Effect of Weight in the Non-Throwing Hand on the Baseball Pitching Motion

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Abstract

Baseball is a sport which includes various sequential motions that utilize the entire kinetic chain. When considering the baseball pitching motion, the sports medicine community often refers to the kinetic chain as the lower extremity, pelvis, torso, pitching arm shoulder, and pitching arm elbow while neglecting the glove arm. The limited research analyzing the glove arm's influence in the pitching motion has not examined the weight of the glove on various aspects of the pitching motion to the author's knowledge. The purpose of this research was to examine the effect that weight in the glove hand has on upper extremity and lumbopelvic-hip complex muscle activation; glove arm, trunk, and pitching arm kinematics; and pitching arm kinetics during the baseball pitch. Nineteen participants (17.88 ± 2.05 yrs.; 184.73 ± 5.65 cm; 82.06 ± 14.18 kg) fell within the inclusion criteria including possession of a stable lumbopelvic-hip complex as deemed by the Closed Kinetic Chain Upper Extremity Stability Test and the Single-leg Squat. Once participants were game ready, the following four conditions were randomized: no glove, normal glove, 0.68 kg. training glove, 1.36 kg. training glove. Data were collected on three fastballs per condition pitched at regulation distance (18.4 m) with the fastest fastball for each condition used for analysis. Results revealed that glove weight significantly impacts glove arm elbow flexion during the pitching motion. Specifically, more glove arm elbow flexion was seen at foot contact and ball release as well as during arm cocking and arm acceleration per heavier glove. Also, significance was seen with glove condition affecting maximal segmental angular velocity magnitude of the pelvis, trunk, humerus, and forearm. These findings shed light on the impact glove weight has on the pitching motion. Future research should examine a wider participant group, including various ages and stability levels, to build on these findings.

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CHAPTER I

INTRODUCTION

Despite widespread claims that the popularity of baseball is in fading,[1–3] baseball continues to be one of the most participated team sports in America. The sport of baseball has long been coined as "America's Pastime" and appears to be holding steady, if not increasing in participation numbers.[4] In the realm of high school participation, baseball is the third most participated boys program and has the fourth most participants of all sports in our country at 487,097.[5] In addition to the participation seen in America, the Little League Baseball Organization has leagues for players 4 – 16 years of age, that include over 2.4 million participants in over 80 different countries.[6]

While the participation in the sport of baseball is not in question, the increasing numbers of shoulder and elbow injuries requiring surgery are a cause for concern. In a recent epidemiology study among high school baseball players, the overall shoulder injury rate was 1.39 per 10,000 athletic exposures while the overall elbow injury rate was 0.89 per 10,000 athletic exposures.[7] Specifically, when examining the baseball injuries within the National Collegiate Athletic Association, ulnar collateral ligament (UCL) injury was determined to occur 1.12 per 10,000 athletic exposures.[8] Additionally, when examining the same population, researchers found that underclassmen had significantly more UCL surgery compared to upperclassman.[9] With the higher incidence of UCL surgeries among younger baseball athletes and the overall increase in injuries of the UCL in need of surgical repair, the baseball community should be alarmed.[10–12]

In addition to surgical repair of the UCL, baseball pitchers are at risk for many injuries including superior labral tear from anterior to posterior (SLAP) lesions, shoulder and elbow tendonitis, rotator cuff tears, stress fractures, and ulnar or cutaneous nerve injuries.[13] Many of the documented injuries among baseball pitchers occur due to cumulative microtrauma at the pitching shoulder and elbow across many games and seasons rather than acute damage that occurs on one specific pitch.[14] The repetitive nature of the dynamic pitching motion potentially results in muscle imbalances throughout the body that lead to injury.[15,16] In a cross-sectional study examining various ages, Fleisig and colleagues suggested that baseball pitchers should learn proper mechanics at an early age in order to reduce the likelihood of injury as they develop.[17] Proper mechanics for sport of baseball consists of dynamic sequential activities for hitting and throwing which involve the entire kinetic chain. When the kinetic chain is not efficient, energy is lost from the larger, proximal muscles in the kinetic chain leaving the smaller, distal muscles to compensate.[18]

In general, throwing a baseball is a movement that utilizes the summation of speed principle, which states one segment's rotational velocity will not begin until the previous segment has reached its maximal rotational velocity.[19,20] In this principle, proximal segment motion should be examined first because it precedes the distal segment. However, external load introduced to the kinetic chain impacts the inertia of the distal joint, thus altering the external forces upon the upper extremity.[21,22] When examining the pitching motion there are two external forces to consider that perturb the upper extremity kinetic chain. According to Newton's third law, both the ball and glove reaction forces would oppose the force placed on the ball and glove by the hand.[21] First to consider is the baseball reaction force, which is varied by acceleration because the baseball carries a constant mass of five ounces across all leagues. The second external force to consider is the glove reaction force. While research has been conducted on the effect of ball mass on pitching kinematics,[23–25] the extent to which the glove mass and subsequent glove reaction force impacts the efficiency of the segmental sequencing in the kinetic chain during a baseball pitch is unknown. In theory, a more efficient kinetic chain throughout the baseball pitch lessens the joint loads on the pitching shoulder and elbow. Therefore, injury susceptibility of the pitcher is reduced.

Previous studies have examined various kinematics and kinetics during a baseball pitch to determine those associated with and potentially leading to injury.[14,26–31] Kinematics in the pitching motion thought to result in potential injury include stride knee flexion, early torso rotation, shoulder range of motion, upper arm elevation, and elbow flexion.[31] Furthermore, the timing of torso rotation has been linked to injury, which implies that proper segmental sequencing is important for the pitching motion. Thus, if torso rotation is not optimally timed during the pitching motion, an inefficient transmission of energy occurs across the kinetic chain. Additionally, the influence glove arm kinematics have on torso kinematics has been examined.[32] An unused glove arm was found to result in less torso twisting occurring throughout the acceleration phase of the pitching motion.[32] However, the glove arm is an often excluded portion of the kinetic chain during a baseball pitch and further investigation into the effects of glove arm kinematics on kinetic chain efficiency during the pitching motion is warranted.

Of the research performed on glove arm kinematics, the torso has been deemed to be a link between the glove and pitching arms.[33] Due to this relationship between upper arms and torso, the glove arm has been determined to have an effect on the torso moment of inertia and various torso kinematics.[32,33] In addition to the relationship between glove arm and torso kinematics, previous research has determined that a relationship between glove arm kinematics and pitching shoulder and elbow joint loads exist.[33] However, the effect that external load in the glove hand, usually differing by glove type, has on kinetic chain efficiency during the baseball pitching motion has yet to be examined.

Purpose

The purpose of this research was to examine the effect that weight in the glove hand has on upper extremity and LPHC muscle activation; glove arm, trunk, and pitching arm kinematics; and pitching arm kinetics during the baseball pitch.

Research Questions

RQ1) Does the amount of weight in the glove hand during a fastball baseball pitch alter the following glove arm kinematics: glove arm elbow flexion, glove arm shoulder horizontal abduction, and glove arm shoulder flexion?

RQ2) Does the weight in the glove hand during a fastball baseball pitch alter the following trunk kinematics: trunk flexion, trunk lateral flexion, and trunk axial rotation?

RQ3) Does the weight in the glove hand during a fastball baseball pitch alter the following pitching shoulder and elbow joint loads: elbow varus/valgus moment, elbow distraction/compression force, resultant elbow moment magnitude, shoulder internal/external rotation moment, shoulder anterior/posterior force, shoulder compression/distraction force, shoulder horizontal ad/abduction moment, and resultant shoulder moment magnitude?

RQ4) Does the weight in the glove hand during a fastball baseball pitch alter overall magnitude and segmental sequencing of the maximal angular velocities and accelerations of the following segments: pelvis, trunk, pitching arm humerus, and pitching arm forearm?

RQ5) Does the amount of weight in the glove hand during a fastball baseball pitch alter the muscle activation peak magnitude and timing to peak magnitude during the pitching motion for the following muscles: glove side latissimus dorsi, throwing side gluteus maximus, throwing side gluteus medius, throwing side lower trapezius, bilateral serratus anterior, and bilateral external oblique?

Hypotheses

H_1) As the weight in the glove hand increases among participants, increased glove arm shoulder flexion, increased glove arm shoulder horizontal abduction, and increased glove arm elbow extension will be observed at foot contact and during arm cocking, while increased glove arm shoulder extension, increased glove arm shoulder horizontal adduction, and increased glove arm elbow flexion will be observed during arm acceleration and at ball release.

H_2) As the weight in the glove hand increases among participants, all trunk kinematics (trunk flexion, trunk lateral flexion, and trunk axial rotation) at foot contact, arm acceleration, and ball release of the pitching motion will be closer to their anatomical neutral position when compared to lighter weight conditions.

H_3) As the weight in the glove hand increases among participants, decreased elbow varus/valgus moment, elbow distraction/compression force, elbow moment magnitude, shoulder internal/external rotation moment, shoulder anterior/posterior force, shoulder compression/distraction force, shoulder horizontal ad/abduction moment, and shoulder moment magnitude will be observed at each event and phase of the pitching motion.

H_4) As the weight in the glove hand increases among participants, segmental velocities and accelerations of the pelvis, trunk, humerus, and forearm will increase and timing between maximal segmental velocities and accelerations will occur in a proximal to distal sequence with more time in between subsequent segment maximums.

H_5) As the weight in the glove hand increases among participants, the timing of peak activation of the latissimus dorsi, lower trapezius, and serratus anterior will occur sooner while the gluteus maximus, gluteus medius, and external oblique peak contraction will occur later in the pitching motion. Additionally, as the weight in the glove hand increases, the latissimus dorsi, gluteus maximus, gluteus medius, and external oblique will display an increase in muscle activation, while the lower trapezius and serratus anterior will display a decrease in muscle activation.

Limitations

Limitations to this study include:

1. Age range (15-22)
2. Variability in normal glove weight
3. Variability in pitch effort
4. Variability in manual muscle test effort

Delimitations

Delimitations to this study include:

1. All data collections will be executed in a controlled laboratory setting located in the Sports Medicine & Movement Laboratory on the campus of Auburn University.
2. Groups of external loads in the glove hand will include the following: no weight, normal glove, 0.68 kg, and 1.36 kg.
3. Conditions altered weight in the glove hand instead of glove weight.
4. LPHC stability will be determined by using both SLS and Davies test.
5. Kinetics will be determined using inverse dynamics.

Definitions

Kinematics: Area of study that examines the spatial and temporal components of motion (position, velocity, and acceleration).[34]

Kinetics: Study of the forces that act on a system.[34]

Glove Arm: Non-throwing arm of a pitcher.

Glove Hand External Load: Mass of the glove or other external load such as a weight worn on the non-throwing hand.

Muscular Torque: Represents the sum of torque generated by contractile elements surrounding a joint[35] that act to accelerate the corresponding joint, and in some cases, induce accelerations in non-corresponding joints as well.[19]

Summation of Speed: states the body moves in a proximal to distal fashion where the more distal segment will reach a greater maximum velocity than that of its most adjacent, proximal segment.[20]

Proximal to Distal Sequencing: achieving maximal speed of a distal segment occurs following that of the proximal segment. The distal segment starts accelerating at the instant of maximal segmental velocity of its proximal segment. When the distal segment reaches peak acceleration, the proximal segment is at a minimum.[19]

Lumbopelvic-hip Complex (LPHC): encompasses the spine, torso, hips, pelvis, proximal lower limbs, and all the associated musculature.[36]

CHAPTER II

REVIEW OF LITERATURE

The purpose of this research was to examine the effect of an external load in the glove hand on upper extremity and lumbopelvic hip complex (LPHC) muscle activation; glove arm, trunk, and pitching arm kinematics; and pitching arm kinetics during the baseball pitch. The following chapter presents relevant literature that explains key components and provides background for this study. Furthermore, this chapter is divided into the following sections: lumbopelvic hip complex stability, lumbopelvic hip complex and pitching/throwing, pitching/throwing injuries, glove arm and pitching, and pitching motion muscle recruitment.

Lumbopelvic Hip Complex Stability

The LPHC includes all musculature connecting the abdomen, proximal lower extremity, pelvis, trunk, and spine.[37] Multiple studies have defined LPHC stability as a person's ability to stabilize the spine and maintain postural control throughout movement.[36,38] Other researchers defined lumbopelvic control as a person's ability to mobilize or stabilize the LPHC in response to internal and external forces acting on their body.[39] LPHC stability is important to all athletes because the body works as a kinetic chain and needs to employ proximal stability for distal mobility.[36] For motions that are considered sequential, force is developed from the ground and transmitted to the most distal extremity. Proximal to distal force development, which is prominent in various sports movements,[36] is built upon the summation of speed principle which states that achieving maximal speed of a distal segment occurs when the distal segment starts accelerating at the instant of maximal segmental velocity of its proximal segment.[19,20] Properly performed sequential sports movements will execute an efficient transmission of energy from proximal to distal segments of the kinetic chain utilizing the summation of speed principle.

When examining specific exercises, coaches and trainers will want athletes to achieve movement efficiency, which is conveyed by demonstrating an efficient kinetic chain. Movement efficiency, through appropriate sequential segmental movement, is created by having a proximal stability which allows for distal mobility. The use of stabilization exercises, which have been defined as any exercise that fosters specific motor patterns to promote stabilization,[40] would aid in promoting and assessing a stable LPHC. Exercises such as the single-leg squat (SLS) and the closed-kinetic chain upper extremity stability (Davies) test are able to test an athlete's LPHC stability.

Single-leg Squat

The Single-leg Squat (SLS) is a movement used as a dynamic assessment of flexibility, LPHC strength, balance, and neuromuscular control.[41] For the SLS assessment, the athlete assumes proper posture with one foot pointed straight ahead and the lower extremity in neutral position. Then the athlete squats to a comfortable level without supporting the non-weight bearing leg with the stance leg or the ground, and returns to the starting position.[41]

The SLS has been a popular assessment, in examining anterior cruciate ligament (ACL) injury susceptibility, for its ability to monitor LPHC control.[42] However, additional connection between hip muscle strength and frontal plane knee motion displayed in the SLS has also been established.[43] The SLS has been used often as a screening tool for dynamic LPHC control and lower extremity kinematics.[44] A dynamic movement such as the SLS allows for coaches and trainers to assess an athlete's weak link and discover the key to preventing injury and improving performance.[45] Poor mechanics during the SLS, such as excessive knee valgus or torso compensations, give a practitioner reason for further examination into hip strength and LPHC control.[45] In addition to the ability of the SLS to be used as a screening tool or a means to detect injury susceptibility, previous research has demonstrated a link between SLS kinematics and pain.[46] In an examination of SLS performance in individuals with and without knee pain, it was found that those with pain were more likely to have greater ipsilateral trunk lean, contralateral pelvic drop, hip adduction, and knee abduction.[46] With the known importance of LPHC stability and injury prevention, the SLS is a valid assessment for clinicians and coaches to monitor LPHC stability and movement compensations.

Due to the ease of assessment in the clinical as well as athletic communities, the SLS has become one of the more popular assessments of choice. Additionally, the SLS has been deemed a valid and reliable test to assess hip muscle function and dynamic knee valgus.[43,47] Assessing different compensations observed in the SLS will help clinicians determine appropriate treatment options. Though the SLS has been reported as a valid assessment tool in differing populations, it should be noted that chronological age is a factor to keep in mind when observing the SLS performance. In a study observing SLS kinematic differences between adolescents, Agresta and colleagues determined age to be a significant predictor of SLS performance.[48] As expected, younger children achieved lower SLS performance scores. While the study showed SLS performance improvements between the ages of 8 to 17, the authors suggested that comparison of SLS scores across ages should be done cautiously because an underlying biological condition affecting the SLS scores may exist. The biggest jump in SLS performance improvement was seen between the ages of 13 and 14. Other research has determined that physically active individuals are more likely to perform a good SLS versus inactive individuals.[49] Both of these studies adhere to the expectation that a worse SLS squat would be observed in a population with less LPHC control.

In order to predict injury or performance through movement assessments, specificity in kinematics analyzed during an assessment, such as the SLS, is needed. Specifically analyzing SLS kinematics and injury potential, a larger frontal plane knee projection angle was found to be linked with an elevated risk of lower extremity injuries in sport; although the authors concluded that the SLS was not specific enough to identify future injury.[50] In a recent analysis of LPHC stability using the SLS,.[51] LPHC stability was determined via the amount of SLS knee valgus at 45 degrees of knee flexion on the descent. While the authors found LPHC stability to have no effect on segmental sequencing or segmental velocities in softball players, they suggested that a multi-variable classification system of the SLS be used for assigning unstable versus stable LPHC.[51] An additional kinematic variable, trunk lean during the SLS, has also been suggested as a means of classifying LPHC stability. Plummer and colleagues found a correlation between trunk lean at 45 degrees of knee flexion in the SLS and trunk lean observed in baseball pitching, and suggested that LPHC muscle performance deficits may be causing the increased trunk lean observed during both the SLS as the baseball pitch.[52] As evident from all the aforementioned SLS literature, one can conclude that the SLS is a good measure of LPHC stability because it indicates an individual's neuromuscular control and strength of their trunk and lower extremity musculature.

