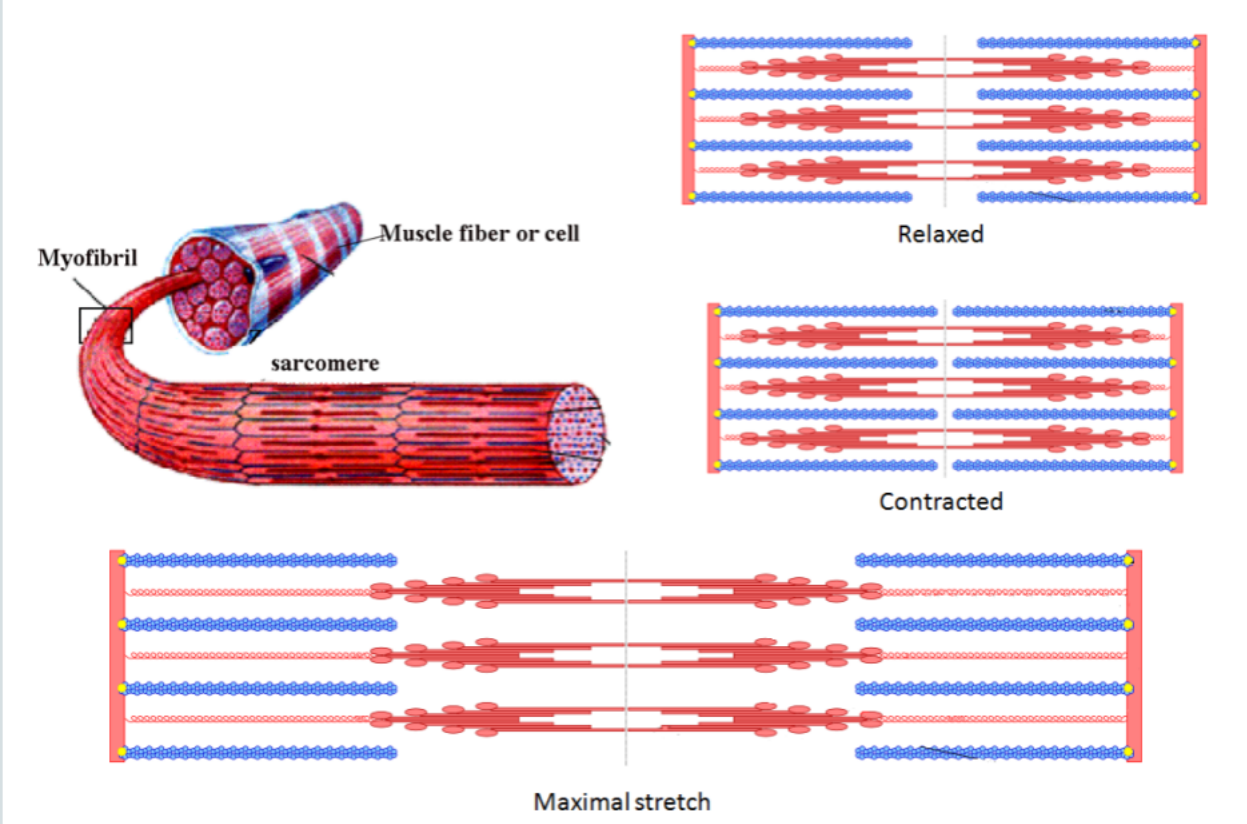


Figure 2. Myofilaments (red=myosin and blue= actin) during a relaxed state, a contracted state and during maximal stretch.
https://antisensescienceblog.wordpress.com/2014/04/25/stretching-whats-the-big-whoop-debunking-one-of-the-oldest-exercise-myths/

fibers then begin to elongate because the area of overlap between the filaments has decreased drastically. The muscles are getting stretched due to the fibers being elongated through this process. Once the muscle fibers are fully stretched, the connective tissue surrounding it begins to move with the muscle to prevent tearing. Some of these muscle fibers are stretching and lengthening, while others are at a stage of rest. The more muscle fibers that are involved in the stretch, the greater the length of the stretched muscle (Appleton, 1998). This would then lead to a larger range of motion, which is defined as how far in degrees a given joint will allow bones to move with certain movements like stretching or other exercise activities (Schoenfeld, 2020).

Another type of structure in the muscle are the mechanoreceptors, also known as muscle spindles (Macefield et Knellwolf, 2018). These structures possess motor innervation, which means they have control over their sensitivity to a stretch (Macefield et Knellwolf, 2018). Intrafusal fibers, which help with proprioceptive function in muscle, are located within the muscle spindles (Barrett et al., 2020). When a muscle is being stretched, the intrafusal fibers of the muscle lengthen and this stretch is detected by the muscle spindles within the muscle. Muscle spindles are also responsible for force production within the muscle. When the neurons in the muscle spindle activate motor neurons, the action potential is achieved, and the contraction occurs to produce the force. Blum et al. (2017) looked at cats and how passive or static stretching affects the muscle spindles. They found that a passive stretch on the muscles led to an increase in force production and an increase in acceleration of the neurons firing within the muscle (Blum et al., 2017). This is because it increases the length between the fibers so that they can contract the muscle harder.

Shoulder Anatomy

The shoulder is a very dynamic structure of the body because of its ability for various degrees of motion due to the interaction of different structures that react and adjust to different events occurring to the shoulder (Lugo et al., 2008). The shoulder is centered around the glenohumeral joint, which is a ball-and-socket joint. It moves in several different directions and the adjoining bone ends are covered with a thin sheet of cartilage, which is joined by a joint capsule lined by a synovial membrane (Davies, 1945). This ball-and-socket joint includes the humeral head and the glenoid fossa in the scapula, which can be seen in Figure 3 (Chang et al., 2022). The joint has various things to ensure that there is no friction between the structure, including a joint capsule that has synovial fluid in it, which gives a protective coating to the joint capsule (Chang et al., 2022). There are also the bursae, which act as a cushion within the joint. The subacromial/subdeltoid bursa helps to decrease friction under the deltoid muscle, which allows for a larger ROM in the shoulder. The subscapular bursa helps to decrease damage occurring from friction during movement of the glenohumeral joint, specifically internal rotation (Chang et al., 2022). There are static stabilizing structures in the shoulder that help when movements are held in place for certain periods of time, like when an individual is performing static stretches. These include the glenohumeral ligaments, the coracoclavicular ligament, and the coracohumeral ligament. There

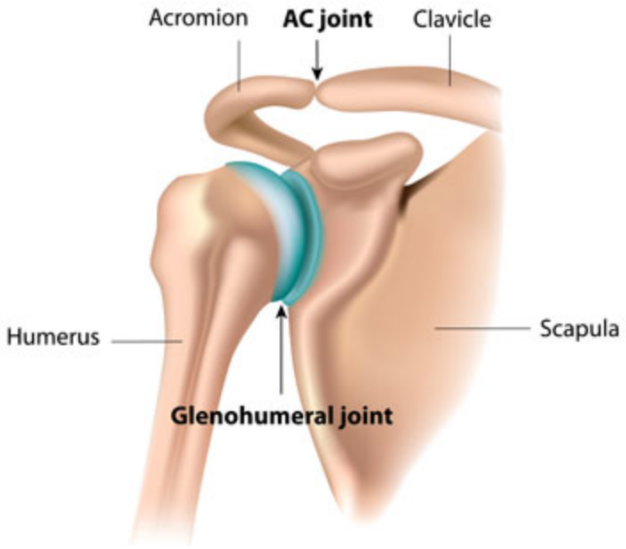


Figure 3. The glenohumeral joint, which includes the humerus and the scapula. https://www.sportsinjuryclinic.net/sport-injuries/shoulder-pain/shoulder-anatomy

are also dynamic stabilizers, which are engaged when the shoulder is moving in quick movements. There is a soft tissue pulley system and the long head of the biceps tendon, which is responsible for stabilizing the entire biceps complex (Chang et al., 2022). This pulley system works so that when one side elongates, the other side shortens.

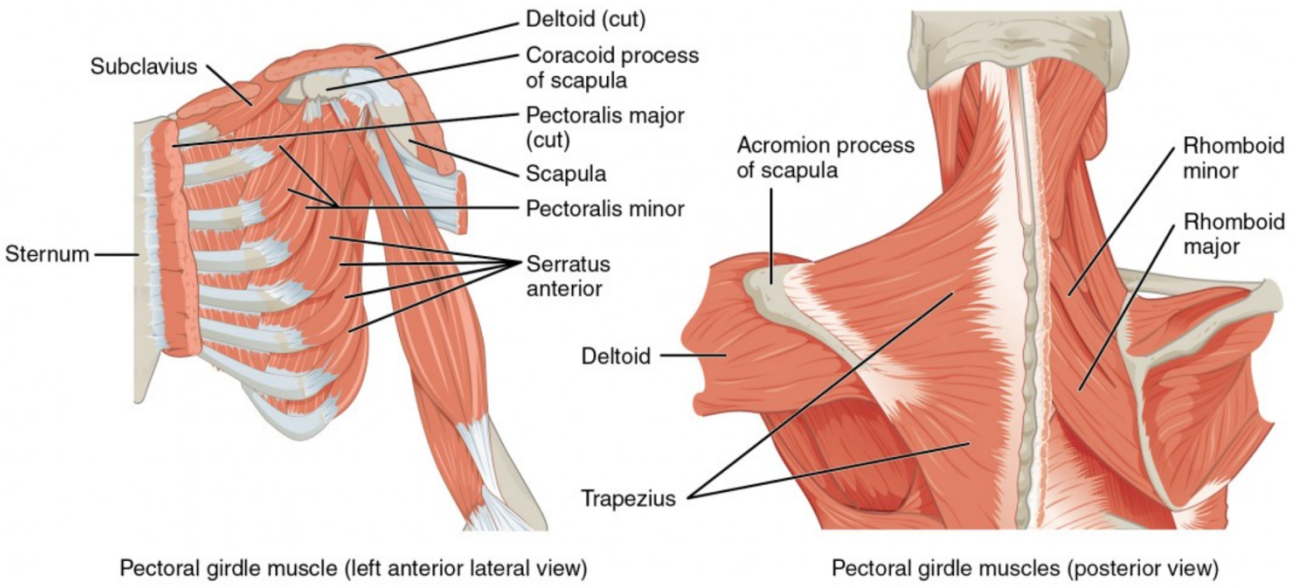


Figure 4. Muscles in the anterior and posterior view of the shoulder https://courses.lumenlearning.com/suny-ap1/chapter/muscles-of-the-pectoral-girdle-and-upper-limbs/

There are various groups of muscles in the shoulder (Figure 4), which create three muscle classes. There are the anterior muscles which work together to connect the arm to the thoracic cage and the clavicle (Vasković, 2022). The second group of muscles is the posterior extrinsic muscles which are in control of moving the arm through overseeing the scapula and humerus (Mitchel et al., 2022). The final group of muscles are the posterior intrinsic muscles, which are responsible for internal and external arm rotation, arm abduction and arm adduction (Vasković, 2022). All of these muscles (Appendix A) are able to be stretched using various different methods.

Types of Stretching

Static stretching consists of moving a body part into a certain position and holding that position for a certain amount of time so that the individual feels no pain, but a "good" stretch. This technique is most commonly utilized in enhancing flexibility because of how easy and safe it is to perform (Torres et al., 2008). Static stretching, if done correctly, allows for the muscle's stretch reflex to remain disengaged (Torres et al., 2008). A stretch reflex is a signal that attempts to resist the length of the muscle fluctuating by contracting the stretched muscle (Appleton, 1998). If this reflex is not activated, the stretching does not inhibit mechanoreceptor-mediated reflexes and therefore there is no temporary increase in the length of the musculotendinous unit (MTU), (Haag et al., 2010). If this reflex is not activated, that means that the MTU is not as flexible and the muscles are tense and contracting more. With enhanced MTU flexibility, there is a drop in force production (Haag et al., 2010). With less force production, there would be less speed and power conducted when performing activities like pitching a baseball or shooting a lacrosse ball.

Dynamic stretching includes movements that are quick and fast and they most likely mimic the movement of the sport that the individual plays that is completing the stretches (Torres et al., 2008). In current athletics, dynamic stretching has been replacing static stretching in a lot of sports (Behm & Chaouachi, 2011). One study had participants complete dynamic stretches and five minutes on the treadmill, or static stretching and five minutes on the treadmill. They found that the dynamic stretching provided similar increases in ROM as the static stretching (Beedle & Mann, 2007). There has also been research that compared the effects of static stretching and dynamic stretching on ROM of the hamstring muscles. They found that the dynamic stretching was not as effective in increasing the ROM as the static stretching (Bandy et

al., 1998). Past research has come to various conclusions, which makes it hard to determine which type of stretching routine is best for whatever an athlete wishes to accomplish.

While stretching is constantly being used by athletes as a warm up, evidence from one study has shown that it does not improve performance, decrease chance of injury, or increase flexibility (Samuel et al., 2008). Contrasting this, in another study, they found two common factors associated with exercise related musculoskeletal injury, which are "muscle stiffness and lack of ROM" (Small et al., 2008). These two factors are able to be solved with stretching. There were inconclusive results in a study that investigated the changes caused by acute static stretching on the upper body's muscular performance (Haag et al., 2010). This research found that static stretching did not have a significant effect on pitching velocity. They did find that field players had more accuracy than the pitchers (Haag et al., 2010). There has been a lack of research when considering the effects of stretching on the upper body, but when the lower body is considered, there have been quite a few studies. One study found that dynamic and static stretching both increased ROM of the knee and decreased the force produced by knee flexion (Matsuo et al., 2019). There was no difference between the two stretching routines, as both achieved the same result (Matsuo et al., 2019). Yamguchi and Ishii conducted a study in 2005 that investigated how static stretching and dynamic stretching affected force produced by leg extension. They found that static stretching had no effect on the force production, while dynamic stretching increased the power produced by the participants in leg extension (Yamaguchi et Ishii, 2005). Focusing on flexibility, O'Sullivan et al. (2009), investigated how warming up, static stretching, and dynamic stretching affected the hamstrings of previously injured participants, but used uninjured individuals as a control. They found that the uninjured participants had an increase in flexibility with the static stretching, but the dynamic stretching did not affect

hamstring flexibility (O'Sullivan et al., 2009). In those that were previously injured, the static stretching increased their flexibility, but it was not statistically significant (O'Sullivan et al., 2009).

Lacrosse is a type of sport that is very dependent on the whole body, but the stronger your upper body is, the faster you are able to shoot the lacrosse ball. Is strength the only thing that could affect the speed of a lacrosse shot? When thinking of other factors, range of motion of the shoulder is something that could be related. Would being able to have a longer arc of motion when shooting be more helpful to increasing the speed?

The purpose of this study is to see which upper-body stretching routine leads to the greatest rotation of the shoulder and if a certain stretching routine affects the speed of the individual shooting a lacrosse ball. This was measured by the (1) change in range of motion pre- and post-stretch regimen and by the (2) difference in the speed of the lacrosse shot for each stretching routine. With current literature on research pertaining to the topic of stretching, that was discussed above, I hypothesize that the static stretching regimen will have the greatest amount of rotation in the shoulder, but the dynamic stretching will have the fastest lacrosse shot data.

Methods

Subjects

This study was approved by the Allegheny College IRB, Women's Lacrosse Head Coach Patricia Pehnke, and Men's Lacrosse Head Coach Thomas Pearce. I recruited nine Women's Lacrosse field players, one of which had to stop participation in the study, and five Men's Lacrosse field players. All subjects were screened for past injuries and/or surgery to the upper body, specifically the shoulder. This screening occurred through a Google Form

(Appendix B) sent to the participants the week prior to the first day of data collection. The Google Form results were confidential in order to protect the participant's medical history, in regards to a past upper body injury/surgery. Subjects also completed an Informed Consent Form when they completed the screening Google Form. All participants had their names entered into a random name generator to receive a $5 gift card to Dunkin Donuts, which was given to the participant chosen by the name generator at the conclusion of the data collection.

Assignment of Stretching Routine

All athletes who participated in this research completed all stretching routines for four days. These routines included: a static routine that consisted of a doorway stretch, sleeper stretch, and crossover arm stretch; a dynamic routine that consisted of a pendulum swing with a 10 pound kettlebell, internal rotation (IR) and external rotation (ER) with a two and a half pound dumbell, and a PVC pipe overhead rotation; and a combination routine that included doorway stretch, crossover arm stretch, pendulum swing and the PVC pipe stretch. There was a random assignment of the stretching routines. This was done by using a randomized name selector, with which I just went through a continuous cycle of picking for static, dynamic, combination, and then started with static again.

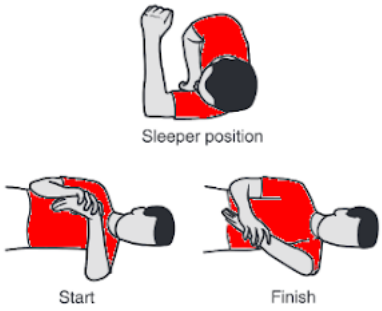
Static Stretching

Participants were asked to do a series of static stretches: a doorway stretch, sleeper stretch, and crossover arm stretch (Figure 5). All three of these stretches were performed continuously. Each was held for 30 seconds and was repeated for three repetitions before moving onto the next stretch in the regimen. These stretches were done until the athlete felt like they were stretching to a comfortable point for them and stopped stretching when they felt pain and held that for the 30 seconds of stretching. In Table 1, the schedule for those in the static stretching group is laid

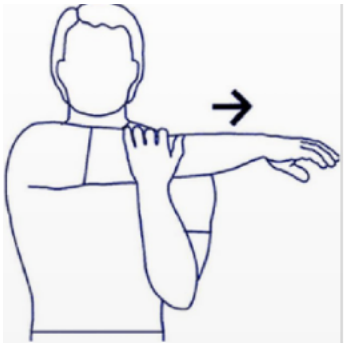
out for the data collection. This schedule was the same for the other two stretching routines but will have the color blocks in a different order.