Davies Test

The Davies test, also known as the closed kinetic chain upper extremity stability test, is another test commonly used to examine LPHC stability. The Davies test can be used to directly assess the upper regions, spine and trunk, of the LPHC. Because all segments are interdependent in a kinetic chain, the Davies test was created as a way to assess upper extremity stability during a closed chain exercise.[53] To perform the Davies test, an individual must assume a push-up position with hands placed three feet apart with no regard to individual anthropometrics.[54] Two pieces of tape are placed three feet apart on the ground to represent the starting position for the hands. Instructions for the Davies test have the individual touch their opposite hand in alternate fashion while keeping one hand fixed on a piece of tape trying to accumulate as many touches as possible in 15 seconds.[54] The participant performs a total of three sets with a 45 second rest between sets.[54] With each touch counted, the total number of touches is tallied and averaged for the score.[53,54] Original design of the Davies test had males assume a push-up position and females assume a modified push-up position with their knees on the ground and hands placed 36 inches apart.[53] However, the hand placement distance has been brought into question. In a study looking into the effect of the set-up position, the original set-up was determined to be best with the hands placed three feet apart.[55] Upon examination of the difference in the demands of the two gender specific set-up positions, Tucci and colleagues determined that 65% of body weight or 24% of body weight could be placed on the upper extremity based on starting position.[55] Males that assume a push-up position at the start of the Davies test were found to place a majority of their body weight on their upper extremity. Whereas females that assumed a modified push-up position with their knees on the ground placed only one fourth of their body weight on their upper extremity. For an examination of upper extremity stability among male baseball players, the set-up position placing a majority of body weight on the upper extremity would be valuable. The Davies test has been determined to be a clinically beneficial test to assess upper extremity function and stability.[56,57] Additionally, previous research examining the Davies test has determined it to be a reliable test.[57,58,59,60]

However, when reporting average values of Davies test scores, differences are apparent.[54,56,61–64] In a study that examined a group of baseball players, the average score was determined to be 30.41.[56] Examining participants in a variety of sports, Audenaert et al. reported scores between 25.1 and 28.06[62], whereas Pontillo and colleagues examined both males and females across sports with the average being 21.8 with the highest female (gymnast) score of 27.6 and the highest male (baseball) score of 27.9.[63] While these studies attempted to set a baseline of performance for the Davies test, only 2 studies have examined gender differences.[49, 59] Interestingly, both studies reported different results.[54,64] When examining the cause for gender differences in Davies test scores seen in the literature, Borms et al. determined the different scores between studies were a result of the starting position.[61] One study had females assume the modified start,[54] while the other study had females assume a push-up position, therefore different scores were recorded.[64] True normative values for the Davies test have yet to be repeated and established among athletes across various sports.

Based on the aforementioned reliability studies of the Davies test, utilization of this test could serve to determine readiness to return to activity for a specific individual by comparing pre and post values.[60] In an effort to determine what change in individual scores of the Davies test could be considered an improvement, one study concluded that males and females needed to see a change of at least 3 touches.[58] In another study that examined the relationship between the Davies test and injury prediction, Davies score cut-off was set at

21.[65] Authors concluded that players who scored less than the cut-off were more likely to get injured when compared to players who scored higher than 21.[65] Specifically, they determined that athletes below the cut-off were 18 times more likely to suffer a shoulder injury.[65] The increase in injury odds ratio seen in Davies test scores below 21 indicate that the Davies test may be considered for more than return to play readiness. Pontillo and colleagues concluded that the Davies test assesses both muscle capacity and neuromuscular efficiency of the upper extremity.[65] While the Davies test may be applicable to assess injury risk,[65] there are gaps in the literature regarding level of athleticism and sport involvement on Davies test performance.[64] These two discrepancies between groups indicate that there is a disparity in muscle capacity and neuromuscular efficiency of the upper extremity between sports and active individuals. However, based on proximal stability for distal mobility,[36] the Davies test could be a method to assess LPHC stability. In order to achieve more touches in the Davies test, an athlete needs to be able to stabilize their LPHC throughout the assessment.

There have been no known studies relating pitching or throwing kinematics with Davies test performance. When attempting to identify LPHC stability among baseball pitchers, having multiple assessments will provide a well-rounded picture into the athlete’s LPHC strength and stability. The SLS serves as a good overall lower extremity assessment. While the Davies test serves as a good upper extremity stability assessment. Both serve as assessments used to identify LPHC stability based on the need of proximal stability for distal mobility. By choosing a test that serves the lower extremity and a separate test that serves the upper extremity, a more robust understanding of the athlete's LPHC stability level can be determined.

Lumbopelvic Hip Complex and Pitching/Throwing

Overhead activities such as pitching and throwing require the entire kinetic chain operating in agreement with the summation of speed principle.[19,20] In accordance with this principle, the body moves in a proximal to distal fashion where the speed at the distal end begins when the preceding proximal segment reaches its maximum speed.[19,20] Previous research in youth overhead athletes has found a strong association between upper extremity pain and pain in the trunk and lower extremities.[66] This association between upper and lower extremities indicates that the body behaves as an interconnected unit during baseball pitching. In a study examining professional baseball pitchers, participants with poor LPHC control were more likely to miss a month of the season due to injury.[39] Additionally, when contrasting high velocity with low velocity pitchers, Kageyama and colleagues concluded that hard throwing pitchers are better able to use their lower extremity to increase the trunk rotation and flexion, which assist in creating greater inertial forces, that lead to increased ball velocity.[67] Therefore, enhanced LPHC control appears to allow pitchers to stay healthier and perform at higher levels.

The LPHC serves as the connection between the upper and lower extremities during sequential motion such as a baseball pitch. In an analysis of the baseball pitching motion, researchers determined that pelvic rotation occurring too early, manifested by the amount of pelvic rotation at stride foot contact, set an unfavorable kinetic chain sequence into effect. This unfavorable sequence was evidenced by increased trunk tilt and decreased hip flexion occurring throughout the pitching motion.[68] In order to increase performance and potentially decrease injury risk, a pitcher should seek to maximize the amount of momentum gathered at the trunk by properly timing pelvis rotation, upper torso rotation, and the arm movement pattern.[69] In a study examining the association of pelvic and torso rotation with a performance variable such as ball velocity, maximum pelvis and torso rotational velocity separation has been determined to have a positive relationship with ball velocity.[70] While optimal segmental sequencing appears beneficial for efficient energy transfer through the kinetic chain in the pitching motion, variability within individual pitching mechanics such as pelvis or upper torso kinematics and rotational velocity timing was considered an issue to be addressed among research inquiring about pelvis and upper torso kinematics.[69]

When examining the timing of peak trunk segmental velocity variability between pitchers, Urbin and colleagues defined a more skillful throwing motion as having greater trunk musculature involvement.[71] It was determined that properly timed trunk rotational velocity resulted in greater LPHC and trunk muscle activation during the throwing motion and thus, greater kinetic energy transferred up the kinetic chain to the upper extremity.[71] The authors argued that stability in the upper torso and shoulder joint rotations led to an increase in kinetic energy in the upper extremity through the conservation of momentum.[71]

These conclusions agree with other research, which determined that less developed throwers show more variability in the timing of distal joint lag.[72,73]

In order to produce increased LPHC stability, pitchers need to have appropriate activation of the LPHC musculature, which can only be induced by proper training. A stable LPHC will assist in producing this well-timed motion.[74] To effectively achieve maximal ball velocity, a pitcher should undergo sequential motion within the kinetic chain, promoting proximal stability for distal mobility.[36] When comparing the kinematics and kinetics of high school and professional baseball pitchers, Luera and colleagues suggested that momentum traveling up the kinetic chain may limit the valgus torque placed on the ulnar collateral ligament.[75] While many coaches and players emphasize improving pitch velocities to help the player reach the next level, this study suggests that attention should be placed elsewhere. Based on the differences seen between the high school and professional pitchers, Luera et al. suggested that coaches should focus on improving rotational kinematics and overall kinetic chain efficiency.[75] In agreement with the study conducted by Urbin and colleagues,[71] LPHC strengthening is suggested to improve a baseball pitcher's rotational sequencing by improving the ability to stabilize the LPHC. However, examining an athlete's LPHC stability relationship with segmental sequencing of a sequential throwing motion has proven unsuccessful[51]. Because of the suggested relationship of LPHC stability and rotational sequencing found in previous studies, the authors concluded that the model used to identify LPHC stability was too simplistic.[51] The authors determined LPHC stability based only on knee valgus in a SLS and suggested future research consider a multi-variable model to determine LPHC stability. Suggested variables to be included in the multi-variable model include but are not limited to knee valgus and trunk lean seen in the SLS.[51] Other research has concluded that athletes who appear unable to use the entire kinetic chain efficiently have lower ball velocity and segmental angular velocities.[36,76,51,77,78]

In baseball pitching, the utilization of an efficient kinetic chain requires LPHC stability throughout the throwing motion. Regarding the link between pelvis and torso during the baseball pitching motion, previous work has found that gluteal activation is needed throughout the baseball pitching motion to limit variability in the pelvic motion.[79] Further examination into optimal muscle activation caused Chowdhary et al. to build a simulation model for the overarm throw. Authors concluded that the simple timing of muscle activation does not correctly describe the patterns of muscle recruitment which can produce optimal throws.[80] Authors suggested that optimal muscle activation strategies varied with the mass of the projectile, anthropometrics, and muscle characteristics of the subjects.[80]

Examining the effect upper trunk rotation has on shoulder joint torque using a laboratory setup, Aguinaldo et al. concluded that a specific pattern in throwing should be utilized to promote a more efficient pitch, thus allowing the pitcher to increase performance and decrease the chance of injury.[81] In order for the most efficient segmental rotation pattern to occur during a pitch, the pitcher needs the ability to stabilize their proximal segments while attempting to accelerate the more distal components of the kinetic chain. For an efficient kinetic chain during the overarm throw, the pelvis should remain stable to allow the trunk to efficiently rotate and transfer kinetic energy to the upper extremity, thus describing a need for LPHC stability.[36,82] Additionally, a relationship between decreased LPHC stability and increased shoulder dysfunction among pitchers has been established.[83] While discussing the importance of this relationship, authors concluded that LPHC strengthening was necessary for pitchers, especially those returning from injury.[83] Following examination of pitchers at the collegiate level, appropriate LPHC musculature strength levels, such as that of the gluteus maximus, are considered integral to LPHC control among baseball pitchers.[84]

Proper transfer of momentum, seen through correct sequencing of muscle activations and segmental rotations, would require less muscle activation from the distal segments to produce ball velocity.[81] Previously, authors have suggested that compensations seen in trunk kinematics to maintain energy transfer, such as contralateral trunk lean, may contribute to upper extremity injury rates seen in baseball pitchers.[52] When examining differences between overhand, three-quarter, and sidearm pitchers, researchers found contralateral trunk tilt to be greater for the overhand group compared to the sidearm pitching group.[85] Excessive contralateral trunk lean has been suggested to be associated with an imbalance between oblique muscles acquired from repetitive pitching. Also, excessive contralateral trunk lean can be seen in individuals who cannot produce necessary trunk rotation due to musculature limitations on their

LPHC.[86,87] Oyama et al. suggested an emphasis be placed on strengthening the LPHC in order to prevent excessive contralateral trunk lean seen in a baseball pitch.[87] Since the pelvis and torso contribute approximately half of the kinetic energy during a throw, attention should be placed on strengthening the LPHC during training.[88] Trunk muscular control has been determined to be a fundamental component to high velocity for a baseball pitch.[89] Looking into handball, researchers found throwing mechanics were affected by LPHC instability, causing energy to be lost throughout the kinetic chain.[78]

Any disturbance in the proximal segments of the kinetic chain during a baseball throw, i.e. LPHC, has been suggested to affect pitching arm shoulder and elbow pain.[66,90] Further examination into the LPHC control and pitching shoulder and elbow kinetics has determined that decreased LPHC control results in increased pitching shoulder and elbow joint load, specifically increased shoulder horizontal abduction torque and elbow valgus torque.[91] Proper timing and coordination of segmental sequencing seen in the LPHC will allow for adequate energy to transfer to the upper extremity during a baseball pitch.[79]

Due to the LPHC vital role in connecting the lower and upper extremity during the sequential motion of a baseball pitch, proper strengthening of LPHC musculature should be encouraged. Without proper LPHC strength, energy will be lost from of the kinetic chain and proper segmental sequencing will be disrupted. However, if a pitcher can attain proper segmental sequencing, performance appears to increase, and injury appears to decrease. Upon review, a baseball pitcher’s ability to stabilize the LPHC should serve to indicate whether proper segmental sequencing will be utilized in the baseball pitching motion. Therefore, to assess the effect that weight in the glove hand has on proper segmental sequencing, only pitchers with a stable LPHC will be included in this study.

Pitching/Throwing Injuries

In the game of baseball, upper extremity injuries are prevalent among all players. In an examination of shoulder and elbow injuries among high school baseball players across a 10-year span, the overall injury rate for the shoulder was found to be higher compared to the elbow. Shoulder injuries occurred at 1.39 injuries per 10,000 athletic exposures compared to 0.86 elbow injuries per 10,000 athletic exposures.[7] It was also found that competition injury rate was higher than the practice injury rate, which led the authors to conclude that increasing the level of play increases injury risk due to a number of reasons, including increased forces acting on the shoulder and elbow.[7] Another epidemiological study of elbow injuries done across high school baseball and softball players across the 2014-2015 school year found similar results with elbow injuries occurring at a rate of 0.92 injuries per 10,000 athletic exposures.[92] Baseball pitchers are susceptible to overuse injuries with all of the practices and games that occur during the season. When examining injury prevalence, ball velocity has been found to be an underlying covariate among all injury occurrences. However, it should be noted that those pitchers who throw at higher ball velocities are also more likely to pitch more.[93]

To achieve maximum ball velocity in a baseball pitch, a pitcher should use the entire kinetic chain, producing energy from the lower extremity, transferring it through the LPHC to the upper extremity. Previously, it has been concluded that an imbalance in strength, flexibility, endurance, or stability at any point of the kinetic chain could affect pitching shoulder and elbow injuries.[90] Additionally, reiterating the influence of the kinetic chain during a baseball pitch, Sekiguchi and colleagues revealed that pain in the lower extremities and trunk have a connection to pain in the pitching shoulder and elbow.[66] Thus, it was concluded that the trunk had a stronger connection to pitching shoulder and elbow injuries than previously believed.[66] Therefore, manipulation of trunk kinematics may serve as a way to prevent pitching shoulder and elbow injuries. In a study analyzing the effect of various segmental rotational kinematics with elbow varus torque, authors determined that optimal timing of pelvis and torso rotation are essential to pitchers because of their influence on preserving momentum up the kinetic chain.[75] Inability to maintain a stable LPHC, indicated by muscle weakness or ROM loss across the season, throughout the pitching motion has been linked to injury risk.[94,95]

While muscle imbalance is viewed as a source of injury susceptibility among clinicians, coaches and scouts also look into body positions during games to determine future performance and injury likelihoods. In the baseball world, reaching certain positions with both arms during the pitching motion, such as the inverted W, which is defined as hyperabduction combined with internal rotation of the pitching and glove arm shoulder,[96] has been thought to increase injury risk.

However, Douoguih et al. determined that it was not the inverted W that was associated with increased injury, it was early trunk rotation which significantly increased a pitchers rate of injury.[96] This indicates that increased injury is associated with improper rotational kinematics instead of upper arm position.