Doorway stretch, a static stretch provided routine. Athlete will move their body slowly, while keeping arms up in the doorway. https://www.saintlukeskc.org/health-library/doorway-pectoral-stretch-flexibility



Sleeper stretch, one of the 3 stretches given to the athlete in the static stretching regimen. "Rotator Cuff and Shoulder Conditioning Program - Orthoinfo - Aaos." *OrthoInfo*, June 2022, https://orthoinfo.aaos.org/en/recovery/rotator-cuff-and-shoulder-conditioning-program/.



Crossover arm stretch, a static stretch in the provided routine. Panagiotopoulos et al., 2019).

Figure 5. Static Stretching Routine Stretches

Days	**Activity**
Day 1	1. Collect ROM measurements and lacrosse shot velocity 2. Complete Static Stretching Routine
Day 2	Complete Static Stretching Routine
Day 3	Complete Static Stretching Routine
Day 4	1. Complete Static Stretching Routine 2. Collect ROM measurements and lacrosse shot velocity
Day 5	Start Dynamic Stretching Routine
Day 6	Complete Dynamic Routine
Day 7	Complete Dynamic Routine
Day 8	1. Complete Dynamic Routine 2. Collect ROM measurements and lacrosse shot velocity
Day 9	Start Combination Routine
Day 10	Complete Combination Routine
Day 11	Complete Combination Routine
Day 12	1. Complete Combination Routine 2. Collect ROM Measurements and lacrosse short speed

Dynamic Stretching

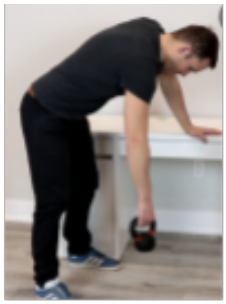
For this regimen of stretching there were also three stretches assigned: a pendulum swing with a five pound weight, IR and ER with a two and a half pound dumbbell, and a PVC pipe overhead rotation (Figure 6). This last stretch had the athlete start with the PVC pipe in front of them and then they swung their arms overhead until they were fully rotated behind their bodies, still holding the PVC pipe. Each of these exercises was completed for a total of three sets of ten repetitions. The athletes were instructed to perform each repetition with a slow speed and to a point of stretching that is not painful, but feels like a "good" stretch.



Weighted Supine IR and ER rotation. https://library.theprehabguys.com/vimeo-video/supine-shoulder-external-internal-rotation-dumbbell/



PVC Pipe rotation. https://www.wellandgood.com/pvc-pipe-mobility-exercises/



Weighted pendulum swing. https://therapia.com/physiotherapy-rehabilitation-exercises/shoulder-pendulum/

Figure 6. Dynamic Stretching Routine Stretches

Dynamic and Static (Combination) Stretching

This regimen combined the two previous stretching routines, with two stretches from each regimen. The athletes performed doorway stretch and crossover arm stretch for three sets of 30 seconds. They also were given the pendulum swing and the PVC pipe stretch, which were performed for three sets of 30 repetitions.

Measurement of Rotation

All athletes had their shoulder range of motion (ROM) measured prior to any stretching with a goniometer (Norkin et al., 2017). This was done by measuring the internal rotation (IR) and external rotation (ER) range of motion (ROM) (Figure 7). The athlete laid supine on the table and had their humerus lying flat on the table. This led to the bottom portion of the arm to be straight up and perpendicular to the table. To measure the IR ROM, the arm came down towards the athlete's feet and the measurement pushed the arm to where it was experiencing a small stretch and no pain. To measure the ER ROM, the arm came back towards the head, making sure that the elbow stayed on the table. The same procedure took place to measure, so that the athlete felt a small amount of stretch and zero pain. For both of these measurements, the goniometer was rooted on the elbow and the arm was on the ulna. The ideal measurement for ER is between 0 and 90 degrees and for IR it is between 0 and 70 degrees (Norkin et al., 2017).

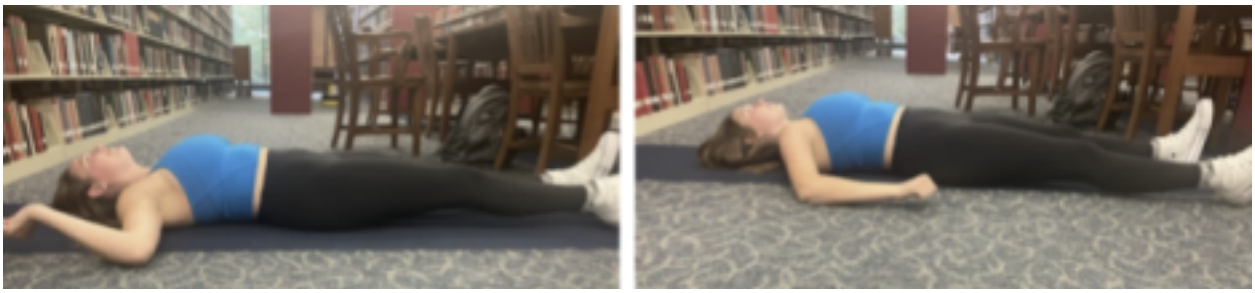


Figure 7. Internal and External Rotation ROM position.

Another measurement assessed the ROM of the shoulder, but in a different way. This measurement used shoulder flexion and shoulder extension to see how far the athlete could rotate their arm straight up near their heads and how far back behind them their arm can go (Shoulder Joint ROM Assessment, 2017). The axis of rotation, where the goniometer is centered, was the proximal humerus in the shoulder, which can be see in Figure 8. The athlete started by

straightening the arm and made a thumbs up, to make sure the arm stayed straight. The athlete went into shoulder flexion by bringing their arm up by their ear and the arm of the goniometer came into line with the humerus to measure the angle of the shoulder flexion (Figure 9). This was the same procedure for shoulder extension, except the athlete brought the straight arm back, or behind them (Figure 9). There were four measurements to assess the ROM of the shoulder before and after each stretching regimen.

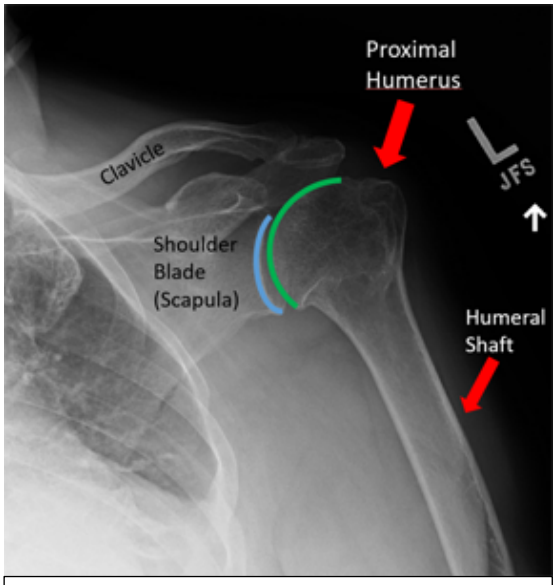


Figure 8. The arrow labeled with "Proximal Humerus" is where the goniometer was placed to measure shoulder flexion and extension. https://ota.org/sites/files/2021-01/PE3831f03.png



Figure 9. Shoulder Flexion and Shoulder Extension ROM position

Speed Measurement of Lacrosse Shot

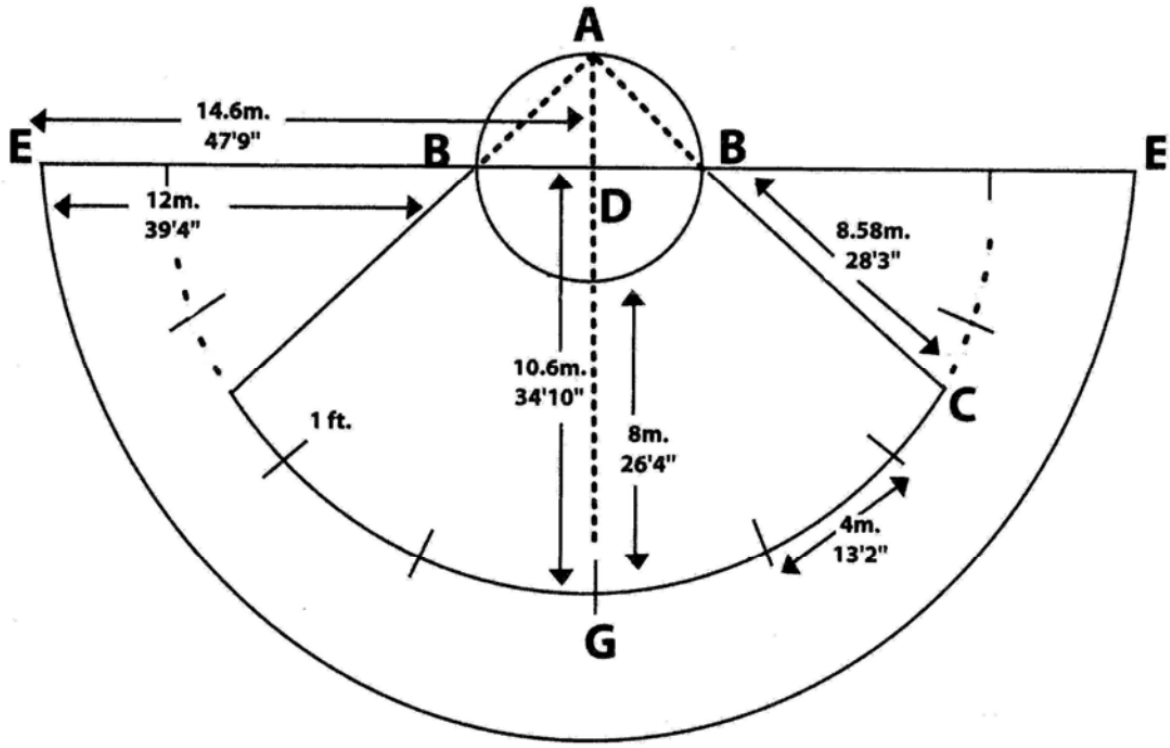


Figure 10. Diagram of the area surrounding the goal in Women's Lacrosse. A, B, D: the crease surrounding the goal, where field players are unable to enter. C: the 8-meter arc, which branches from the back of the crease. G: the hash on the 8-meter arc, where players will have to shoot by. C: the 12-meter arc. https://www.usalacrosse.com/field-diagrams.

Athletes were asked to shoot a lacrosse ball prior to completing the stretching routine on the first day. This was the baseline measurement for the speed measurement to see if there was a difference after completing each stretching regimen. The speed was captured using a Ball Coach Radar detector from the brand Ball Coach. This was borrowed from the Allegheny College Softball team for the duration of the study. The athlete was placed on the 12-meter arc of the lacrosse field (Figure 10). They were given 4 meters to move towards the goal and had to release the ball to shoot by the time they reached the 8-meter arc lined on the field. On the final

day of the three regimens, the speed was recorded again to see if there was a change after the stretching routine was completed.

Statistics

I ran a repeated measure ANOVA test, for my normal data, using JMP Pro 17 as my software. I set the stretching routine as the fixed variable and the person as the random variable. I compared the range of motion in the four positions for both of these variables. The lacrosse shot velocity was not normal when goodness of fit was assessed, so I created a set of data that was the log of the velocity. This still was not normal when the goodness of fit was assessed. I used a ranking method of the stretching routine and their lacrosse shot velocities for each participant. Using these rankings, I was able to run a one-way ANOVA.

Results

Overall, flexion was the only variable that showed a significant difference, internal rotation, external rotation, extension, and velocity were not.

There was no significant difference between the stretching routines when internal rotation ROM was compared ($F=2.16$, $df= 3, 36$, $p=0.11$) (Figure 11). Below are graphs made from all of the averages in Table 2. There was no significant change of the participants range of motion in external rotation between any of the stretching regimens ($F=1.44$, $df= 3, 30$, $p= 0.25$) (Figure 12). There was a significant difference ($F=3.96$, $df=3, 36$, $p= 0.02$) (Figure 13), between the flexion measurement in the baseline and after the static stretching routine was completed. The baseline ROM was significantly lower than the post-static ROM in the flexion position. There was no significant difference between the stretching routines and the participant's range of motion in shoulder extension ($F=1.59$, $df= 3, 36$, $p=0.21$) (Figure 14).

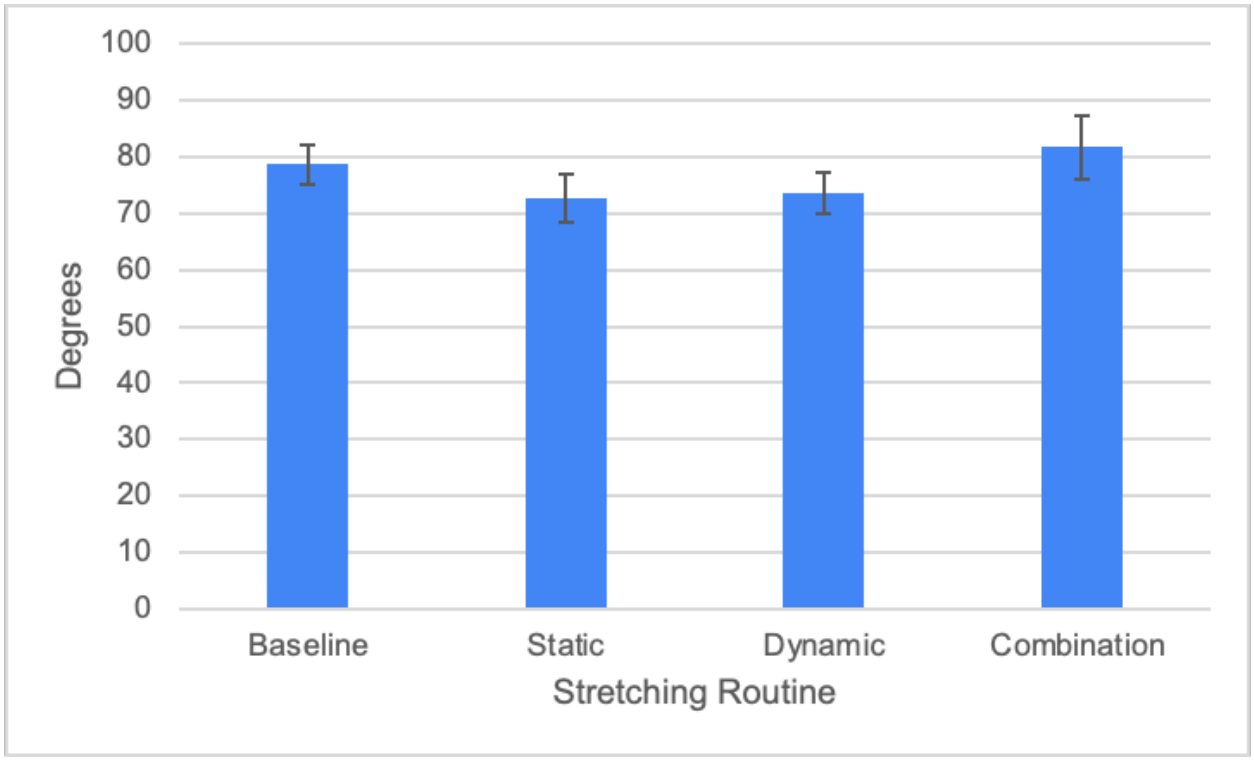


Figure 11. Averages of Internal Rotation ROM. Standard error is used for error bars.

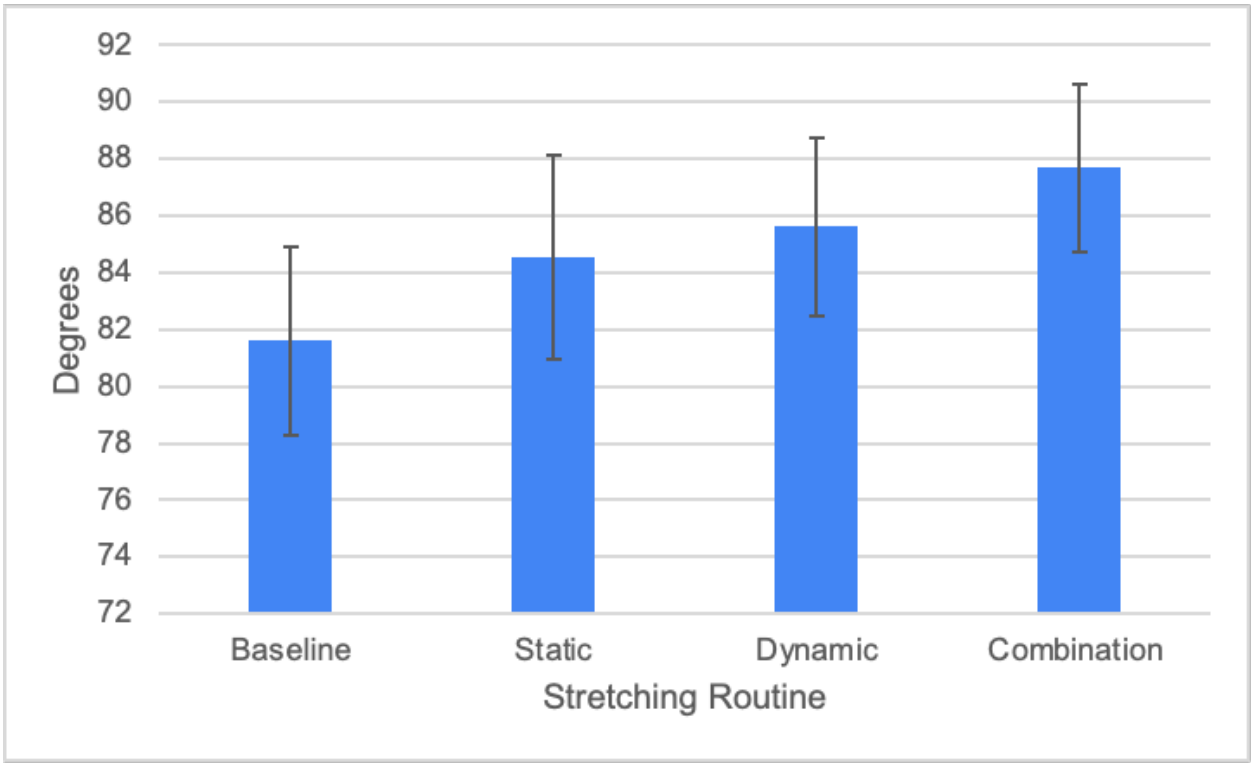


Figure 12. Averages of External Rotation ROM. Standard error is used for error bars.