Examining upper extremity biomechanics in youth and adolescent pitchers, authors proposed that the most efficient energy transfer through the kinetic chain depended on the correct timing and sequencing of segmental movements as much as the actual quality of movement itself.[97] It was thus concluded that better pitching mechanics may help prevent shoulder and elbow injuries.[97] Within sports medicine research that focuses on biomechanics, some researchers believe that increased kinetics cannot be directly linked to increased injury.[17,28] However, knowledge of functional anatomy and mechanics can allow educated decisions to be made about injury cause.[98] Additionally, this anatomical and mechanical knowledge allows for improved preventive and rehabilitative protocols for baseball pitchers to be executed.[99] Although high joint loads may lead to pitching shoulder and elbow injury, increases in certain shoulder and elbow kinetics are necessary to resist joint distraction force of the pitching arm shoulder and elbow during the pitching motion.[100] In order to improve the pitching shoulder and elbow joint loads that are necessary for an efficient pitching motion, improving the strength of LPHC musculature should be considered. For the pitching motion to conserve momentum through the kinetic chain and hopefully decrease joint loads, importance should be placed in strengthening the LPHC musculature.[100] Aguinaldo and colleagues have produced two studies that demonstrate that late trunk rotation, which has been deemed appropriate timing of segmental rotation, helps produce lower pitching shoulder rotational torque and elbow valgus torque.[81,101]

In a study examining the relationship between joint loads and injury, Anz and colleagues determined that increased levels of shoulder and elbow torque on the pitching arm can lead to injury. Upon concluding their study, they suggest that improved knowledge of pitching mechanics among coaches and clinicians can help prevent injury amongst players.[26] The authors acknowledged the importance of torso rotation to help transfer the momentum generated by the lower extremity to the upper extremity and cause an efficient pitching delivery.[26] In order to conserve energy throughout the kinetic chain, a pitching motion needs to operate in accordance with the necessity for proximal stability to achieve distal mobility. Failure to maintain a stable LPHC during the pitching motion will cause the youth to generate more ball velocity from smaller musculature surrounding the shoulder.[30] In a study observing youth and professional athletes, youth baseball pitchers were found to experience significantly large anterior shoulder forces and pitching shoulder internal rotation torques when pitching.[102] Takagi and colleagues suggested that increased pitching shoulder horizontal abduction at shoulder maximal external rotation causes increased anterior shear force on the pitching shoulder.[103] In a study examining the relationship between torque and elbow injury in baseball pitchers, authors determined that the high levels of energy generated during a baseball pitch, such as shoulder external rotation torque and elbow valgus torque, will have effects on the weakest link of the kinetic chain. In conclusion, the high levels of pitching elbow valgus torque and shoulder external rotation torque generated in the baseball pitching motion is a risk factor for injury for the pitching elbow. [26] In an epidemiological study of pitching elbow ulnar collateral ligament injuries from 2009 – 2014 among NCAA baseball players, an injury rate of 1.12 per 10,000 athletic exposures was reported.[8] Similar results were reported in an epidemiological study done from 1988 to 2004 on elbow ligament sprain that had an injury rate of 0.18 per 1000 athletic exposures, the high elbow injury risk for pitchers warrants concern.[104]

The sport of baseball is rife with shoulder and elbow injuries, especially among baseball pitchers.[7,8,11,92,104] Proper sequential kinematics achieved via proximal stability to get distal mobility will help pitchers conserve energy throughout the entire kinetic chain during the pitching motion. LPHC stability of a pitcher is a key component to the joint loads experienced among the pitching shoulder and elbow, linked to injury. With all the known mechanics associated with increased joint loads and/or injury, Sabrick et al. brought up a good point suggesting that these mechanics are not easily controlled by the pitcher.[98] Baseball pitchers should concentrate on performing correct segmental sequencing, which is affected by LPHC strengthening, instead of certain performance measures such as reaching a certain ball velocity.[75]

Glove Arm and Pitching

There is paucity in literature regarding glove arm kinematics and the influence on baseball pitching. In a study with only three participants examining the pelvis, upper trunk, and upper extremity contribution to the throwing motion, the glove arm contribution to the pitching motion was determined to be minimal and variable.[89] However, the authors concluded that different throwers make use of their LPHC sequencing differently and optimal use of their capabilities is difficult to achieve.[89] Thus, understanding optimal segmental sequencing of the LPHC and upper extremity is vital to uncovering how the kinetic chain works during the pitching motion. Naito and colleagues demonstrated a dynamic coupling that occurs during the baseball pitch, in order to achieve maximum arm velocity.[35] Their model of maximum fingertip velocity consisted of contributions from muscular torques, passive-movement dependent torques, centrifugal forces, Coriolis force, and gyroscopic moments, in addition to other interactive torque components.[35] For an efficient transmission of energy through the kinetic chain during the pitching motion, a pitcher would want maximum contribution to fingertip velocity coming from the passive-motion dependent torques, centrifugal forces, and Coriolis force instead of muscular torques.[35] It was thus determined that the passive motion-dependent torques, that create greater angular velocities of thorax rotation, elbow extension, and wrist flexion, were major contributors to maximum fingertip velocity.[35] Centrifugal force contribution to maximum fingertip velocity is increased by a properly coordinated motion between limb configuration and timing of proximal segment rotation.[35] The model for maximum fingertip velocity also determined a compensatory mechanism existed in muscular torque contribution which was seen through both positive and negative contributions from the muscular torque components.[35] If the kinetic chain is not efficiently transmitting energy, proximally to distally, then maximum velocity will require higher contribution of muscular torque for pitching. Future research should build on the knowledge that increased contribution towards maximum fingertip velocity of passive motion dependent torques, such as trunk angular velocity, will lead to decrease demand placed on muscular torques around that specific joint. Any kinematic variables that can impact trunk rotation should be further examined. By considering all the various types of kinetics and compensatory mechanisms that comprise maximum fingertip velocity of the baseball pitch, Naito et al. underscored the importance of proper segmental sequencing during the pitching motion.[35]

The timing of trunk rotation during the pitching motion is also important to kinetic energy conservation.[71] When examining pelvis and upper torso kinematics and ball velocity, Stodden et al. concluded that the sequencing of pelvis rotation, upper torso rotation, and throwing arm movement pattern would need to be properly timed for the body to maximize momentum transfer in agreement with the kinetic link theory.[69] For the upper extremity to avoid playing catch-up during the pitching motion, torso rotation needs to be delayed in order to increase the separation of maximal pelvis and torso rotational velocity. Proper timing of delayed torso rotation conserves momentum which in turn decreases pitching shoulder and elbow torques.[105] The notion of increased momentum traveling to the distal segments of the upper extremity would cause increased ball velocity and increased joint loads, is commonly argued.[69] However, Oyama and colleagues examined the connection between ball velocity, trunk lateral flexion, and pitching shoulder and elbow kinetics and found that no direct connection exists between increased ball velocities and increased pitching shoulder and elbow joint loads.[86,106] Thus, indicating that efficient use of segmental sequencing, or utilizing the summation of speed principle, can aid in reducing joint loads in the pitching shoulder and elbow.

High velocity pitchers have been found to use an increased amount of momentum generated from their lower extremities compared to low velocity pitchers.[67] In addition, high ball velocity pitchers have the ability to stabilize their LPHC over their stride leg during the pitching motion, which is another indication of an efficient kinetic chain.[67] In a comparison between high school and professional baseball pitchers, authors speculated the physical immaturity of the high school group led to them not being able to effectively utilize segmental rotation. Thus, ineffective torso rotation in high school pitchers was found to lead to a higher normalized elbow varus torque when compared to the professionals.[75] When examining pitch efficiency via pitching shoulder joint load, it has been found that a specific pattern in throwing minimizes the shoulder joint load while maintaining ball velocity. [81] Thus, authors provided evidence that delayed trunk rotation allows the pitcher to increase the efficiency of the pitching motion and maintain proper segmental sequencing.[81] This increased efficiency ultimately will allow a pitcher to decrease injury risk and improve performance.[81] When observing this sequence, the authors noted that early trunk rotation allowed rotational energy to be transferred to the upper arm too early and dissipate instead of being applied to the ball.[81] It was concluded that future research be conducted to determine how trunk rotation can be modified to reduce pathomechanics.[81] Additionally, others have suggested that the trunk plays an important role in pitching, and further pain in the trunk or lower extremities could be a sign of potential kinetic chain disturbance that could influence pitching shoulder and elbow pain.[66] Standing in agreement with the above propositions, future research directions suggested by Oyama and colleagues include exploring the effects of modifying trunk kinematics in an effort to prevent pitching related injuries.[86]

With the importance of LPHC stability and proper segmental sequencing throughout the pitching motion documented, implications of glove arm kinematics should be considered. Ishida and Hirano determined that a fixed or unused glove arm will alter the segmental sequencing of pelvis and torso rotation, cause more upper torso rotation at stride foot contact, and result in less separation between the pelvis and upper torso.[32] In their study design they had a normal and restricted condition. The only difference between conditions required the use of a rubber band affixed from the participant’s glove arm to their trunk for the restricted condition. Thus, based on the differences in trunk rotation found between groups, the authors concluded that the glove arm influenced trunk kinematics.[32] It was suggested that an unused glove arm will restrict control of the upper torso, further resulting in less twisting of the trunk, which allows kinetic energy to dissipate from the chain instead of being applied to the upper extremity during the baseball pitch.[32] The glove arm was found to contribute to ball velocity by altering the upper torso moment of inertia.[32]

An additional study on glove arm kinematics performed by Murata, examined glove arm shoulder joint movement in relation to ball velocity.[107] Glove arm shoulder joint movement was expressed as the displacement of the shoulder joint.[107] Murata found that smaller glove arm shoulder joint movement was related to higher ball velocity.[107] Thus concluding that the glove arm shoulder acted as a fulcrum about which the upper trunk and throwing arm to rotates. Murata suggested that future research should examine the implications that glove arm shoulder joint movement has on throwing arm kinetics.[107]

In a recent investigation into the relationship of glove arm kinematics with pelvic, trunk, and pitching arm kinematics as well as pitching arm kinetics, Barfield and colleagues examined the pitching events of maximal external rotation and ball release.[33] The authors defined an active glove arm as sustained glove arm muscle activation throughout the pitch, seen by an attempt of the pitcher to close the gap between the glove arm and pitching arm during arm acceleration. The authors concluded that an active glove arm could serve as advantageous to performance and injury prevention.[33] An active glove arm was indicated by more horizontal shoulder abduction and more extended elbow at maximal pitching arm shoulder external rotation.[33] At ball release, an active glove arm was seen as one that was more horizontal adducted at the shoulder and more flexed at the elbow.[33] These recent results agreed with previous research stating there is a relationship between glove arm and trunk positioning.[32,33] The authors concluded that a pitcher could help set the trunk in an optimal position by paying attention to glove arm positioning during the pitching motion.[33] Optimal trunk position occurs when there is increased timing separation between pelvis and trunk rotational velocities.[70] The glove arm and trunk relationship provides an example of the claim by Hirashima et al. that joints can alternate between a leading and subordinate role during different phases in a motion.[22] A pitcher that uses the glove arm in the leading role to delay trunk rotation will place themselves in optimal position.

While the research into glove arm kinematics and the effects that the glove arm has on the rest of the kinetic chain is limited, some confounding results have been produced. Ishida and Hirano indicated that future research should consider glove weight used by the pitcher because of the effect the mass and moment arm of the glove arm that the weight would have on the pitching motion.[32] Fleisig and colleagues did not analyze glove arm kinematics; however, based on trunk rotational kinematics, they implied that the glove weight for young pitchers seems too heavy.[108] They determined that an unused glove arm during the arm acceleration phase, seen by glove out and low by the lead knee, would increase the moment of inertia compared to an active glove arm.[108] Thus further resisting upper trunk rotation and having an effect on decreasing upper torso angular velocity.[108] An example of this taken from the Fleisig study can be seen in Figure 1.

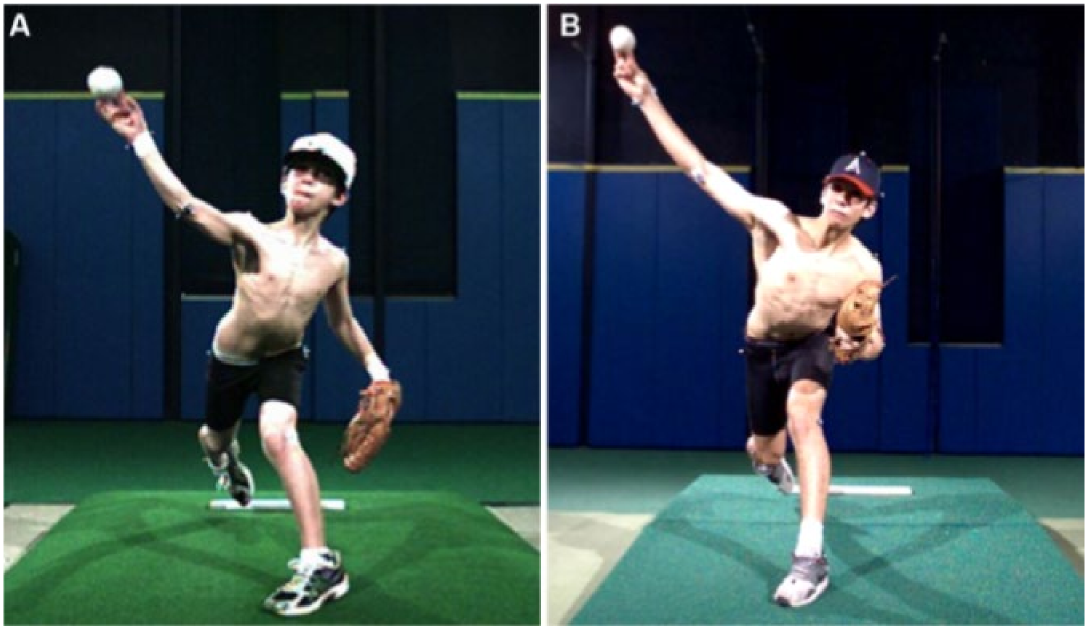

Figure 1. *Instant of ball release for a participant at 2 different ages. (A) When he was younger, the glove was down by his knee; (B) when he was older, his glove was in front of his chest.*[108]

In baseball pitching, the glove arm has a known connection to trunk kinematics.[32,33] Ishida and Hirano concluded that proper use of a glove arm, later defined as an active glove arm by Barfield and colleagues, will aid in proper rotational sequencing of the torso,[32,33] and an inactive glove arm would limit torso rotation.[32] As previously suggested by Hirashima et. al., joints can take on and alternate between leading and subordinate roles through a dynamic motion such as the baseball pitching motion.[22,109] Once foot contact occurs the upper extremity acts in subordinate role, with the upper arms of both the glove side and pitching side allowing the trunk to take lead in the dynamic motion.[22,33] Having an inactive glove arm as defined by Barfield and colleagues, or one more shoulder horizontally abducted and elbow flexed at MER and shoulder horizontally adducted and elbow extended at BR, would lengthen the moment arm of the torso during the arm acceleration phase, thus in turn lessening torso rotational velocity.[33] Due to the competitive nature of a pitcher, achieving a high ball velocity is always the primary objective in order to deliver an effective pitch, get an out, and get the win. However, with an inactive glove arm, the pitcher will have to use force derived from the smaller distal segments in effort to deliver the ball instead of the capitalizing on the energy generated from the pelvis/torso.[32,51,66,97] The lack of momentum transfer through the kinetic chain occurring due to improper timing of torso rotation, aided by an inactive glove arm, would increase pitching shoulder and elbow joint loads and increase the injury risk for the baseball pitcher.[33]

Pitching Motion Muscle Recruitment

Determining how much muscle recruitment is affected by the external load in the glove arm hand, could assist in validating previous findings. Validations could be found for research that suggested extending the glove arm over the lead knee could increase the moment of inertia for the upper torso.[108] If the external load in the glove hand alters the moment of inertia of the torso, it will also alter segmental sequencing. Thus, possibly allowing more torque to be derived from muscles surrounding the distal segment, to produce competitive velocity. Because maximum fingertip velocity is generated from a dynamic coupling system that includes passive motion dependent torques,[35] such as momentum generated from efficient segmental sequencing, and muscle dependent torque, altered muscle activity would be expected if segmental sequencing was altered. Previous research on overarm throwing has indicated how muscle coordination patterns can be altered based on one's physical properties.[80] When describing resistance training effects on the body, Siff suggested that functional effects such as intramuscular and intermuscular coordination occur with any resistance exercise.[110] While the pitching motion is not often thought of as a resistance exercise, an external resistance such as the glove and the ball is applied to both hands during the motion. Therefore, the principles associated with resistance exercises would apply, even with light external loads. Understanding muscle activations during the pitching motion, when different external loads are applied to the glove hand, could assist in training and possibly attaining more efficient movement. According to Hirashima and colleagues, the proximal muscles such as the pectoralis major, anterior deltoid and serratus anterior, are essential for high ball velocity.[109] Whereas the distal muscles are responsible for accuracy rather than velocity production.[109]

According to Newton's second law, the acceleration of the baseball will depend on the net sum of forces acting on the baseball.[21] Kaizu et al. suggested that a major principle of joint load on the pitching arm, during the pitching motion, is the inertia placed on the distal segment.[21] While the baseball is a constant weight across all leagues and is located at the most distal segment of the pitching motion, weight of the glove can fluctuate between pitchers, glove manufacturer, and model. Also, a baseball glove would be actively positioned by the pitcher before torso rotation and able to influence torso rotation.[32,33] If the upper torso acts as a system as suggested by Barfield and colleagues,[33] the effects of glove weight on the kinetic chain should be considered. The distal to proximal influence on joint rotation experienced by the kinetic chain in baseball pitching[21,22] may apply to the musculature of the upper torso[32,33], effect torso rotation, and have an influence on pitching arm joint kinetics.[33,106] Authors investigating the impact that the trunk on the baseball pitch, concluded that improper trunk and upper torso segmental sequencing during a pitch would impact pitching arm joint loading in ways that increases injury risk.[106] By assessing muscle activity, the overall effect of various movement variables, such as weight in the glove hand on limb motion during a pitching motion, can be considered.[22]

Anecdotal evidence in the baseball world suggests that professional pitchers from Latin America suffer fewer pitching arm injuries than American born players. Finances are a major difference in the cultural upbringing, with Latin Americans more likely to use a cut-up piece of milk jug or an old worn-out glove instead of a new, heavier model. The impact that glove weight has on proximal muscle activation could determine if there is a potential need for further evaluation on the association between glove weight and injury susceptibility. Multiple authors have suggested that muscle activity helps control intersegmental interaction as well as accelerate the limb.[22,111] In a study examining muscle contraction properties during overarm throwing, authors concluded that ball velocity could be increased by increasing the rotational velocity of the more proximal segments, or enhanced usage of the stretch-shortening cycle.[112] Escamilla et al. determined that there is a difference in kinetic chain muscle activation between football and baseball throws, indicating that an external force can impact the kinetic chain.[113] With the known link between glove arm kinematics and trunk kinematics, external mass placed in the hand of the glove arm and the effects on muscle activity should be considered. Improper sequencing of trunk rotation during the pitching motion could cause more muscle activation in the distal regions.[32,51,66,97] Improper balance of muscle activity between LPHC musculature and smaller distal areas, such as the pitching shoulder, could promote throwing related pain.[114] Therefore, the implications that glove weight has on muscle activity should be examined.