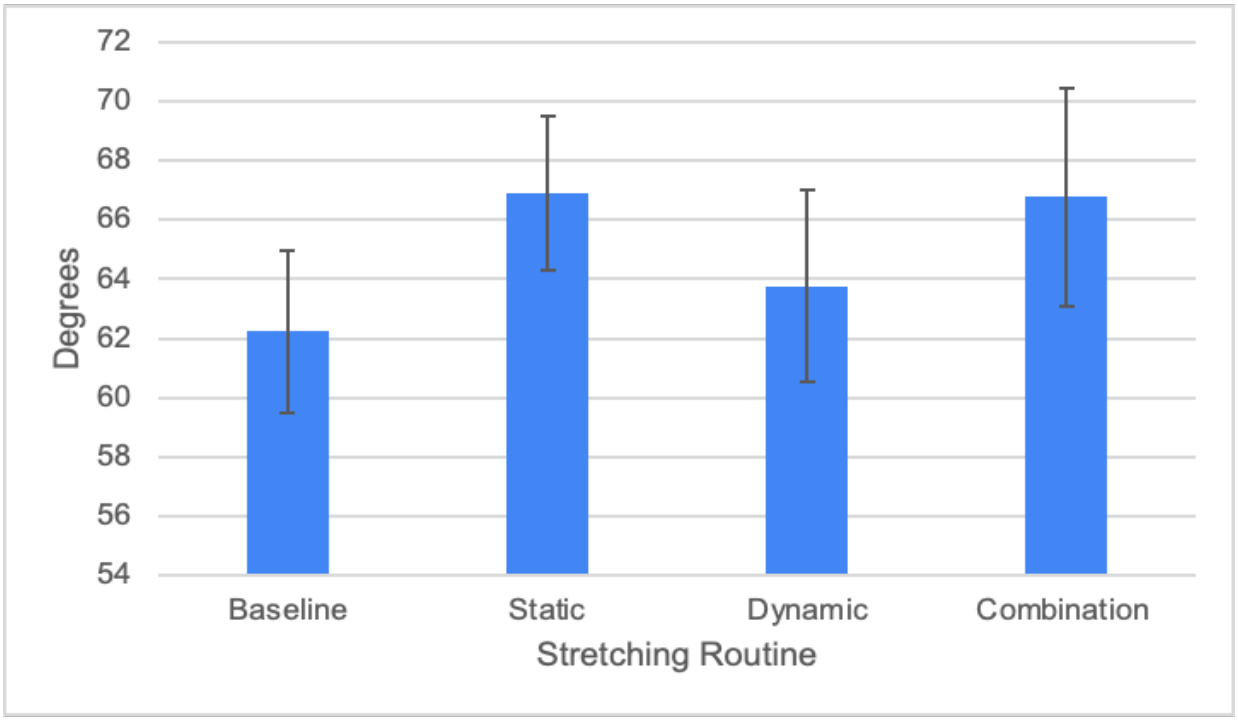


Figure 13. Averages of Flexion ROM. Standard error is used for error bars.

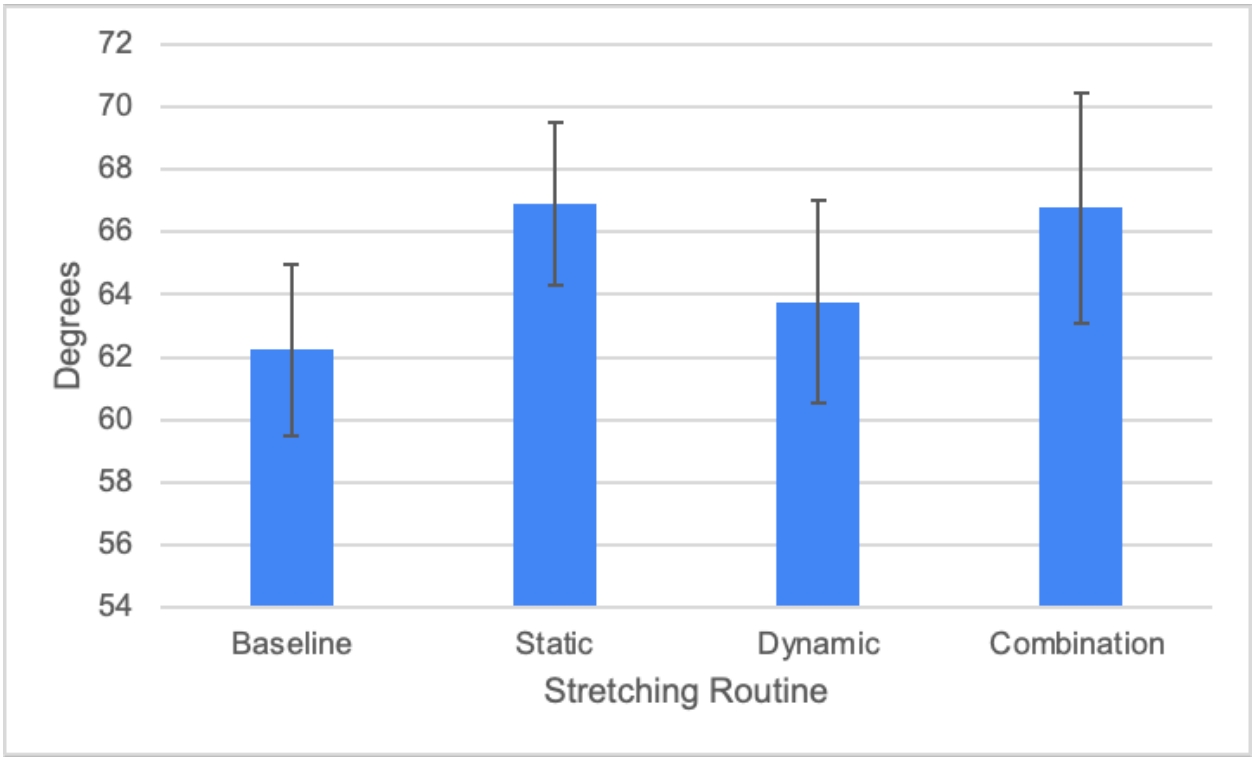


Figure 14. Averages of Extension ROM. Standard error is used for error bars.

Velocity of Lacrosse Shot

Due the data not being normally distributed, a one-way ANOVA was completed with the rankings of the velocities for each of the stretching routines for all of the participants. However, the ANOVA on ranks showed that the rankings of velocity were not significantly different. When looking at the averages (Figure 15), after completing the combination routine the participants had the slowest lacrosse shot, but after completing the dynamic stretching routine the participants had the fastest lacrosse shots.

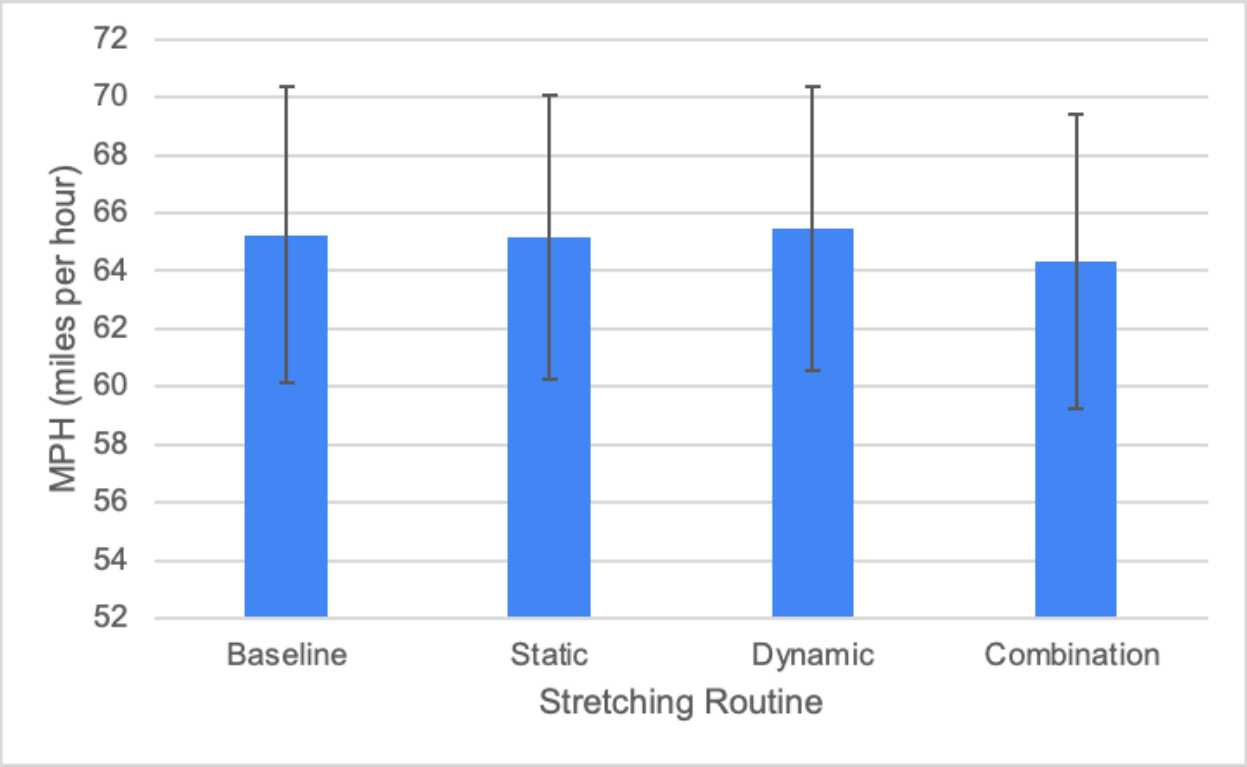


Figure 15 Averages of Lacrosse Shot Velocities. Standard error is used for error bars.

Stretching Routine	External Rotation (Degrees)	Internal Rotation (Degrees)	Flexion (Degrees)	Extension (Degrees)	Velocity (MPH)
Baseline	81.62	78.62	161.23	62.23	65.23
Static	84.54	72.69	153	66.92	65.15
Dynamic	85.62	73.69	155.08	63.77	65.46
Combo	87.69	81.69	158.62	66.77	64.31

Table 2 Averages of ROM positions and lacrosse shot velocities for each stretching routine

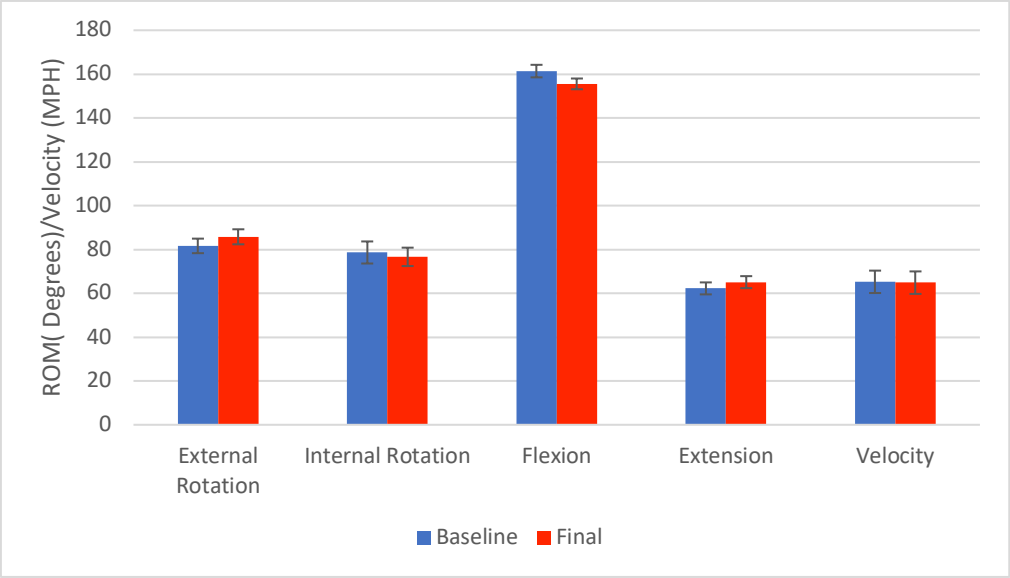


Figure 16. Comparison of ROM and Velocity for baseline and post-stretching. Standard error is used for error bars.

Baseline versus Final Measurements

There was not a large difference when the baseline measurements were compared to the end of the data collection's measurements (Figure 16). External rotation and extension increased, but internal rotation, flexion, and velocity decreased.

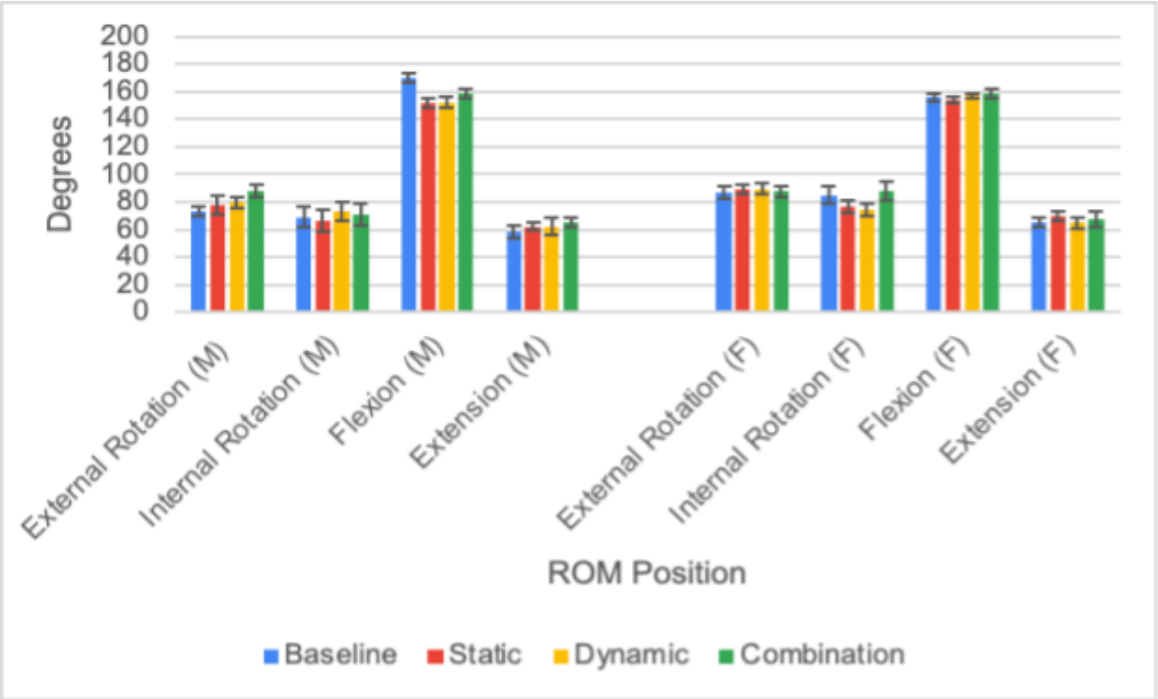


Figure 17. Comparison of ROM measurements between males (M) and females (F). Standard error is used for error bars.

In Figure 17, there is a comparison between males and females that participated in the study and it is shown how their ROM measurements differed for each stretching routine. This shows that there was a difference between male's and female's when looking at ROM because females had a higher degree of rotation.