CHAPTER III

METHODS

The purpose of this research was to examine the effect that weight in the glove hand has on upper extremity and LPHC muscle activation; glove arm, trunk, and pitching arm kinematics; and pitching arm kinetics during the baseball pitch. This chapter outlines the methodology behind this study.

Participants

Twenty-five participants (mean ± SD: age, 17.54 ± 1.96 years; height, 184.89 ± 5.76 cm; weight, 80.09 ± 14.36 kg) were recruited to participate. Barfield et al.[33], which had 33 participants, was used to find an effect size of 0.62. This effect size along with a power of 0.8 and an α level probability of $p \leq 0.05$ was placed in GPower 3.1.9.2 to determine a total sample size of 18 males was needed. All participants were between the ages of 15 and 22, actively participating on a competitive baseball team for their age (either high school or college), in good physical condition, free from injury within the 6 months prior to testing, and deemed stable through the Single-leg Squat (SLS) and the Davies test. To be considered stable, knee valgus at 45 degrees of knee flexion during the descent phase of the SLS had to be less than 15 degrees[51] and the average number of touches across all three trials of the Davies test had to be 21 or greater.[63] The Institutional Review Board of Auburn University approved all testing protocols. Prior to data collection, all testing procedures were explained to the participant and their parent(s)/legal guardian(s) and informed written consent and participant assent was obtained (Appendix A).

Protocol

Upon arrival to the lab, participants were asked to fill out a health history questionnaire (Appendix B) to determine if they qualified for the study. Location of the glove side latissimus dorsi, throwing side gluteus maximus, bilateral external obliques, bilateral serratus anterior, throwing arm side lower trapezius, and throwing arm side gluteus medius was identified by palpation of the muscle belly. Single differential electrodes with an interelectrode distance of 10 mm were positioned parallel to the muscle fibers and attached to the muscle bellies.[115–119] Latissimus dorsi electrode placement was oblique, below the inferior tip of the scapula, approximately half the distance between the spine and lateral torso.[115] Gluteus maximus electrode placement was the greatest prominence of the middle of the buttocks at a distance of 50% on the line between the second sacral vertebrae and the greater trochanter.[116] External oblique electrode placement was oblique and approximately three cm anterior to and mid-way along a line drawn from the lateral pelvic crest to the lateral lower ribcage.[120] Serratus anterior electrode placement was vertical below the axilla, anterior to the latissimus dorsi, over the fourth to sixth ribs.[115] Lower trapezius electrode placement was obliquely upward and laterally between the spine of the scapula and vertebral border of scapula and seventh thoracic spinous process.[115] Gluteus medius electrode placement was the proximal third of the distance from the iliac crest and greater trochanter, and care was taken to place the electrode anterior to the gluteus maximus to minimize cross-talk.[116] An additional electrode was placed on the anterior superior iliac spine (ASIS) to serve as a ground lead. The intraclass correlation coefficient (ICC) for each muscle in the study were the following: latissimus dorsi = 0.879, $p < 0.001$; gluteus maximus = 0.952, $p < 0.001$; external oblique = 0.903, $p = 0.027$; serratus anterior = 0.982, $p < 0.001$; lower trapezius = 0.914, $p < 0.001$; and gluteus medius = 0.858, $p < 0.001$. For ICC collections, participants were asked to perform 3 different 5 second isometric contractions with a 10 second rest period between contractions on two separate days. There was a 2-minute rest period between muscle groups to allow for a change in test position. Electromyographic data were collected using a Delsys Bagnoli-8-channel electromyography (EMG) system. The signal was full-wave rectified and root mean squared at 100 milliseconds. Surface EMG data were sampled at a rate of 1200 Hz and notch filtered at frequencies between 59.5 and 60.5 Hz.[121] After application of surface electrodes, manual muscle tests (MMTs) techniques by Kendall et al. was used to ensure appropriate electrode placement and determine steady-state contraction.[122] Three MMT lasting five seconds were performed for each muscle with the first and last second of each test removed to obtain steady state results. The MMT provided baseline maximum voluntary isometric contraction (MVIC) data to which all sEMG was normalized.

Electromyographic data was collected at 1200 Hz and synchronized through The MotionMonitor® (Innovative Sports Training) and synced with kinematic data.

Kinematic data were collected at 240 Hz with an electromagnetic tracking system (trakSTAR; Ascension Technologies Inc) synced through The MotionMonitor (Innovative Sports Training). Electromagnetic sensors were attached to the following locations: (1) posterior aspect of the torso at the first thoracic vertebrae (T1) spinous process; (2) posterior aspect of the pelvis at the first sacral vertebrae (S1); (3 and 4) flat, broad portion on the superior aspect of the acromion on bilateral scapula; (5 and 6) lateral aspect of the bilateral upper arm at the deltoid tuberosity; (7 and 8) posterior aspect of the bilateral distal forearm, centered between the radial and ulnar styloid processes; (9) dorsal aspect of the second metatarsal of the stride foot; (10 and 11) lateral aspect of bilateral upper leg, centered between the greater trochanter and the lateral condyle of the knee; (12 and 13) lateral aspect of bilateral lower leg, centered between the head of the fibula and lateral malleolus; and (14) dorsal aspect of the third metacarpal of the pitching hand. A 15th movable sensor was attached to a plastic stylus used for the digitization of bony landmarks (Table 1).[79,88,123,124] Electromagnetic sensor setup is shown in Figure 2.

Figure 2: Posterior view of *electromagnetic sensor setup of a right-handed participant*

The error in determining position and orientation of the electromagnetic sensors with the current calibrated world axis system is less than 0.01 m and less than 3°, respectively. To ensure accurate identification and palpation of bony landmarks, the participant stood in anatomical neutral throughout the duration of the digitization process so that his body segments were able to be defined. The shoulder and hip joints were determined using the rotation method, which is performed by stabilizing the joint and passively moving the joint in 6 small, circular positions. This method has been reported to provide valid positional data for the shoulder and the hip.[123–125] The shoulder joint center was calculated from the rotation of the upper arm to the thorax, while the hip joint center was calculated from the rotation of the femur to the sacrum.[123–125] Variation in the measurement of the joint center done by root mean square was accepted for values less than 0.003m.

Table 1. *Description of bony landmarks to be palpated and digitized in order to create the skeletal model of each participant.*

Bony Landmarks	Digitized Bony Process
Upper Extremity	
Medial Elbow	Medial Epicondyle
Lateral Elbow	Lateral Epicondyle
Lateral Wrist (Thumb Side)	Most Distal Aspect of the Radius
Medial Wrist	Most Distal Aspect of the Ulna
Third Metacarpalphalangeal Joint	Dorsal, Distal Aspect of the 3rd Metacarpal
Third Distal Phalanx	Most Distal Aspect of the 3rd Phalanx
Torso	
Seventh Cervical Vertebra (C7)	C7 Spinous Process
Twelfth Thoracic Vertebra (T12)	T12 Spinous Process
Eighth Thoracic Vertebra (T8)	T8 Spinous Process
Suprasternal Notch	Most Cranial Aspect of the Sternum
Xiphoid Process	Most Distal Aspect of the Sternum
Lower Extremity	
Lateral Knee	Lateral Femoral Condyle
Medial Knee	Medial Femoral Condyle
Lateral Ankle	Lateral Malleolus
Medial Ankle	Medial Malleolus
Foot	Second Phalange Metacarpal Joint

Raw data regarding sensor position and orientation were transformed to locally based coordinate systems for each body segment. For the world axis, the Y-axis represented the vertical direction; in the direction of movement was the positive X-axis; and orthogonal to X and Y to the right was the positive Z-axis. Position and orientation of the body segments were obtained with Euler angle sequences that were consistent with the International Society of Biomechanics standards and joint conventions.[123,124] More specifically, a ZX'Y" sequence was used to describe pelvis, trunk, and elbow motion and a YX'Y" sequence to describe shoulder motion (Table 2). All pelvis and trunk motions were captured in reference to the world axis. For research questions 1-3, all elbow kinematic data were calculated in reference to the proximal upper arm segment axis, glove arm shoulder flexion data were calculated by proximal upper arm in reference to the scapula, and all other shoulder kinematic data were calculated in reference to the trunk segment axis. For research question 4, maximum segmental angular velocities and accelerations of the pelvis, trunk, throwing arm humerus, and throwing arm forearm were collected throughout the throwing motion. These velocities were the resultant magnitude of movement in all three planes in reference to the global coordinate system to provide the most accurate representation of movement. The angular velocity of the pelvis was the resultant of axial rotation, lateral tilt, and anterior/posterior tilt; angular velocity of the trunk was the resultant of axial rotation, lateral tilt, and flexion/extension; angular velocity of the humerus was the resultant of internal/external rotation, flexion/extension, and horizontal abduction/adduction; while angular velocity of forearm was the resultant of pronation/supination and elbow flexion/extension. The point at which each of these maximum values occurred was determined and calculated as a percentage of the throwing motion ranging from foot contact (FC) to ball release (BR).[126] All raw data were independently filtered along each global axis with a fourth-order Butterworth filter with a cutoff frequency of 13.4 Hz.[79,88,127] All data were synchronized by a data acquisition board and timestamped through The MotionMonitor. For research question 3 regarding pitching shoulder and elbow kinetics, the baseball was added as a point mass (0.142 Kg) to the center of mass to the pitching hand and added to the overall mass of each participant in order to adequately provide information needed to calculate accurate kinetics. The following pitching arm kinetics were examined during this study: elbow compression (+)/distraction (-) force; elbow varus (+)/valgus (-) moment; overall resultant elbow moment magnitude; shoulder internal (+)/external (-) rotation moment; shoulder anterior (+)/posterior (-) force; shoulder compression (+)/distraction (-) force; and overall resultant shoulder moment magnitude. All joint kinetics were determined through top down (hand to ground) inverse dynamics calculated by The MotionMonitor using previously validated anthropometric parameters.[128–130] Joint forces were weight normalized while joint moments were normalized by weight x height. Inverse dynamic equations for all joint kinetics can be found in Appendix C.

Table 2. *Euler Angle Decomposition Sequence Orientation*

Segment	Axis of Rotation	Angle
Pelvis	Z	Anterior Tilt/Posterior Tilt
	X'	Left Lateral Flexion/Right Lateral Flexion
	Y"	Left Rotation/Right Rotation
Trunk	Z	Flexion/Extension
	X'	Left Lateral Flexion/Right Lateral Flexion
	Y"	Left Rotation/Right Rotation
Shoulder	Y	Humeral Plane of Elevation/Horizontal Abduction
	X'	Humeral Elevation
	Y"	Internal Rotation/External Rotation
Elbow	Z	Flexion/Extension
	X'	Varus/Valgus
	Y"	Pronation/Supination

Once all electromagnetic sensors were attached and digitized, electrodes attached and MMT performed, participants performed three SLS on each leg and completed the Davies test in order to determine LPHC stability. For the SLS, the participant stood on one foot, with the other leg flexed at the knee and foot behind their body. Also, the participant placed their hands on their hips and point their grounded toe straight ahead. The participant squatted to a comfortable level and then returned to the starting position without hitting the ground with the foot behind them, or resting the leg that is off the ground onto the stance leg.[41] For the Davies test, the participant started in a push-up position with both hands placed on pieces of tape that are 36 inches apart. Once told to go by the tester, the athlete then moved their right hand to touch their left hand. Alternate hand touching occurred for 15 seconds. Three trials of this assessment were performed. A rest period of 45 seconds was allotted between trials.[41] The order of these two stability assessments were randomly assigned using a random list generator. Participants with knee valgus values less than 15 degrees at 45 degrees knee flexion during the descent of the SLS and an average score of 21 or higher on the Davies test were considered as having a stable LPHC and included in this study.

Following the stability assessments, each participant was allotted an unlimited amount of time to warm up and become familiar with all testing procedures. Average warm-up time was 371.8 seconds (6.2 minutes). Once participants indicated they were ready, they were asked to pitch fastballs using no weight in the glove hand, normal glove, 0.68 kg (1.5 lbs.), and 1.36 kg (3 lbs.) in the glove hand from a mound to a catcher located at an age appropriate regulation distance. Across a small pilot study, average glove weight was determined to be 0.68 kg. The normal glove weight of all participants was recorded (mean = 0.57 kg., S.D. = 0.12 kg.) and compared to the 0.68 kg condition. The 1.36 kg weight condition was used because it is twice that of an average glove. The order of weight conditions was randomly assigned using a random list generator. The number of trials per each glove hand weight condition was determined based on a pilot of two experienced pitchers and the variability in glove arm shoulder elevation during two conditions: normal glove and 2.72 kg weight. This pilot study was used to determine if there was a learned effect of increased weight placed on the glove hand. The variability seen for three trials did not suggest a learned effect, was within the accepted system error across all trials and can be seen in Figure 3. Therefore, three fastballs were thrown at each weighted condition with a total of 12 fastballs being collected. Fastball velocity was recorded using a Stalker Pro II radar gun (Applied Concepts Inc., TX, USA) and can be found in Table 3.

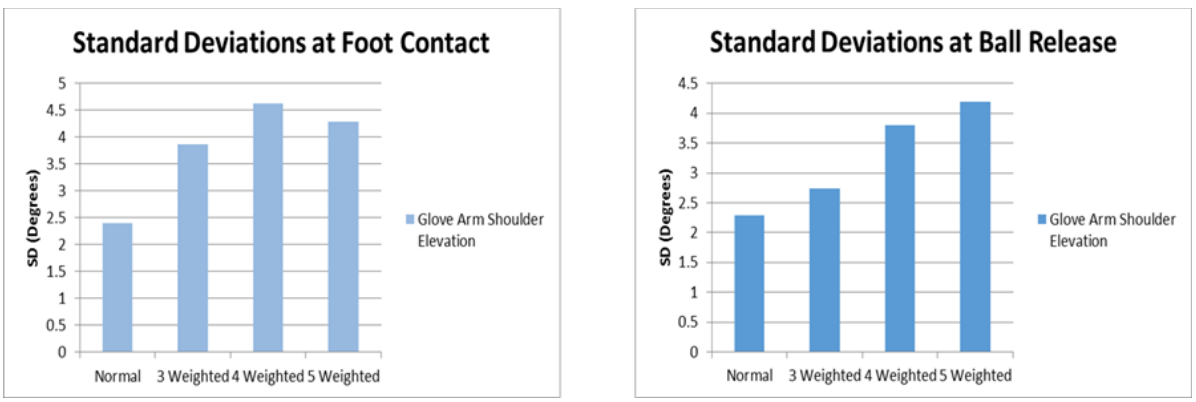

Figure 3: *Variability seen in pilot of two experienced pitchers in glove arm shoulder elevation between three trials with normal glove, three trials with 2.72 kg in the glove hand, four trials with 2.72 kg in the glove hand, and five trials with 2.72 kg in the glove hand.*

Table 3: Mean and Standard Deviation (S.D.) of ball velocity across all 4 weight in glove conditions.

Glove Condition	Mean(m/s)	S.D.(m/s)
Condition 1 (No Glove)	31.94	2.71
Condition 2 (Normal Glove)	32.09	2.51
Condition 3 (0.68 kg)	31.91	2.54
Condition 4 (1.36 kg)	31.79	2.43

Statistical Analysis

In an analysis of kinematic and kinetic data across a simulated game of over 100 pitches by collegiate pitchers, minimal variation was noticed between variables.[131] Therefore, for each weighted condition, only the fastest fastball was used for analysis.[35,81,132–134] Kinematic data was event marked at: FC, pitching shoulder maximum external rotation (MER), and BR. FC was determined by obtaining the initial ground reaction force in the Y direction of the stride foot greater than 10 N using a 40 cm × 60 cm Bertec force plate (Bertec Corp., Columbus OH) embedded into the platform located at the bottom of a pitching mound. Pitching shoulder MER was defined as the maximum shoulder external rotation during the pitching motion occurring after FC. The event of BR was determined by obtaining the halfway point between MER and maximum internal rotation (MIR) of the shoulder.[33] Pitching shoulder MIR was defined as the maximum shoulder internal rotation during the pitching motion occurring after MER. Data were analyzed at the events of FC and BR and the phases of arm cocking (phase 1 - between FC and MER) and arm acceleration (phase 2 -

between MER and BR).[108] For both phases, data were averaged between the time points (Figure 4).

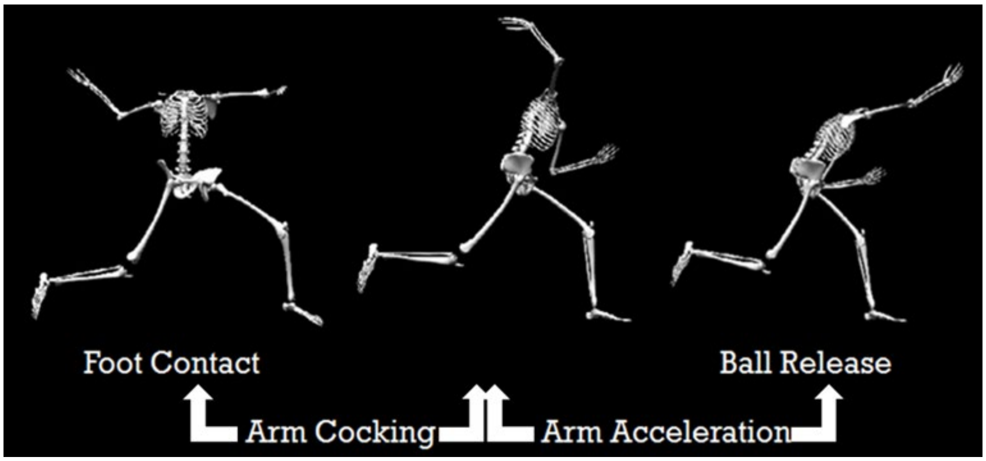

Figure 4: *Events and Phases of Data Analysis*

Data were processed by MatLab and analyzed with SPSS 21 for Windows (IBM). All dependent variables and analysis used for each research question can be found in Table 4.