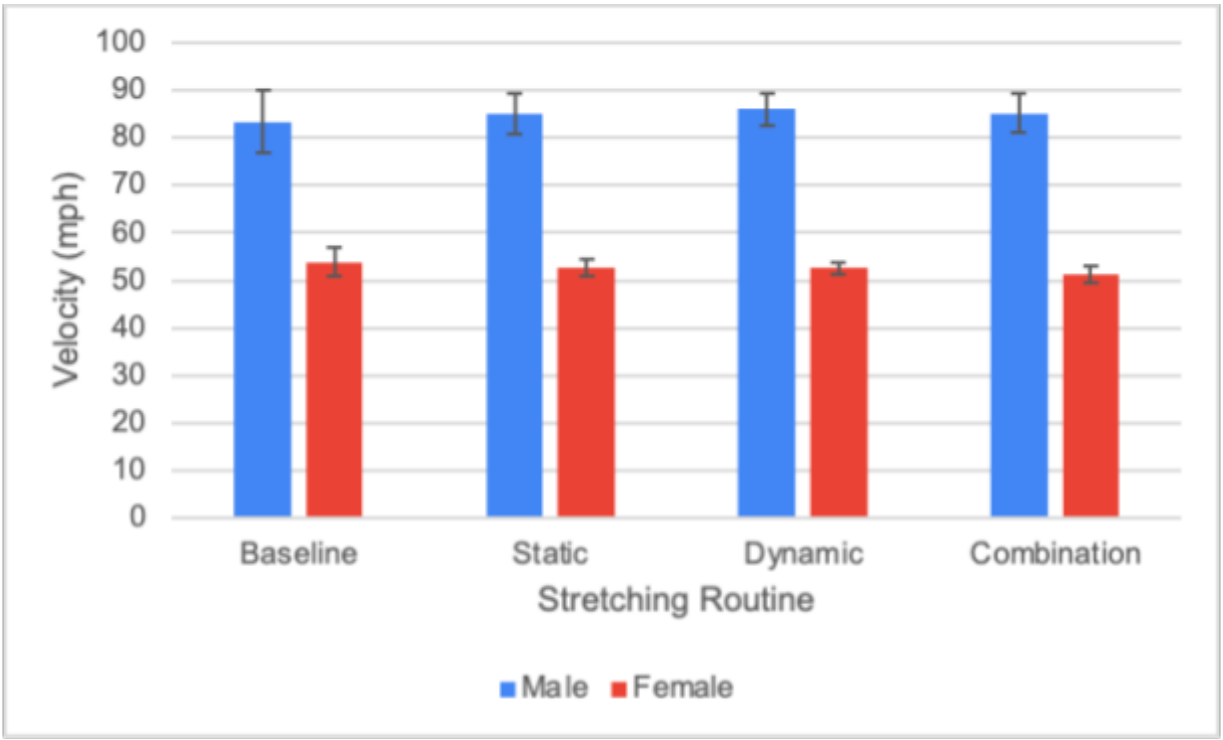


Figure 18. Comparison of average velocity of each stretching routine between males and females. Standard error is used for error bars.

There was a large difference between the lacrosse shot velocities when comparing males and females (Figure 18). Velocities for each stretching routine, respective to males and females, were relatively the same no matter the stretching routine.

Discussion

These results show that the three stretching routines had no significant effect on range of motion measurements for shoulder extension, internal and external rotation of the shoulder, or the velocity of the lacrosse shot. However, the results do show that the stretching routines had significantly different measures for range of motion of the shoulder in shoulder flexion. Specifically, the baseline measurements were much different from the measurements collected after the participants completed the static stretching routine. These findings do not support the original hypothesis that the dynamic stretching would lead to a greater range of motion in the shoulder and that the static stretching would lead to a faster lacrosse shot.

The reason why there is only one measurement that ended up being significant could have been that there is no relationship between stretching routine and more range of motion and velocity of a lacrosse shot, but this could simply be because this study was dealing with humans. Human variability was most likely responsible for these results not being significant because everyone has a different style of shooting and different body structure. I noticed that some of the participants would shoot with sidearm and some would shoot overhand (personal observation). I also noticed that the players that typically play defense had a slower shot, while those that play offense had a faster shot (personal observation). Players tend to develop their "go-to" shooting style, with their own personal flare.

The insignificance of the ROM measurements and the velocity data could have also been because there is no difference between types of stretching. Each type of stretching can achieve the same effects and it is just up to the individual to decide which type of stretching they complete. These results suggest that the type of stretching an individual chooses to do, will not affect their athletic performance or shoulder ROM. Many of the participants in this study preferred the dynamic stretching routine because they felt like they were getting a deeper stretch (personal observation). They also liked how their muscles felt like they got a break from stretching (personal observation).

The ROM results from this study add to the contradicting results from studies researching the effects of different types of stretching on range of motion. Previously,
Matsuo et al., concluded that static stretching and dynamic stretching both increase ROM and that they do not have a significant difference between the two (2019). In another study, the ankle ROM was much greater in participants that completed the static stretch than of those that completed ballistic stretching (Beedle et Mann, 2007). Bandy et al., measured knee flexion ROM

after participants completed either a dynamic stretching routine, static stretching routine or no stretching routine (1998). They concluded that dynamic and static stretching both had a significant increase in ROM from the no stretching group, but they found that static stretching led to a significantly larger knee flexion ROM when compared to the dynamic stretching routine (Bandy et al., 1998).

The results of this study are similar to those presented in research focusing on how static stretching affected baseball pitchers and their pitches velocity. This study found that the stretching had no significant effect on the velocity of the pitch (Haag et al., 2010). The insignificant results were caused by the acute static stretching not having a great enough effect on the MTU compliance of the muscles (Haag et al., 2010). These results are similar to the velocity results from my study because there was no significant difference between the velocities collected for each of the stretching routines. The same explanation for this study's results could hold for my data. The static stretching could have just not had the intended effect due to when the participant was completing it. The stretches could also just not have the effect of increasing or decreasing the velocity. Another study that had similar results to mine was looking at how cyclic and static stretching affected the spike speed of volleyball players. The researchers found that neither of the types of stretching had any effect on the spike speed (Çelik, 2017). This study put together previous research with their own to conclude that static stretching reduces strength and power production by the individual muscles (Çelik, 2017). This supports my velocity data because there was no significance to the velocities of any of the stretching routines, including the static stretching regimen.

There was no clear pattern that was consistent with all of the participants with their shooting velocities. The major difference among the participants is that five were male and eight

were female. In men's lacrosse the shooting technique is much different than women's lacrosse. Women typically shoot overhand, while men typically shoot side arm. I did see this when collecting velocity measurements from participants in my study. One study set out to find what kind of shot produced the highest velocity and found that the side arm and underhand shots had this result (Macaulay et al., 2016). This difference could have caused the raw data to come across as non-normal in JMP because there was such a difference in the velocity measurements.

Something that could have affected the results of this research is that stretching that was being done outside of the data collection. The men's team had been practicing every day for the last week of the data collection and lifting as a team three times a week for the whole data collection. The women's team had only been lifting two times a week and not practicing. This would have allowed their muscles to recover from the lifts and they would not be as sore because they were not practicing. Some of the participants would come after they had their lifting session, so they had already stretched and lifted weights. This could have caused a difference in data compared to if the participant had come in for stretching prior to the lifting session. After lifting or performing activities that increase body temperature, the laxity of the muscles increases (Mason, pers.comm). This would have increased the ROM measurements for those that had just performed physical activity prior to coming to the data collection. Another issue that this schedule caused was that the participants could have been sore from the practice the previous day. They also could have tweaked it, pinching a nerve or something that would be causing pain, just enough that it decreased their range of motion and lacrosse shot velocity.

A limitation that I came across was that there was an unequal number of males versus females, so this could have skewed the data towards what measurements for range of motion of the shoulder and velocity of lacrosse shot looks like for a female. Another limitation that occurred was that every participant used their own stick and lacrosse sticks tend to be very different from each other, especially men's versus women's lacrosse sticks. This is because the pocket in men's sticks is much deeper than that of the women's stick, which is strung tightly (Figure 17). This difference takes place because of the level of contact that men's lacrosse entails. There is more contact between players, which would cause the ball to come out of their stick without the deeper pocket (Norkin). The deeper pocket also allows for a faster shot, which was seen in the velocity data collected in this research, with males having a higher velocity (Putukian et al., 2014) (Figure 18). There are also different types of stringing aimed for specific positions in both men's and women's lacrosse. This different type of stringing includes having different levels of tautness in the shooting strings (Figure 19). Having tighter shooting strings is typically targeted for those that play offense because this type of stringing allows for a faster shot. This could have influenced the results of the shooting velocity, as those with tighter shooting strings would have a higher velocity reading, regardless of how the stretching had affected the ROM of the shoulder.



Figure 19. Comparison on Women's pocket and Men's pocket. https://www.bramptonlacrosse.ca/page/show/291168-equipment-needs

Specifically for a future Allegheny College Senior Projects, it would be beneficial to look at other upper body sports, such as tennis or basketball, and look at how different stretching routines affect their shoulder ROM, without including any velocity measurement.

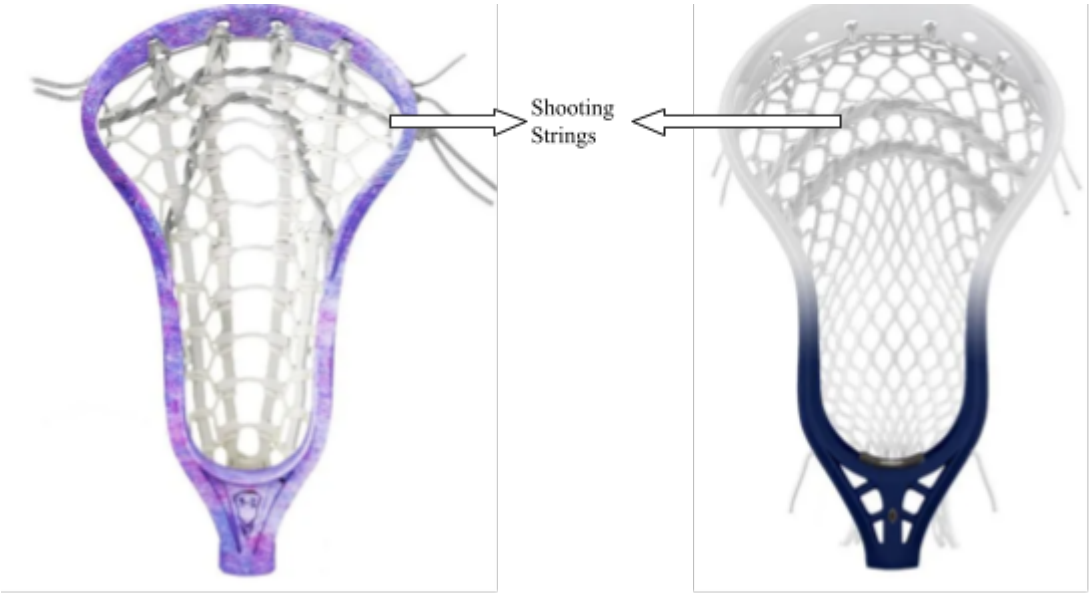


Figure 20. Men's and Women's stringing, with shooting strings labeled.
https://www.lacrosseunlimited.com/unicorn-speckle-girls-dyed-lacrosse-head.html?gclid=CjwKCAjwl6OiBhA2EiwAuUwWZSiKoUKffRkxPUqxEZtPgCBRZZj97hyGi_ZfxgkVihDdIH7yupuPIRoCq9wQAvD_BwE
https://www.lacrosseunlimited.com/colored-bottom-fade-dyed-lacrosse-head.html

For further research, I believe that it would be beneficial to look further into the differences between males and females and how they pertain to stretching. This would include the discussion of differences in how various hormones affect the stretch and how structurally there might be differences that allow for larger range of motion in a certain sex. One study of the worker population in Taiwan found that women in the study had a larger range of motion in the upper extremities when compared to the male workers (Chung & Wang, 2009). Another study accounted for the differences in hormones between males and females, so that when they were analyzing the range of motion of the ankle, they collected the women's data when they were on their period. This study found that there was increased laxity when estradiol was at its highest, during ovulation, so they collected data when the participants were all experiencing their menses, when estradiol is the lowest (Hoge et al., 2010). Specifically, to my study, this could have caused a variation among the female participants' range of motion measurements. In Figure

20, this possible explanation for variation in the data takes hold, as it was observed that the females in this study had a higher average of ROM for external and internal rotation and extension.

I would also suggest that inertial measurement sensors be used to assess the shoulder range of motion. These sensors are placed on the participant to see how their shoulder range of motion is in various positions, which could then be compared to the range of motion data that is collected using a goniometer. In studies using this technology, researchers have been unable to confirm the accuracy of these sensors in measuring the range of motion of whatever appendage was being analyzed (Rigoni et al., 2019). In 2019, researchers were analyzing the shoulder range of motion using these sensors and found that they still needed to do further research so that these sensors could be used in clinical and research settings (Rigoni et al., 2019). It would have been interesting to see if there was a difference between the goniometer reading that I collected and, if these sensors were used, what measurements they would collect.

Further research could also include looking at injured athletes and seeing how the stretching affects their range of motion. One could add in the level of pain that the participants feel during the stretching, but this would be difficult because everyone feels pain differently and describes it differently. I would predict that the participants with higher levels of pain would have a smaller ROM, while those with lower levels of pain will be able to move their shoulder more. I think that it would also be interesting to see how using manual stretching compared to a combination routine would affect the range of motion. I would predict that the manual stretching would have a larger range of motion because it allows for a deeper stretch. When someone else is pushing the participant's arm to stretch their range of motion, they will be able push them past the point the individual would do if they were stretching themselves.

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Appendix A: Shoulder Muscles and their Functions

Region	Muscle Name	Function
Anterior	Pectoralis major	- Flexion, adduction and medial rotation of the arm at the glenohumeral joint -Clavicular head causes flexion of the extended arm -Sternoclavicular head causes extension of the flexed arm (Solari et Burns., 2022)
	Pectoralis minor	Stabilizes the scapula (Baig et Bordoni, 2022)
	Subclavius Anterior	- Stabilization of the sternoclavicular joint (SCJ) - Resisting elevation of the lateral end of the clavicle (Crepaz-Elrich, 2022)
	Serratus Anterior	- Responsible for the protraction of the scapula - Acts with the upper and lower fibers of the trapezius muscle to sustain upward rotation of the scapula (Lung et al., 2022)

Posterior Extrinsic	Trapezius	Stabilizes and moves the scapula (Ourieff, 2022)
	Latissimus Dorsi	Adduct, medially rotate, and extend the arm at the glenohumeral joint (Jeno et Varacallo., 2022)
	Levator Scapulae	-Elevates the scapula -Inferiorly rotates the scapula -Assists in neck extension, ipsilateral rotation, and lateral flexion (Henry et Munakomi., 2022)
	Rhomboid Major & Minor	-Helps form the shoulder girdle -Retracts, elevates and rotates the scapula (Farrell et Kiel, 2022)
Posterior Intrinsic	Deltoid	-Assists in abducting the arm past 15 degrees - Stabilizes surrounding structures (Elzanie et Varacallo, 2022)
	Teres Major	-Extends, medially rotates and adducts the humerus - Aids in medial rotation and adduction of the humerus -Adducts the humeral head (Syros et Rizzo, 2022)
	Supraspinatus	-Abducts the humerus - Stabilizes the humerus head on the glenoid fossa during joint movements (Jeno et al., 2022)

	Infraspinatus	- Provides glenohumeral stability -Stabilizes the humeral head during shoulder abduction (Williams et al., 2022)
	Teres minor	-Stabilizes the ball-and-socket glenohumeral joint - Laterally & externally rotates the arm at the shoulder joint (Juneja et Hubbard, 2022)
	Subscapularis	-Internal rotation -Aids in adducting the humerus (Aguirre et al., 2022)

Appendix B: Recruiting Google Form

Comp Participation - Lacrosse ball shooting & stretching study

Informed Consent

Upper Body Stretching: Effects on Range of Motion and Speed of Lacrosse Shot

Allegheny College

Department of Biology

Purpose of Research: While stretching is constantly being used by athletes as a warm up, there is scientific evidence from research that has shown that it does not improve performance, decrease chance of injury, or increase flexibility (Samuel et al., 2008). Contrasting this, in another study, they found two common factors associated with exercise related musculoskeletal injury, which are "muscle stiffness and lack of ROM [range of motion]" (Small et al., 2008). Therefore, the purpose of this study is to examine the effect of different stretching methods on the range of motion in the shoulder and to see if there is any relation to the speed of a lacrosse shot.

Method/Procedure: I understand that I will be asked to complete a stretching routine every day for 12 days and will be subject to four range of motion measurements. I also understand that I will be asked to shoot a lacrosse ball, as the speed is measured.

Length of Participation: I understand that the stretching, ROM measurements, and lacrosse shot speed measurements will take approximately 12 days

Risks to the Individual: I understand that there will be risks associated with this research. I understand that in order to measure my ROM, the researcher will have to put a goniometer on my shoulder. I understand that I may get injured from performing a stretch incorrectly. I understand that when shooting a lacrosse ball I am able to injure myself if I shoot with incorrect form. I understand that new stretching techniques may cause pain or injury. I understand that the researcher will not be at fault if pain or injury occur.

Benefits of the Research: I understand that this research will help individuals learn more about how stretching routines affect the body. I understand that this research will specifically help those playing lacrosse to learn what type of stretching leads to a faster lacrosse shot.

Compensation: I understand that I may receive a $5 gift card to Dunkin's Donuts if I win the raffle my name is entered into.

Confidentiality, Recording Information, and Data Security: I understand that my name and data collected about me will be kept on a password-protected computer. I also understand that my information will only be able to be accessed by Chelsea Esser and her comp advisor, Dr. Lisa Whitenack. I understand that the results from this research will be published on D-Space.

Voluntary Nature of Participation: I understand that I do NOT have to participate in this research project. Furthermore, I may choose to withdraw my participation at any time without penalty. I understand that I may skip any individual questions that I do not wish to answer, and I may choose not to participate in any part of the study without being questioned.

Participant Typed Signature: *

Your answer

Date (MM/DD/YYYY): *

Your answer

Are you 18 or older? *

- Yes
- No

Results of Research Project: I understand that I am entitled to a copy of the results once this study is completed, which will be available on D-space. A summary will also be sent to the lacrosse coaches and participants.

Contact Information: If I have any questions about this research project, I can contact Chelsea Esser at esserc@allegheny.edu or the research advisor, Dr. Lisa Whitenack at lwhitena@allegheny.edu. If I have questions or concerns about the treatment of research participants in this IRB-approved project, I can contact the Chair of the Allegheny Institutional Review Board (IRB) at IRB@allegheny.edu.

I understand that my signature(s) below indicate(s) that I am at least 18 years of age at the time of my participation in this study, and that I have received a copy of this informed consent form. I have carefully read and understood the information on this form and all of my questions thus far have been answered.

Study screening section

Please fill out these questions to the best of your ability. All answers to this survey are confidential and are used for screening purposes only.

Have you ever had a shoulder injury that you went to see a physician for?

- Yes
- No

Have you ever had shoulder surgery?

- Yes
- No

Are you on the men's or women's team?

- Men's
- Women's