Table 4: Dependent variables, timing in the pitching motion, and analysis used for each research question.

Research Question (RQ)	Analysis	Dependent Variables (DV)	Pitching Motion Event/Phase
RQ1	4x4 within-subject MANOVA	Glove arm elbow flexion Glove arm shoulder horizontal abduction Glove arm shoulder flexion	FC; Phase 1; Phase 2; BR
RQ2	3x4 within-subject MANOVA	Trunk flexion Trunk lateral flexion Trunk axial rotation	FC; Phase 2; BR
RQ3	2x4 within-subject MANOVA	Pitching elbow varus/valgus moment Pitching elbow compression/distraction force Pitching elbow moment magnitude	Phase 1; Phase 2
	2x4 within-subject MANOVA	Pitching shoulder horizontal abduction moment Pitching shoulder internal/external rotation moment Pitching shoulder anterior/posterior force Pitching shoulder compression/distraction force Pitching shoulder moment magnitude	
RQ4	4-way within-subject MANOVA	Pelvis angular velocity Trunk angular velocity Pitching arm humerus angular velocity Pitching arm forearm angular velocity Pelvis angular acceleration Trunk angular acceleration Pitching arm humerus angular acceleration Pitching arm forearm angular acceleration	Maximal value
	4-way within-subject MANOVA		Timing to maximal value
RQ5	4-way within-subject MANOVA	Glove side serratus anterior Glove side external oblique Glove side latissimus dorsi Throwing side lower trapezius Throwing side gluteus maximus Throwing side gluteus medius Throwing side external oblique Throwing side serratus anterior	Peak Magnitude
	4-way within-subject MANOVA		Timing to peak magnitude

Note: FC = Foot Contact; Phase 1 = Arm Cocking; Phase 2 = Arm Acceleration; BR = Ball Release.

Each research question had 4 conditions of weight placed in the glove hand as hand as independent variables. Examples of the conditions of weight placed in the glove hand can be seen in Figure 5.

Figure 5: *Four conditions (A - no glove, B – normal glove, C - 0.68 kg, and D - 1.36 kg) of weight placed in the glove hand.*

Testwise error was set at α = 0.05. Prior to running any MANOVA, univariate normality was assessed by skewness and kurtosis. A variable was considered univariate normal if it was less than two times the standard error for skewness or kurtosis. For any significant MANOVAs, follow-up within-subjects ANOVAs and paired samples t-tests were conducted to determine individual variable significance. For all follow-up tests, the Bonferroni correction was applied to adjust for multiple comparisons.

CHAPTER IV

RESULTS

The purpose of this research was to examine the effect that weight in the glove hand has on upper extremity and lumbopelvic-hip complex (LPHC) muscle activation; glove arm, trunk, and pitching arm kinematics; and pitching arm kinetics during the baseball pitch. Twenty-five male baseball pitchers were recruited to participate. Nineteen participants (17.88 ± 2.05 yrs.; 184.73 ± 5.65 cm; 82.06 ± 14.18 kg) fell within the inclusion criteria of being stable as determined by the single-leg squat (SLS) and the closed kinetic chain upper extremity stability test and were used for statistical analysis for research questions 1 and 2. For research questions 3 – 5, one participant had to be excluded as an outlier for the results, leaving a sample size of 18. This chapter outlines and describes the results of the study and are according to the following:

RQ1) Does the amount of weight in the glove hand during a fastball baseball pitch alter the following glove arm kinematics: glove arm elbow flexion, glove arm shoulder horizontal abduction, and glove arm shoulder flexion?

RQ2) Does the weight in the glove hand during a fastball baseball pitch alter the following trunk kinematics: trunk flexion, trunk lateral flexion, and trunk axial rotation?

RQ3) Does the weight in the glove hand during a fastball baseball pitch alter the following pitching shoulder and elbow joint loads: elbow varus/valgus moment, elbow distraction/compression force, resultant elbow moment magnitude, shoulder internal/external rotation moment, shoulder anterior/posterior force, shoulder horizontal ab/abduction moment, shoulder compression/distraction force, and resultant shoulder moment magnitude?

RQ4) Does the weight in the glove hand during a fastball baseball pitch alter overall magnitude and segmental sequencing of the maximal angular velocities and accelerations of the following segments: pelvis, trunk, pitching arm humerus, and pitching arm forearm?

RQ5) Does the amount of weight in the glove hand during a fastball baseball pitch alter the muscle activation peak magnitude and timing to peak magnitude during the arm cocking and arm acceleration phase for the following muscles: glove side latissimus dorsi, throwing side gluteus maximus, throwing side gluteus medius, throwing side lower trapezius, bilateral serratus anterior, and bilateral external oblique?

RQ1: Does the amount of weight in the glove hand during a fastball baseball pitch alter the following glove arm kinematics: glove arm elbow flexion, glove arm shoulder horizontal abduction, and glove arm shoulder flexion?

Normality was assessed by skewness and kurtosis. With the first condition of no glove on the glove hand, glove arm elbow flexion at FC was left skewed and leptokurtotic (*skew* = -1.58, *SE* = .52; *kurtosis* = 2.08, *SE* = 1.01) and glove arm elbow flexion at BR was left skewed and leptokurtotic (*skew* = -2.86, *SE* = .52; *kurtosis* = 10.44, *SE* = 1.01). With the glove condition, glove arm shoulder horizontal abduction at FC was right skewed (*skew* = 1.11, *SE* = .52) and glove arm shoulder horizontal abduction during arm cocking (phase 1) was right skewed and leptokurtotic (*skew* = 1.09, *SE* = .52; *kurtosis* = 2.44, *SE* = 1.01). With the 0.68 kg training glove condition, glove arm elbow flexion was left skewed at FC (*skew* = -1.19, *SE* = .52). The assumption of sphericity was not met for interaction between glove type and time. Upon follow-up ANOVAs for Glove arm elbow flexion (W_2 <.001, p < .001), glove arm shoulder flexion (W_2 < .001, p < .001), and glove arm shoulder horizontal abduction (W_2 < .001, p < .001), the Greenhouse-Geisser correction to those univariate tests was applied. However, the assumption of sphericity was met for the simple effect of glove type for all variables, glove arm elbow flexion (W_2 = .781, p = .530) glove arm shoulder flexion (W_2 = .786, p < .547) and glove arm shoulder horizontal abduction (W_2 = .691 p = .290). Descriptive statistics can be found in Tables 5-8.

Table 5: Mean, Standard Deviation (S.D.), Skewness, and Kurtosis for Condition 1 (no glove) of glove arm elbow flexion, glove arm shoulder flexion, and glove arm shoulder horizontal abduction at foot contact, phase 1, phase 2, and ball release of the pitching motion (N = 19).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
GA elbow flexion(˚)	FC	124.93	25.93	-1.58*	2.08*
	Phase 1	108.03	21.34	-.82	.88
	Phase 2	89.92	20.38	-.16	.23
	BR	83.03	21.27	-.11	-1.13
GA shoulder flexion(˚)	FC	-52.07	11.08	-.11	.40
	Phase 1	-31.02	9.79	-.29	-.68
	Phase 2	10.20	16.65	-.63	-.76
	BR	23.82	18.10	.10	-.98
GA shoulder horizontal abduction(˚)	FC	39.57	22.61	.68	-.25
	Phase 1	45.96	19.84	.27	-.31
	Phase 2	-10.59	37.18	-.65	.29
	BR	-31.68	29.84	-.74	1.90

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .52; standard error of kurtosis = 1.01. ***Elbow Flexion:*** *(−) = flexion, (+) = extension;* ***Shoulder Flexion:*** *(+) = extension, (−) = flexion;* ***Shoulder Horizontal Abduction:*** *90° = forward flexion, 0° = abduction.*

Table 6: Mean, Standard Deviation (S.D.), Skewness, and Kurtosis for Condition 2 (no glove) of glove arm elbow flexion, glove arm shoulder flexion, and glove arm shoulder horizontal abduction at foot contact, phase 1, phase 2, and ball release of the pitching motion (N = 19).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
GA elbow flexion(˚)	FC	119.13	24.11	-1.07*	1.54
	Phase 1	104.19	19.67	-.39	.04
	Phase 2	91.38	17.26	.33	-.74
	BR	86.39	20.21	.28	-1.22
GA shoulder flexion(˚)	FC	-50.85	12.40	.43	1.81
	Phase 1	-31.67	11.12	.05	-.69
	Phase 2	8.25	17.01	-.80	.14
	BR	21.43	19.61	-.16	-.14
GA shoulder horizontal abduction(˚)	FC	40.75	23.01	1.11*	.77
	Phase 1	44.99	22.17	1.10*	2.44*
	Phase 2	-6.63	27.54	.50	.50
	BR	-32.55	27.69	-.74	-.33

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .52; standard error of kurtosis = 1.01. ***Elbow Flexion:*** *(−) = flexion, (+) = extension;* ***Shoulder Flexion:*** *(+) = extension, (−) = flexion;* ***Shoulder Horizontal Abduction:*** *90° = forward flexion, 0° = abduction.*

Table 7: Mean, Standard Deviation (S.D.), Skewness, and Kurtosis for Condition 3 (0.68 kg. training glove) of glove arm elbow flexion, glove arm shoulder flexion, and glove arm shoulder horizontal abduction at foot contact, phase 1, phase 2, and ball release of the pitching motion (N = 19).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
GA elbow flexion(˚)	FC	111.75	24.96	-1.19*	1.23
	Phase 1	96.58	22.23	-.77	.70
	Phase 2	86.89	18.93	-.53	.69
	BR	83.21	18.93	-.27	-.85
GA shoulder flexion(˚)	FC	-49.06	13.26	-.24	-.10
	Phase 1	-29.28	12.35	-.50	-.79
	Phase 2	7.81	17.80	-.85	-.51
	BR	20.34	18.12	-.62	-.68
GA shoulder horizontal abduction(˚)	FC	42.88	21.32	.49	-.46
	Phase 1	45.48	21.93	-.02	.02
	Phase 2	-6.07	31.05	.09	-.45
	BR	-30.56	28.66	-.31	-.66

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .52; standard error of kurtosis = 1.01. ***Elbow Flexion:*** *(−) = flexion, (+) = extension;* ***Shoulder Flexion:*** *(+) = extension, (−) = flexion;* ***Shoulder Horizontal Abduction:*** *90° = forward flexion, 0° = abduction.*

Table 8: Mean, Standard Deviation (S.D.), Skewness, and Kurtosis for Condition 4 (1.36 kg. training glove) of glove arm elbow flexion, glove arm shoulder flexion, and glove arm shoulder horizontal abduction at foot contact, phase 1, phase 2, and ball release of the pitching motion (N = 19).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
GA elbow flexion(˚)	FC	108.19	26.55	-.84	-.52
	Phase 1	92.79	20.90	-.59	-.60
	Phase 2	83.43	18.02	-.41	-.57
	BR	80.76	19.14	-.37	-.81
GA shoulder flexion(˚)	FC	-47.24	12.73	-.46	.30
	Phase 1	-30.14	10.20	-.17	-1.14
	Phase 2	8.82	15.51	-.81	.19
	BR	21.79	19.21	-.62	.39
GA shoulder horizontal abduction(˚)	FC	38.53	25.67	.40	-.33
	Phase 1	40.72	22.83	.13	.66
	Phase 2	-8.02	29.88	.13	.64
	BR	-24.52	30.99	-.21	.85

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .52; standard error of kurtosis = 1.01. ***Elbow Flexion:*** *(−) = flexion, (+) = extension;* ***Shoulder Flexion:*** *(+) = extension, (−) = flexion;* ***Shoulder Horizontal Abduction:*** *90°=forward flexion, 0°=abduction.*

Although the sample collected upon was a convenience sample and several variables struggled with univariate normality, the rest of the multivariate assumptions were met. Therefore, a 4 X 4 within-subjects MANOVA was used to determine significant differences between the set of dependent variables, glove arm elbow flexion, glove arm shoulder flexion, and glove arm shoulder horizontal abduction, with the interaction of weight in the glove hand and time. There was a significant difference in the set of dependent variables based on the interaction of glove type and time ($\Lambda = .532$, $F_{27, 467.93} = 4.18$, $p < .001$). Furthermore,19% of the variance in the set of dependent variables was explained by the combination of glove type and time ($\eta^2 = .19$). When examining the main effect of glove type, significance was found in the set of dependent variables ($\Lambda = .680$, $F_{9, 126.71} = 2.42$, $p = .014$). About 12% of the variance in the set of dependent variables was explained by the main effect of weight in the glove hand ($\eta^2 = .12$).

Following the significant multivariate tests, three 4 X 4 within-subjects ANOVAs each with a Greenhouse-Geisser correction were used to determine whether there was an interaction on each of the dependent variables. The testwise Type I error rate was set to .017 for all follow-up analyses, using the Bonferonni inequality to control for familywise error. A significant univariate effect was seen with the interaction between time and glove arm elbow flexion ($F_{2.13, 38.38} = 11.09$, $p < .001$). Furthermore, 38% of the variance in glove arm elbow flexion was explained by the interaction between glove type and time ($\eta^2 = .38$). No significance was found for either glove arm shoulder flexion ($F_{3.33, 59.93} = 2.82$, $p = .041$, $\eta^2 = .14$) or glove arm shoulder horizontal abduction ($F_{2.09, 37.65} = 1.27$, p

= .294, η^2 = .07). After further examination, the interaction between weight in glove hand and the timing in the pitching motion affects glove arm elbow flexion.

Three 4 x 4 within-subjects ANOVAs were used to determine if there was significance with the glove weight simple effect at the univariate level. Significance was seen with the glove weight simple effect and glove arm elbow flexion ($F_{3,\ 1749.98}$ = 7.85, p < .001). About 30% of the variance in glove arm elbow flexion was explained by the glove weight simple effect. No significance was found for either glove arm shoulder flexion ($F_{3,\ 30.21}$ = 0.40, p = .728, η^2 = .02) or glove arm shoulder horizontal abduction ($F_{3,\ 57.99}$ = 0.14, p = .904, η^2 = .01). After conducting univariate ANOVAs for the simple effect of glove weight, glove weight simple effect has a significant impact on glove arm elbow flexion.

Following the significant ANOVAs examining the interaction between glove weight and time and the glove weight simple effect, a paired samples t-test was used to assess specific differences between glove arm elbow flexion and the interaction of glove type and the timing of the pitching motion. A significant difference was observed between glove arm elbow flexion at FC with significantly less glove arm elbow flexion seen in the no glove condition compared to the 0.68 kg training glove (t_{18} = 5.90, p <.001), the no glove condition compared to 1.36 kg training glove (t_{18} = 4.89, p <.001), the normal glove condition compared to the 0.68 kg training glove (t_{18} = 3.00, p =.008), and the normal glove condition compared to the 1.36 kg training glove (t_{18} = 3.08, p =.007). During arm cocking (phase 1) of the pitching motion, a significant difference was observed with significantly less glove arm elbow flexion seen in the no glove condition compared to the 0.68 kg training glove condition (t_{18} = 5.28, p < .001), the no glove condition compared to the 1.36 kg training glove condition (t_{18} = 5.59, p < .001), the normal glove condition compared to the 0.68 kg training glove (t_{18} = 3.32, p = .004), and the normal glove condition compared to the 1.36 kg training glove (t_{18} = 3.88, p = .001). During arm acceleration (phase 2) of the pitching motion, a significant difference was observed with less glove arm elbow flexion seen in the no glove condition compared to the 1.36 kg training glove (t_{18} = 2.75, p = .013), and the normal glove condition compared to the 1.36 kg training glove (t_{18} = 2.87, p = .010). All of the results from the repeated measures t-test can be found in Table 9.

Table 9: Repeated measures t-test for Glove Arm Elbow Flexion with the following conditions: no glove, normal glove, 0.68 kg. training glove, and 1.36 kg. training glove.

Foot Contact	Sample 1	Sample 2	t	df	p-value
	No glove	Normal glove	2.13	18	.047
		0.68 kg. training glove	5.90	18	**<.001**
		1.36 kg. training glove	4.89	18	**<.001**
	Normal glove	0.68 kg. training glove	3.00	18	**.008**
		1.36 kg. training glove	3.08	18	**.007**
	0.68 kg. training glove	1.36 kg. training glove	1.06	18	.304
Phase 1	Sample 1	Sample 2	t	df	p-value
	No glove	Normal glove	1.49	18	.155
		0.68 kg. training glove	5.28	18	**<.001**
		1.36 kg. training glove	5.59	18	**<.001**
	Normal glove	0.68 kg. training glove	3.32	18	**.004**
		1.36 kg. training glove	3.88	18	**.001**
	0.68 kg. training glove	1.36 kg. training glove	1.30	18	.210
Phase 2	Sample 1	Sample 2	t	df	p-value
	No glove	Normal glove	-.53	18	.601
		0.68 kg. training glove	1.20	18	.244
		1.36 kg. training glove	2.75	18	**.013**
	Normal glove	0.68 kg. training glove	1.85	18	.081
		1.36 kg. training glove	2.87	18	**.010**
	0.68 kg. training glove	1.36 kg. training glove	1.40	18	.180
Ball Release	Sample 1	Sample 2	t	df	p-value
	No glove	Normal glove	-1.20	18	.246
		0.68 kg. training glove	-.07	18	.942
		1.36 kg. training glove	1.09	18	.290
	Normal glove	0.68 kg. training glove	1.31	18	.207
		1.36 kg. training glove	1.97	18	.064
	0.68 kg. training glove	1.36 kg. training glove	1.01	18	.328

Note: Significance was indicated by $p \leq .017$

RQ2. Does the weight in the glove hand during a fastball baseball pitch alter the following trunk kinematics: trunk flexion, trunk lateral flexion, and trunk axial rotation?

Normality was assessed by skewness and kurtosis. For the second condition of normal glove on the non-throwing hand, Trunk Axial Rotation during phase 2 was left skewed and leptokurtotic (*skew* = -1.19, *SE* = .52; *kurtosis* = 2.65, *SE* = 1.01) and trunk lateral flexion was left skewed at BR (*skew* = -1.11, *SE* = .52). The rest of the variables checked out univariate normal for skewness and kurtosis. The assumption of sphericity was not met for interaction between glove type and time. Upon follow-up ANOVAs for trunk flexion (W_2 = .037, $p < .001$), trunk lateral flexion (W_2 =.006, $p < .001$), and trunk axial rotation (W_2 =.023, $p < .001$), the Greenhouse-Geisser correction to those univariate tests was applied. The full results of skewness and kurtosis for question 2 along with the rest of the descriptive statistics can be found in Tables 10-13.

Table 10: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 1 (no glove) of Trunk Flexion, Trunk Lateral Flexion, and Trunk Axial Rotation at foot contact, phase 2, and ball release of the pitching motion (N = 19).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
Trunk Flexion(˚)	FC	12.24	13.87	.67	.35
	Phase 2	-9.44	10.23	.29	-.62
	BR	-19.52	11.48	.75	.50
Trunk Lateral Flexion(˚)	FC	25.95	11.31	-.29	-.78
	Phase 2	-13.65	12.96	.09	.98
	BR	-22.21	12.85	-.36	.79
Trunk Axial Rotation(˚)	FC	-101.78	17.01	.19	-.81
	Phase 2	-5.18	11.31	-.90	1.45
	BR	10.51	9.65	.02	-.99

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .52; standard error of kurtosis = 1.01. **Trunk Flexion:** (+) = flexion, (−) = extension; **Trunk Lateral Flexion:** (+) = toward pitching arm side, (−) = toward glove arm side; **Trunk Axial Rotation:** 0° = facing forward to the catcher, 90° = rotated toward the glove arm side.

Table 11: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 2 (normal glove) of Trunk Flexion, Trunk Lateral Flexion, and Trunk Axial Rotation at foot contact, phase 2, and ball release of the pitching motion (N = 19).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
Trunk Flexion(˚)	FC	11.20	12.80	.71	.54
	Phase 2	-8.52	10.13	.09	-.61
	BR	-19.01	11.42	.42	.22
Trunk Lateral Flexion(˚)	FC	28.04	12.50	.04	-.46
	Phase 2	-13.43	11.73	-.78	.71
	BR	-22.55	12.41	1.11	1.37
Trunk Axial Rotation(˚)	FC	-98.70	16.06	-.17	-.60
	Phase 2	-2.50	10.37	-1.19	2.65
	BR	12.47	7.59	.20	.42

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .52; standard error of kurtosis = 1.01. **Trunk Flexion:** (+) = flexion, (−) = extension; **Trunk Lateral Flexion:** (+) = toward pitching arm side, (−) = toward glove arm side; **Trunk Axial Rotation:** 0° = facing forward to the catcher, 90° = rotated toward the glove arm side.

Table 12: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 3 (0.68 kg. training glove) of Trunk Flexion, Trunk Lateral Flexion, and Trunk Axial Rotation at foot contact, phase 2, and ball release of the pitching motion (N = 19).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
Trunk Flexion(˚)	FC	10.15	12.17	.58	.94
	Phase 2	-8.01	9.19	-.35	.11
	BR	-17.55	10.44	.35	.66
Trunk Lateral Flexion(˚)	FC	25.01	11.39	-.30	-.95
	Phase 2	-14.25	10.20	-.98	.53
	BR	-22.99	11.20	-.84	.23
Trunk Axial Rotation(˚)	FC	-95.90	20.24	.31	.56
	Phase 2	-2.10	14.42	-.86	.58
	BR	12.36	10.50	.16	-.71

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .52; standard error of kurtosis = 1.01. **Trunk Flexion:** (+) = flexion, (−) = extension; **Trunk Lateral Flexion:** (+) = toward pitching arm side, (−) = toward glove arm side; **Trunk Axial Rotation:** 0° = facing forward to the catcher, 90° = rotated toward the glove arm side.

Table 13: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 4 (1.36 kg. training glove) of Trunk Flexion, Trunk Lateral Flexion, and Trunk Axial Rotation at foot contact, phase 2, and ball release of the pitching motion (N = 19).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
Trunk Flexion(˚)	FC	9.55	12.96	.72	.32
	Phase 2	-7.72	11.01	-.02	-.33
	BR	-18.55	12.08	.57	.23
Trunk Lateral Flexion(˚)	FC	25.83	14.89	-.11	-.42
	Phase 2	-13.44	12.53	.20	.17
	BR	-22.08	13.42	-.21	-.09
Trunk Axial Rotation(˚)	FC	-97.78	15.36	-.03	-1.07
	Phase 2	-4.42	12.71	-.45	-.15
	BR	10.36	10.15	.84	.71

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .52; standard error of kurtosis = 1.01. **Trunk Flexion:** (+) = flexion, (−) = extension; **Trunk Lateral Flexion:** (+) = toward pitching arm side, (−) = toward glove arm side; **Trunk Axial Rotation:** 0° = facing forward to the catcher, 90° = rotated toward the glove arm side.

With the rest of the multivariate assumptions being met, a 3 X 4 within-subjects MANOVA was used to determine significant differences between the set of dependent variables, trunk flexion, trunk lateral flexion, and trunk axial rotation, with the interaction of weight in the glove hand and time. There was not a significant difference found in the set of dependent variables based on the interaction of glove type and time (Λ = .785, $F_{18,\ 300.30}$ = 1.49, p = .092, η^2 = .08) or the main effect of glove type (Λ = .876, $F_{9,\ 126.71}$ = 0.79, p = .630, η^2 = .04). Trunk kinematics are not significantly affected by the interaction of weight in the glove hand and the timing of the pitching motion or the main effect of weight in the glove hand.

RQ3. Does the weight in the glove hand during a fastball baseball pitch alter the following pitching shoulder and elbow joint loads: elbow varus/valgus moment, elbow distraction/compression force, resultant elbow moment magnitude, shoulder internal/external rotation moment, shoulder anterior/posterior force, shoulder horizontal ab/adduction moment, shoulder compression/distraction force, and resultant shoulder moment magnitude?

Normality was assessed by skewness and kurtosis. For the first condition of no glove on the non-throwing hand, elbow distraction/compression force was leptokurtotic during phase 1(*kurtosis* = 2.55, *SE* = 1.04), shoulder horizontal abduction/adduction moment was left skewed and leptokurtotic during phase 1 (*skew* = -2.38, *SE* = .54; *kurtosis* = 4.84, *SE* = 1.04), overall elbow moment magnitude was right skewed during phase 2 (skew = 1.25, *SE* = .54), and shoulder internal/external rotation moment was left skewed and leptokurtotic during phase 2 of the pitching motion (*skew* = -1.71, *SE* = .54; *kurtosis* = 6.48, *SE* = 1.04). During the second condition of normal glove on the non-throwing hand, shoulder horizontal abduction/adduction moment was left skewed and leptokurtotic during phase 1 (*skew* = -2.30, *SE* = .54; *kurtosis* = 4.60, *SE* = 1.04), shoulder internal/external rotational moment was left skewed and leptokurtotic during phase 1 (*skew* = -1.15, *SE* = .54; *kurtosis* = 3.38, *SE* = 1.04) and phase 2 (*skew* = -1.51, *SE* = .54; *kurtosis* = 6.19, *SE* = 1.04), and elbow varus/valgus moment was right skewed during phase 2 of the pitching motion (*skew* = 1.21, *SE* = .54). For the third condition of a 0.68 kg training glove, shoulder horizontal abduction/adduction moment was left skewed and leptokurtotic during phase 1 (*skew* = -2.17, *SE* = .54; *kurtosis* = 4.19, *SE* = 1.04), overall elbow moment magnitude was right skewed during phase 2 (*skew* = 1.10, *SE* = .54), overall shoulder moment magnitude was right skewed and leptokurtotic during phase 2 (*skew* = 1.43, *SE* = .54; *kurtosis* = 2.71, *SE* = 1.04), and shoulder internal/external rotational moment was left skewed and leptokurtotic during phase 2 of the pitching motion (*skew* = -2.01, *SE* = .54; *kurtosis* = 6.53, *SE* = 1.04). For the fourth condition of a 1.36 kg training glove, overall elbow moment magnitude was right skewed and leptokurtotic during phase 1 (*skew* = 1.61, *SE* = .54; *kurtosis* = 4.57, *SE* = 1.04), shoulder horizontal abduction/adduction moment was left skewed and leptokurtotic during phase 1 (*skew* = -2.43, *SE* = .54; *kurtosis* = 5.01, *SE* = 1.04), and shoulder internal/external rotational moment was leptokurtotic during phase 1 (*kurtosis* = 4.23, *SE* = 1.04), and left skewed and leptokurtotic during phase 2 (*skew* = -1.41, *SE* = .54; *kurtosis* = 4.57, *SE* = 1.04). The rest of the variables checked out univariate normal for skewness and kurtosis. The full results of skewness and kurtosis along with the descriptive statistics for question 3 can be found in Tables 14 - 17.

Table 14: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 1 (no glove) of Elbow Varus/Valgus Moment, Elbow Distraction/Compression Force, Elbow Moment Magnitude, Shoulder Horizontal Abduction/Adduction moment, Shoulder Anterior/Posterior force, shoulder Distraction/Compression force, Shoulder internal/external rotation torque, and shoulder moment magnitude averaged across phase 1 and phase 2 of the pitching motion (N = 18).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
Elbow					
Varus/Valgus Moment	Phase 1	0.10	0.39	-.23	.26
	Phase 2	-1.12	1.23	.94	1.31
Distraction/Compression Force	Phase 1	6.41	4.94	.98	2.55*
	Phase 2	40.01	17.84	-.14	-.97
Moment Magnitude	Phase 1	1.76	0.76	.86	.43
	Phase 2	5.15	1.54	1.25*	.67
Shoulder					
Horizontal Ad/Abduction Moment	Phase 1	2.47	2.43	-2.38*	4.84*
	Phase 2	1.87	3.07	-.55	-.72
Anterior/Posterior Force	Phase 1	24.67	11.67	.22	1.43
	Phase 2	-6.98	26.58	-.09	-.43
Distraction/Compression Force	Phase 1	5.68	5.30	.08	-1.02
	Phase 2	-19.17	16.93	-.23	-.37
Internal/External Rotational Moment	Phase 1	1.48	0.89	-.32	1.42
	Phase 2	2.88	1.70	-1.71*	6.48*
Moment Magnitude	Phase 1	4.28	0.87	.59	.26
	Phase 2	6.99	2.28	1.01	1.54

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04. All moments were normalized to weight x height (N*m) while forces were normalized to weight. **Varus/valgus Moment:** (+) = Varus; (–) = Valgus; **Compression/distraction force:** (+) = compression; (–) = distraction; **Horizontal ad/abduction moment:** (+) = Adduction; (–) = Abduction; **Anterior/posterior** force: (+) = anterior; (–) = posterior. **Shoulder Internal/External Rotation:** (+) = internal, (−) = external.

Table 15: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 2 (normal glove) of Elbow Varus/Valgus Moment, Elbow Distraction/Compression Force, Elbow Moment Magnitude, Shoulder Horizontal Abduction/Adduction moment, Shoulder Anterior/Posterior force, shoulder Distraction/Compression force, Shoulder internal/external rotation torque, and shoulder moment magnitude averaged across phase 1 and phase 2 of the pitching motion (N = 18).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
Elbow					
Varus/Valgus Moment	Phase 1	0.92	0.35	.39	.29
	Phase 2	-1.08	1.40	1.21*	1.40
Distraction/Compression Force	Phase 1	5.82	4.45	.20	.11
	Phase 2	40.52	16.53	-.19	-1.06
Moment Magnitude	Phase 1	1.76	0.63	.76	.417
	Phase 2	5.12	1.42	.59	.95
Shoulder					
Horizontal Ab/Adduction Moment	Phase 1	2.59	2.43	-2.30*	4.60*
	Phase 2	1.81	2.65	-.37	-1.05
Anterior/Posterior Force	Phase 1	26.41	9.73	.17	.74
	Phase 2	-6.37	25.71	.45	-.09
Distraction/Compression Force	Phase 1	6.33	5.34	-.04	-1.51
	Phase 2	-22.52	13.23	-.26	-.40
Internal/External Rotational Moment	Phase 1	1.49	0.80	-1.15*	3.38*
	Phase 2	2.88	1.70	-1.51*	6.19*
Moment Magnitude	Phase 1	4.34	0.66	.45	-.16
	Phase 2	7.05	2.68	1.00	1.56

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04. All moments were normalized to weight x height (N*m) while forces were normalized to weight. **Varus/valgus Moment:** (+) = Varus; (–) = Valgus; **Compression/distraction force:** (+) = compression; (–) = distraction; **Horizontal ad/abduction moment:** (+) = Adduction; (–) = Abduction; **Anterior/posterior** force: (+) = anterior; (–) = posterior. **Shoulder Internal/External Rotation:** (+) = internal, (−) = external.

Table 16: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 3 (0.68 kg. training glove) of Elbow Varus/Valgus Moment, Elbow Distraction/Compression Force, Elbow Moment Magnitude, Shoulder Horizontal Abduction/Adduction moment, Shoulder Anterior/Posterior force, shoulder Distraction/Compression force, Shoulder internal/external rotation torque, and shoulder moment magnitude averaged across phase 1 and phase 2 of the pitching motion (N = 18).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
Elbow					
Varus/Valgus Moment	Phase 1	0.92	0.40	.20	.40
	Phase 2	-1.29	1.50	.73	.88
Distraction/Compression Force	Phase 1	6.53	5.24	.45	.63
	Phase 2	42.88	18.77	-.24	-.77
Moment Magnitude	Phase 1	1.86	0.73	41	-.37
	Phase 2	5.14	1.32	1.10*	.50
Shoulder					
Horizontal Ab/Adduction Moment	Phase 1	2.58	2.42	-2.17*	4.19*
	Phase 2	1.58	2.91	-.44	-1.04
Anterior/Posterior Force	Phase 1	25.36	10.80	-.20	.22
	Phase 2	-9.04	26.78	-.24	-.55
Distraction/Compression Force	Phase 1	5.14	6.02	.50	-.57
	Phase 2	-22.90	16.56	-.16	-.07
Internal/External Rotational Moment	Phase 1	1.63	0.87	-.65	1.32
	Phase 2	2.78	1.62	-2.01*	6.53*
Moment Magnitude	Phase 1	4.41	0.81	.56	-.44
	Phase 2	7.25	2.34	1.43*	2.71*

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04. All moments were normalized to weight x height (N*m) while forces were normalized to weight. **Varus/valgus Moment:** (+) = Varus; (–) = Valgus; **Compression/distraction force:** (+) = compression; (–) = distraction; **Horizontal ad/abduction moment:** (+) = Adduction; (–) = Abduction; **Anterior/posterior** force: (+) = anterior; (–) = posterior. **Shoulder Internal/External Rotation:** (+) = internal, (−) = external.

Table 17: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 4 (1.36 kg. training glove) of Elbow Varus/Valgus Moment, Elbow Distraction/Compression Force, Elbow Moment Magnitude, Shoulder Horizontal Abduction/Adduction moment, Shoulder Anterior/Posterior force, shoulder Distraction/Compression force, Shoulder internal/external rotation torque, and shoulder moment magnitude averaged across phase 1 and phase 2 of the pitching motion (N = 18).

Variable	Time Point	Mean	S. D.	Skewness	Kurtosis
Elbow					
Varus/Valgus Moment	Phase 1	0.09	0.34	.25	.65
	Phase 2	-1.03	1.62	.56	1.94
Distraction/Compression Force	Phase 1	6.36	4.65	-.64	.55
	Phase 2	38.60	19.57	.54	-.73
Moment Magnitude	Phase 1	1.68	0.67	1.61*	4.57*
	Phase 2	5.01	1.48	.31	-.64
Shoulder					
Horizontal Ab/Adduction Moment	Phase 1	2.47	2.40	-2.43*	5.01*
	Phase 2	1.71	2.66	-.62	-1.14
Anterior/Posterior Force	Phase 1	24.56	11.29	-.53	-.36
	Phase 2	-5.14	28.09	.17	.62
Distraction/Compression Force	Phase 1	5.58	5.92	.20	-.71
	Phase 2	-20.62	16.79	-.48	-.30
Internal/External Rotational Moment	Phase 1	1.42	0.83	-.45	4.23*
	Phase 2	2.80	1.79	-1.41*	4.57*
Moment Magnitude	Phase 1	4.17	0.66	.63	.81
	Phase 2	7.00	1.89	.37	1.07

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04. All moments were normalized to body weight x height (N*m) while forces were normalized to weight. **Varus/valgus Moment:** (+) = Varus; (–) = Valgus; **Compression/distraction force:** (+) = compression; (–) = distraction; **Horizontal ad/abduction moment:** (+) = Adduction; (–) = Abduction; **Anterior/posterior** force: (+) = anterior; (–) = posterior. **Shoulder Internal/External Rotation:** (+) = internal, (−) = external.

The assumption of sphericity was not met for interaction between glove type and time. Upon follow-up ANOVAs for elbow distraction/compression force

(W_2 = .493, p =.049), the Greenhouse-Geisser correction to those univariate tests was applied.

Although several variables struggled with univariate normality and the sample was a convenience sample, a 2 X 4 within-subjects MANOVA was used to determine significant differences between the set of dependent variables including elbow kinetics, elbow varus/valgus moment, elbow distraction/compression force, and overall elbow moment magnitude, with the interaction of weight in the glove hand and time because the rest of the assumptions were met. There was not a significant difference found in the set of dependent variables based on the interaction of glove type and time (Λ = .843, $F_{9,\ 119.40}$ = .964, p = .473, η^2 = .06) or the main effect of glove type (Λ = .903, $F_{9,\ 119.40}$ = 0.57, p = .822, η^2 = .03). Elbow kinetics are not significantly affected by the interaction of weight in the glove hand and the timing within the pitching motion or the main effect of weight in the glove hand.

For all the shoulder kinetics, the assumption of sphericity was not met for the interaction between glove type and time. Upon follow-up ANOVAs for shoulder horizontal abduction/adduction moment (W_2 = .298, p = .002) and overall shoulder moment magnitude (W_2 = .327, p = .004), the Greenhouse-Geisser correction to those univariate tests was applied.

Since all other multivariate assumptions were met, another 2 X 4 within-subjects MANOVA was used despite several variables struggling with univariate normality and the sample being a convenience sample. This MANOVA was used to determine significant differences between the set of dependent variables containing shoulder kinetics, shoulder horizontal abduction/adduction moment, shoulder anterior/posterior force, shoulder distraction/compression force, shoulder internal/external rotational moment, and overall shoulder moment magnitude, with the interaction of weight in the glove hand and time. There was not a significant difference found in the set of dependent variables based on the interaction of glove type and time (Λ = .762, $F_{15,\ 130.15}$ = .897, p = .569, η^2 = .09) or the main effect of glove type (Λ = .736, $F_{15,\ 130.15}$ = 1.02, p = .439, η^2 = .10). Shoulder kinetics are not significantly affected by the interaction of weight in the glove hand and the timing of the pitching motion or the main effect of weight in the glove hand.

RQ4. Does the weight in the glove hand during a fastball baseball pitch alter overall magnitude and segmental sequencing of the maximal angular velocities and accelerations of the following segments: pelvis, trunk, pitching arm humerus, and pitching arm forearm?

Univariate normality for all segmental velocities and accelerations were assessed using skewness and kurtosis. For the first condition of no glove in the non-throwing hand, maximum trunk angular acceleration during the pitching motion was right skewed (*skew* = 1.28, *SE* = .54). All other velocity and acceleration variables were univariate normal for skewness and kurtosis. The full results of skewness and kurtosis along with other descriptive statistics for question 4 can be found in Tables 18 - 21. The assumption of sphericity was met among the intervention of glove type on maximal velocities and accelerations.

Table 18: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 1 (no glove) of maximum velocity and acceleration for the pelvis, trunk, pitching arm humerus and pitching arm forearm during the pitching motion (N = 18).

Variable	Mean	S. D.	Skewness	Kurtosis
Maximum Velocity				
Pelvis (degrees/second)	721.05	143.78	-.75	.32
Trunk (degrees/second)	1047.52	117.33	.28	-.89
Humerus (degrees/second)	2933.88	470.94	.34	-.64
Forearm (degrees/second)	4411.14	282.70	.10	-.69
Maximum Acceleration				
Pelvis $(degrees/second)^2$	14275.57	2280.37	.52	-.69
Trunk $(degrees/second)^2$	23154.50	8147.80	1.28*	1.74
Humerus $(degrees/second)^2$	120905.58	25401.81	.41	-.98
Forearm $(degrees/second)^2$	173891.82	17564.72	.71	.09

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04.

Table 19: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 2 (normal glove) of maximum velocity and acceleration for the pelvis, trunk, pitching arm humerus and pitching arm forearm during the pitching motion (N = 18).

Variable	Mean	S. D.	Skewness	Kurtosis
Maximum Velocity				
Pelvis (degrees/second)	761.46	138.90	-.41	-.55
Trunk (degrees/second)	1062.42	117.87	-.11	-1.82
Humerus (degrees/second)	2945.45	454.78	-.03	-1.09
Forearm (degrees/second)	4424.92	297.74	.12	-.51
Maximum Acceleration				
Pelvis $(degrees/second)^2$	14286.15	3319.87	.71	.28
Trunk $(degrees/second)^2$	22107.20	6695.15	.78	.37
Humerus $(degrees/second)^2$	123093.79	25883.97	.39	-.82
Forearm$(degrees/second)^2$	174299.72	21146.54	-.46	.35

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04.

Table 20: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 3 (0.68 kg. training glove) of maximum velocity and acceleration for the pelvis, trunk, pitching arm humerus and pitching arm forearm during the pitching motion (N = 18).

Variable	Mean	S.D.	Skewness	Kurtosis
Maximum Velocity				
Pelvis (degrees/second)	734.69	137.00	-.55	-.74
Trunk (degrees/second)	1035.93	115.27	.10	-1.03
Humerus (degrees/second)	2959.71	451.61	.05	-1.28
Forearm (degrees/second)	4379.40	294.36	-.32	.15
Maximum Acceleration				
Pelvis $(degrees/second)^2$	15424.16	3647.44	.45	-.31
Trunk$(degrees/second)^2$	21854.91	7471.56	.92	.23
Humerus$(degrees/second)^2$	125743.28	24843.79	.07	-.84
Forearm $(degrees/second)^2$	172437.70	16936.19	-.14	-.62

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04

Table 21: Descriptive statistics (mean, standard deviation (S.D.) skewness, kurtosis) for condition 4 (1.36 kg. training glove) of maximum velocity and acceleration for the pelvis, trunk, pitching arm humerus and pitching arm forearm during the pitching motion (N = 18).

Variable	Mean	S. D.	Skewness	Kurtosis
Maximum Velocity				
Pelvis (degrees/second)	725.84	111.77	-.33	.03
Trunk (degrees/second)	1044.94	112.86	.07	-.74
Humerus (degrees/second)	2932.47	408.29	-.02	-.63
Forearm (degrees/second)	4392.29	293.22	-.06	-.55
Maximum Acceleration				
Pelvis$(degrees/second)^2$	14010.05	2580.14	-.24	-.22
Trunk$(degrees/second)^2$	21711.88	6047.06	.84	.58
Humerus $(degrees/second)^2$	120718.80	23223.17	.15	-.11
Forearm $(degrees/second)^2$	169693.48	15647.55	-.11	.02

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04

A 4-way within-subjects MANOVA was used to determine significant differences between the set of dependent variables, maximal velocities and accelerations of the pelvis, trunk, humerus, and forearm, with weight in the glove hand. There was a significant difference found in the set of dependent variables based on glove type (Λ = .436, $F_{24,\ 128.22}$ = 1.77, p = .023). About 24 percent of the variance seen in maximal velocities and accelerations of the pelvis, trunk, humerus, and forearm are accounted for by weight in the glove hand (η^2 = .24). Eight 4-way ANOVAs were used to determine whether there was significance on each of the dependent variables. The testwise Type I error rate was set to .006 for all follow-up analyses, using the Bonferonni inequality to control for familywise error. No significant univariate effect was found among the dependent variables. Full results of the follow up ANOVAs can be found in Table 22.

Table 22: Analysis of Variance Results for Glove Condition (No Glove, Normal Glove, 0.68 kg. training glove, and 1.36 kg. training glove).

Measure	Sum of Squares	d.f.	Mean Square	F	Sig. of F	η^2
Maximum Velocity						
Pelvis	17571.35	3	5857.12	3.19	.031	.16
Trunk	6529.11	3	2176.37	1.04	.384	.06
Humerus	8626.75	3	2875.58	0.19	.867	.01
Forearm	21853.33	3	7284.44	0.75	.530	.04
Maximum Acceleration						
Pelvis	21423780.09	3	7141260.03	2.28	.090	.12
Trunk	22982907.10	3	7660969.03	1.70	.187	.09
Humerus	297595520.00	3	135423689.70	1.05	.377	.06
Forearm	234549654.70	3	78183218.24	1.19	.322	.07

Note: Significance was indicated by $p \leq .006$.

Although several variables struggled with univariate normality and the sample was a convenience sample, all other multivariate assumptions were met. Therefore, another 4-way within-subjects MANOVA was used to determine significant differences between the set of dependent variables, sequencing of the pelvis, trunk, humerus, and forearm velocities and accelerations, with weight in the glove hand. There was no significant difference found in the set of dependent variables based on glove type (Λ = .519, $F_{24,\ 128.22}$ = 1.36, p = .142, η^2 = .20). Sequencing of pelvis, trunk, humerus, and forearm velocities and acceleration are not significantly affected by weight in the non-throwing hand. Timing of the pitching motion can be seen in Figure 6. Descriptive statistics can be found in Tables 23 - 26.

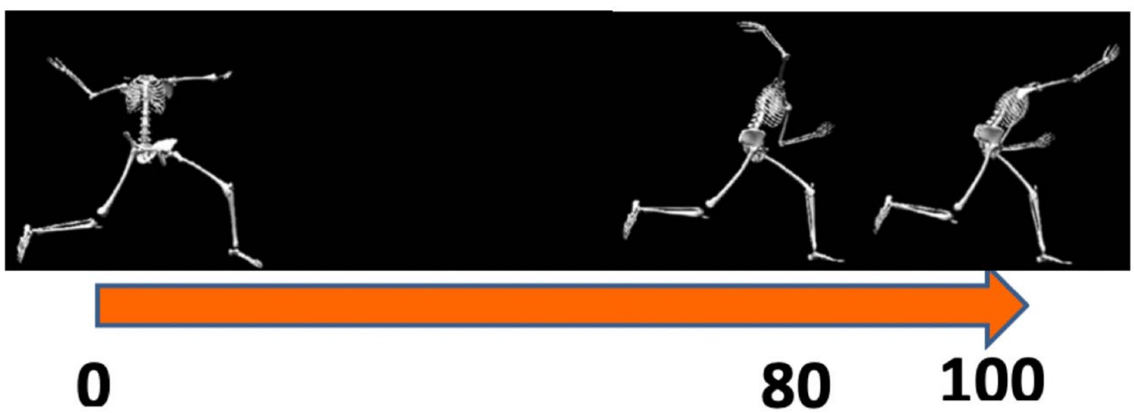

Figure 6: Timing of the pitching motion with events of Foot Contact, MER (Maximum Shoulder External Rotation), and Ball Release.

Table 23: Descriptive statistics (mean, standard deviation (S.D.), skewness, kurtosis) of percentage of pitching motion of maximum velocity and acceleration for the pelvis, trunk, pitching arm humerus and pitching arm forearm for condition 1 (no glove) (N = 18).

Variable	Mean	S. D.	Skewness	Kurtosis
Maximum Velocity				
Pelvis (%)	30.48	13.65	-.94	.22
Trunk (%)	50.98	12.74	-1.60*	1.90
Humerus (%)	94.25	3.32	-.78	.02
Forearm (%)	88.11	3.75	-.55	-.70
Maximum Acceleration				
Pelvis (%)	66.76	19.54	.43	-.71
Trunk (%)	81.20	20.74	-3.16*	11.80*
Humerus (%)	100.87	3.04	-2.99*	9.53*
Forearm (%)	88.04	7.01	.42	-1.06

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04.

Table 24: Descriptive statistics (mean, standard deviation (S.D.), skewness, kurtosis) of percentage of pitching motion of maximum velocity and acceleration for the pelvis, trunk, pitching arm humerus and pitching arm forearm for condition 2 (normal glove) (N = 18).

Variable	Mean	S.D.	Skewness	Kurtosis
Maximum Velocity				
Pelvis (%)	29.76	15.58	.85	2.41*
Trunk (%)	49.11	13.94	-.70	-.26
Humerus (%)	92.32	4.13	-1.51*	2.75*
Forearm (%)	85.97	4.47	-.98	2.45*
Maximum Acceleration				
Pelvis (%)	63.70	22.21	-.48	-.32
Trunk (%)	83.24	18.49	-1.70*	2.48*
Humerus (%)	100.32	3.55	-2.91*	9.82*
Forearm (%)	84.85	7.98	.90	-.38

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04.

Table 25: Descriptive statistics (mean, standard deviation (S.D.), skewness, kurtosis) of percentage of pitching motion of maximum velocity and acceleration for the pelvis, trunk, pitching arm humerus and pitching arm forearm for condition 3 (0.68 kg. training glove) (N = 18).

Variable	Mean	S.D.	Skewness	Kurtosis
Maximum Velocity				
Pelvis (%)	25.78	11.17	-.13	-.26
Trunk (%)	50.52	8.32	-.74	.39
Humerus (%)	92.82	2.86	.78	.71
Forearm (%)	86.28	2.78	.56	.29
Maximum Acceleration				
Pelvis (%)	62.03	17.37	.65	-.24
Trunk (%)	86.00	10.20	-.10	-1.30
Humerus (%)	99.69	4.61	-2.12*	4.12*
Forearm (%)	87.02	7.39	.20	-1.84

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04.

Table 26: Descriptive statistics (mean, standard deviation (S.D.), skewness, kurtosis) of percentage of pitching motion of maximum velocity and acceleration for the pelvis, trunk, pitching arm humerus and pitching arm forearm for condition 4 (1.36 kg. training glove) (N = 18).

Variable	Mean	S.D.	Skewness	Kurtosis
Maximum Velocity				
Pelvis (%)	30.24	14.81	.32	-.55
Trunk (%)	51.48	11.92	-.65	.12
Humerus (%)	94.06	2.55	-.66	-.46
Forearm (%)	87.71	3.03	-.24	-.01
Maximum Acceleration				
Pelvis (%)	54.99	20.93	-.54	1.30
Trunk (%)	89.35	8.21	-.66	-.08
Humerus (%)	100.03	4.83	-2.67*	7.06*
Forearm (%)	87.29	7.78	.55	-1.24

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04.

RQ5. Does the amount of weight in the glove hand during a fastball baseball pitch alter the muscle activation peak magnitude and timing to peak magnitude during the baseball pitching motion for the following muscles: glove side latissimus dorsi, throwing side gluteus maximus, throwing side gluteus medius, throwing side lower trapezius, bilateral serratus anterior, and bilateral external oblique?

Univariate normality was assessed using skewness and kurtosis. Initially, data were not univariate normal. Therefore, a natural log transformation was applied to all the variables. The reported results below were after the data transformation. For the first condition of no glove, lower trapezius was right skewed (*skew* = 1.12, *SE* = .54), gluteus medius was right skewed and leptokurtotic (skew = 1.35, SE = .54, *kurtosis* = 2.91, *SE* = 1.04) and the throwing side serratus anterior was leptokurtotic (*kurtosis* = 2.63, *SE* = 1.04). For the second condition of normal glove, glove side serratus anterior was right skewed and leptokurtotic (*skew* = 1.89, *SE* = .54, *kurtosis* = 3.48, *SE* = 1.04). For the third condition of a 0.68 kg training glove, glove side serratus anterior was right skewed and leptokurtotic (*skew* = 1.79, *SE* = .54, *kurtosis* = 3.04, *SE* = 1.04), gluteus medius was right skewed and leptokurtotic (*skew* = 1.40, *SE* = .54; *kurtosis* = 2.55, *SE* = 1.04), and the throwing side serratus anterior was right skewed and leptokurtotic (*skew* = 1.74, *SE* = .54; *kurtosis* = 4.93, *SE* = 1.04). For the fourth condition of a 1.36 kg training glove, the glove side serratus anterior was right skewed and leptokurtotic (*skew* = 2.05, *SE* = .54; *kurtosis* = 4.08, *SE* = 1.04) and gluteus medius was right skewed (*skew* = 1.08, *SE* = .54). All other variables were univariate normal by skewness and kurtosis and can be found in tables 27 - 30 along with the rest of the descriptive statistics.

Table 27: Descriptive statistics (mean, standard deviation (S.D.), skewness, kurtosis) of maximum muscular activity as a percentage of MVIC and timing of maximum muscular activity during the baseball pitching motion for condition 1 (no glove) (N = 18).

Muscle	Mean	S.D.	Skewness	Kurtosis	% of Pitch	S.D.
Glove Side						
Serratus Anterior	237.16	205.41	.79	1.80	45.08	24.41
External Oblique	1253.89	2315.43	.20	-.48	63.14	32.38
Latissimus Dorsi	276.93	612.70	.60	.33	66.57	37.82
Throwing Side						
Lower Trapezius	40.06	54.45	1.12*	.44	89.03	18.12
Gluteus Maximus	166.27	83.98	.08	-.23	52.49	37.87
Gluteus Medius	240.12	494.24	1.35*	2.91*	52.29	40.80
External Oblique	354.80	598.31	.46	-.73	58.26	36.41
Serratus Anterior	153.58	74.31	-.68	2.63*	57.92	43.80

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04.

Table 28: Descriptive statistics (mean, standard deviation (S.D.), skewness, kurtosis) of maximum muscular activity as a percentage of MVIC and timing of maximum muscular activity during the baseball pitching motion for condition 2 (normal glove) (N = 18).

Muscle	Mean	S.D.	Skewness	Kurtosis	% of Pitch	S.D.
Glove Side						
Serratus Anterior	260.73	231.26	1.89*	3.48*	45.09	21.83
External Oblique	550.60	677.13	.25	-.80	59.06	28.07
Latissimus Dorsi	179.07	245.97	.20	-.70	71.46	35.05
Throwing Side						
Lower Trapezius	33.06	34.31	.80	.24	90.92	15.58
Gluteus Maximus	169.53	119.28	.30	-.52	47.98	36.31
Gluteus Medius	132.53	144.17	.37	-.26	46.95	38.48
External Oblique	305.18	432.42	.77	.22	60.01	36.57
Serratus Anterior	160.87	75.85	-.20	.91	51.98	45.95

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04.

Table 29: Descriptive statistics (mean, standard deviation (S.D.), skewness, kurtosis) of maximum muscular activity and timing of maximum muscular activity during the baseball pitching motion for condition 3 (0.68 kg. training glove) (N = 18).

Muscle	Mean	S.D.	Skewness	Kurtosis	% of Pitch	S.D.
Glove Side						
Serratus Anterior	194.35	177.61	1.79*	3.04*	39.88	25.77
External Oblique	1914.46	4491.78	.69	.01	58.86	29.36
Latissimus Dorsi	227.30	391.86	.38	-.43	76.81	24.84
Throwing Side						
Lower Trapezius	50.09	79.97	.84	.92	90.06	10.01
Gluteus Maximus	172.84	144.95	.73	-.42	40.46	38.31
Gluteus Medius	203.96	475.80	1.40*	2.55*	45.98	40.00
External Oblique	629.51	924.40	.41	-.86	65.77	38.15
Serratus Anterior	174.00	216.09	1.74*	4.93*	44.84	45.48

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04.

Table 30: Descriptive statistics (mean, standard deviation (S.D.), skewness, kurtosis) of maximum muscular activity as a percentage of MVIC and timing of maximum muscular activity during the baseball pitching motion for condition 4 (1.36 kg. training glove) (N = 18).

Muscle	Mean	S.D.	Skewness	Kurtosis	% of Pitch	S.D.
Glove Side						
Serratus Anterior	216.70	213.87	2.05*	4.08*	46.24	26.85
External Oblique	2583.07	6052.77	.41	.07	55.68	30.36
Latissimus Dorsi	199.57	291.12	.17	-.26	43.70	39.17
Throwing Side						
Lower Trapezius	41.39	54.72	.24	-.46	90.53	10.27
Gluteus Maximus	158.35	110.28	.77	.30	50.14	35.81
Gluteus Medius	295.03	582.84	1.08*	.36	54.79	37.49
External Oblique	279.91	306.48	-.37	-.48	44.01	35.03
Serratus Anterior	158.89	83.87	.97	1.07	42.79	42.13

*Note: *indicates that the value is twice the standard error.* Standard error of skewness = .54; standard error of kurtosis = 1.04

Although some variables struggled with univariate normality and the sample was a convenience sample, all other multivariate assumptions were met. Therefore, a 4-way within-subjects MANOVA was used to determine significant differences between the set of dependent variables, peak magnitude of the glove side serratus anterior, glove side external oblique, glove side latissimus dorsi, throwing side lower trapezius, throwing side gluteus maximus, throwing side gluteus medius, throwing side external oblique, and throwing side serratus anterior, with weight in the glove hand. There was no significant difference found in the set of dependent variables based on glove type (Λ = .650, $F_{24,\ 128.22}$ = .856, p = .660, η^2 = .13). Peak muscle activation during the baseball pitch was not significantly affected by the amount of weight in the glove hand.

With regard to timing to peak magnitude, another 4-way within-subjects MANOVA was used to determine the significant differences between the set of dependent variables, percent of the pitching motion at which peak magnitude of the glove side serratus anterior, glove side external oblique, glove side latissimus dorsi, throwing side lower trapezius, throwing side gluteus maximus, throwing side gluteus medius, throwing side external oblique, and throwing side serratus anterior, with weight in the glove hand. There was no significant difference found in the set of dependent variables based on glove type (Λ = .521, $F_{24,\ 128.22}$ = 1.35, p = .148, η^2 = .20). The timing to peak muscle magnitude during the baseball pitch was not significantly affected by the amount of weight in the glove hand.

CHAPTER V

DISCUSSION

The purpose of this research was to examine the effect that weight in the glove hand has on upper extremity and LPHC muscle activation; glove arm, trunk, and pitching arm kinematics; and pitching arm kinetics during the baseball pitch. This chapter discusses the results from this study and elaborates on practical applications for baseball pitchers and future directions of the findings.

RQ1: Does the amount of weight in the glove hand during a fastball baseball pitch alter the following glove arm kinematics: glove arm elbow flexion, glove arm shoulder horizontal abduction, and glove arm shoulder flexion?

The hypothesis that as the weight in the glove hand increases among participants, increased glove arm shoulder flexion, shoulder horizontal abduction, and elbow extension would be observed at foot contact and during arm cocking was rejected. However, the hypothesis that increased glove arm shoulder extension, shoulder horizontal adduction, and elbow flexion would be observed as weight increases in the glove hand during arm acceleration and at ball release was partially supported. Results revealed that as weight increased in the glove hand, glove arm kinematics were affected. Specifically, glove arm elbow flexion increased not only during arm acceleration and ball release but also at foot contact and arm cocking. Of the glove arm kinematics examined in this study, weight in the glove hand only had a significant impact on elbow flexion/extension in the glove arm. Interestingly, no significance was found with the interaction between weight in the glove hand and the timing of the pitching motion affecting either glove shoulder flexion or glove shoulder horizontal abduction.

In a study observing biomechanical changes across the first few years of a pitcher's career, Fleisig and colleagues indicated that a heavy glove seemed to inhibit the pitcher's ability to tuck their glove to their chest.[108] In the current study, results counter this observation made by Fleisig et. al. However, the differences in inclusion criteria and participant age should be included as a potential reason for this difference. Fleisig et. al. chose to conduct a longitudinal study on youth baseball pitchers beginning their first year of kid pitch.[108] The current study examined participants classified as having a stable lumbopelvic-hip complex (LPHC) between the ages of 15 – 22 that were currently pitching on a competitive high school or college baseball team. Examining the influence that glove weight has on glove arm kinematics of participants with a stable LPHC, the current study provides evidence of the participants performing the pitching motion with increased glove arm elbow flexion throughout the entire motion as the weight in the glove hand increased. For further insight into the impact that glove weight has on glove elbow flexion and extension, please see Figure 7 (below).

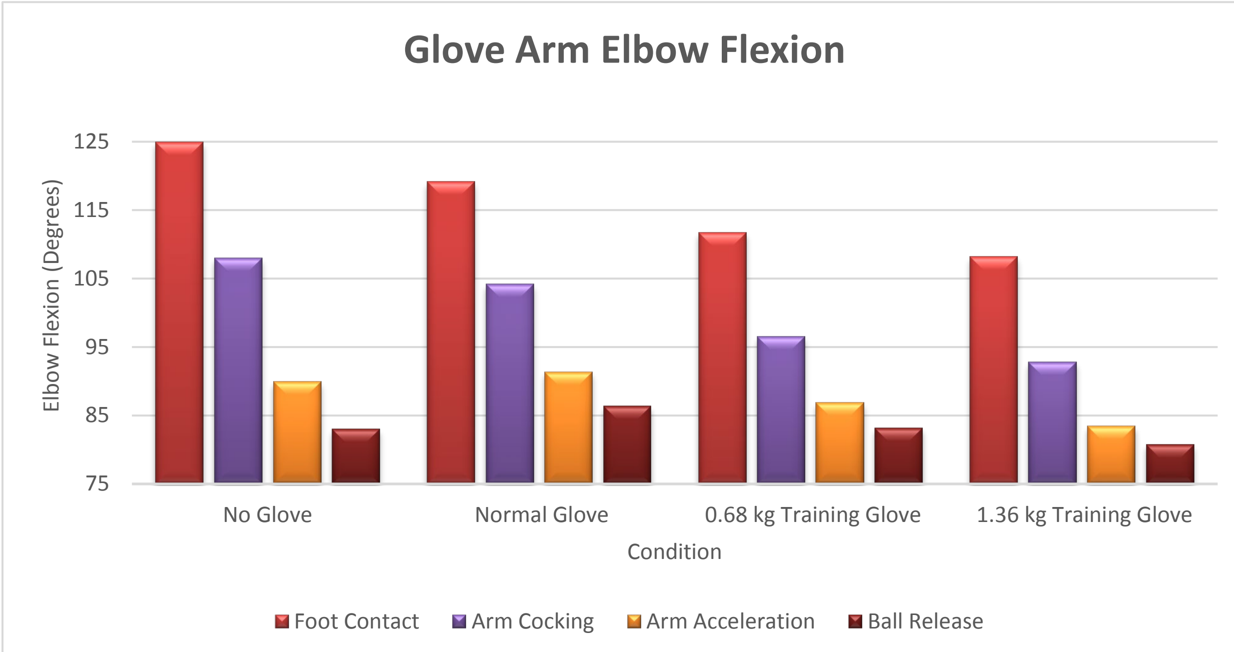

Figure 7: Amount of glove arm elbow flexion throughout the pitching motion for all four conditions. (**Flexion** = 0˚; **Extension** = 180˚)

Previous research has indicated that glove arm elbow flexion impacts the moment of inertia of trunk rotation.[33,108] The current results indicate that participants with a stable LPHC are naturally aware of the impact that elbow flexion has on the trunk's moment of inertia during the pitching motion. The trunk's moment of inertia decreases as elbow flexion increases. In concordance with the effect on segmental sequencing seen in the fourth research question, the separation between pelvis and trunk angular velocity increased as the weight in the glove hand increased, Participants with a stable LPHC, increased glove arm elbow flexion throughout the pitching motion in order to increase the usage of passive motion dependent torque for maximum ball velocity. Future studies should examine the impact that weight in the glove hand has on elbow flexion/extension between participants with both stable and unstable LPHC as well as between novice youth baseball pitchers and more advanced ages. Also, future research should determine the full effect that elbow flexion/extension has on the trunk's moment of inertia, angular velocity, and angular acceleration.

While multivariate significance was found when examining the influence of the interaction between weight in glove hand with the timing of the pitching motion has on glove arm kinematics, follow-up univariate tests revealed no specific significant impact that the interaction has on either of the glove shoulder kinematics examined. Murata examined the relationship between glove shoulder motion and baseball pitch velocity and found an inverse relationship between those variables.[107] According to Murata, minimal glove shoulder motion has a positive relationship with increased ball velocity.[107] Although ball velocity across all four glove conditions were similar (Table 3), they were slightly slower than those reported by Murata.[107] Given these points, future studies examining the influence that weight in the glove hand has on glove arm shoulder flexion or glove arm shoulder horizontal abduction should control for ball velocity.

Limitations to this study include not controlling for strength in a pitcher's non-throwing arm elbow flexors. This prevents designation of increased elbow flexion throughout the pitching motion to be strictly linked to a pitcher's LPHC stability and their willingness to decrease the moment of inertia for torso rotation. Future studies should control for elbow flexor strength when examining the impact that glove weight has on glove arm kinematics. Also, future studies should examine the training implications across a longitudinal study of using various weights in the glove hand for glove arm kinematics during the pitching motion. Findings from the current study suggest that while glove weight influences glove arm kinematics, pitchers with a stable LPHC may only have their glove arm elbow flexion/extension affected. Coaches and players should consider the weight of the glove used by pitchers as a mechanism to alter glove arm kinematics in an effort to affect the dynamic coupling occurring during the pitching motion.

RQ2: Does the weight in the glove hand during a fastball baseball pitch alter the following trunk kinematics: trunk flexion, trunk lateral flexion, and trunk axial rotation?

The hypothesis that as the weight in the glove hand increases among participants, trunk kinematics (trunk flexion, trunk lateral flexion, and trunk axial rotation) at each event and phase of the pitching motion would be closer to their anatomical neutral position when compared to lighter weight conditions was rejected. Results revealed that the interaction between weight in the glove hand and time during the pitching motion has no significant effect on trunk kinematics.

Previous research has documented the implications that glove arm kinematics have on trunk kinematics.[32,33] These studies concluded that glove arm kinematics impact the torso moment of inertia therefore effecting trunk kinematics during the baseball pitch.[32,33] However, none of the previous studies examined the influence of weight in the glove hand on trunk kinematics.

In the current study, the examination of the impact that weight in the glove hand had on trunk kinematics could have been nullified due to the inclusion criteria. Inclusion criteria called for participants that tested as stable by both the closed kinetic chain upper extremity stability test (CKCUEST) and the Single-leg Squat (SLS). These results suggest that if a pitcher can maintain stability in their LPHC, then adding a small weight to the glove hand could have no direct effect on trunk kinematics. However, future studies should examine the effect fatigue plays when examining the impact varying glove weights have on trunk kinematics. This branch of study should include the impact that glove weight has at the end of a single game or 100 pitches as well as the impact that glove weight has across the season.

Limitations for this question include excluding the arm cocking phase in the data analysis. By deciding to define trunk kinematics in reference to the world axis, this created a conundrum for the arm cocking phase due to the axial rotation occurring during that phase. At foot contact, with the trunk axially rotated 90 degrees to the pitching arm side, trunk lateral flexion was about the Z-axis and trunk flexion was about the X-axis. Upon the trunk rotating square to the target, trunk lateral flexion was about the X-axis and trunk flexion was about the Z-axis. Therefore, averaging the value across the arm cocking phase, when trunk rotation was occurring, was not possible as the variables were defined. From the findings of this study, baseball coaches and players can coach and train knowing that the trunk kinematics of a pitcher with stable LPHC are not significantly influenced by altered external load in the glove hand. However, the baseball community should examine the influence that various glove weights have on pitchers with an unstable LPHC before making the claim that glove choice has no significant impact on trunk kinematics during the baseball pitching motion.

RQ3: Does the weight in the glove hand during a fastball baseball pitch alter the following pitching shoulder and elbow joint loads: elbow varus/valgus moment, elbow distraction/compression force, resultant elbow moment magnitude, shoulder internal/external rotation moment, shoulder anterior/posterior force, shoulder compression/distraction force, shoulder horizontal ad/abduction moment and resultant shoulder moment magnitude?

The hypothesis that as the weight in the glove hand increases among participants, decreased pitching shoulder and elbow kinetics would be observed at each event and phase of the pitching motion was not supported. Data collected were comparable to other normalized pitching shoulder and elbow kinetics reported in the literature.[33,100,108,135,136] Results revealed that the interaction of weight in the glove hand with the timing of the pitching motion exhibited no significant effect on either pitching elbow or pitching shoulder kinetics. This was the first study to the author's knowledge to examine the effects that weight in the glove hand has on pitching shoulder kinetics.

Previous research has concluded that an active glove arm, deemed as the pitcher closing the gap between the glove arm and pitching arm during arm acceleration is advantageous to achieving an efficient pitching motion.[33] Barfield and colleagues determined that a relationship exists between glove arm elbow flexion and glove arm shoulder horizontal abduction with various kinetics of the pitching shoulder and elbow at MER and BR.[33] While glove arm kinematics have shown to have a relationship with pitching shoulder and elbow kinetics in previous research,[33] the apparent weight of the glove has no significant impact on joint stress observed in the pitching shoulder and elbow during the pitching motion of participants with a stable LPHC.

The inclusion of participants classified as having LPHC stability may have had an effect on the pitcher's ability to withstand varying weights in the glove hand. A pitcher who can dynamically stabilize their LPHC should be able to withstand additional loads added to their glove hand and maintain consistent dynamic coupling used to achieve maximal ball velocity. Comparing the effects of glove weight on pitching shoulder and elbow kinetics between LPHC stable and unstable participants is a future direction for studies examining the influence of weight in the glove hand.

Limitations to this question include examining only participants with a stable LPHC without considering unstable LPHC participants as a control. Also, to combat system error, this study was only a within-subjects design. The findings of the current study suggest that pitchers able to stabilize their LPHC will be capable of minimizing changes in pitching shoulder and elbow joint loads despite altered weight in the glove hand. Pitchers with stable LPHC should be able to choose a heavier or lighter glove model without significant impact to their pitching shoulder and elbow kinetics.

RQ4: Does the weight in the glove hand during a fastball baseball pitch alter overall magnitude and segmental sequencing of the maximal angular velocities and accelerations of the following segments: pelvis, trunk, pitching arm humerus, and pitching arm forearm?

Data for maximal segmental velocities and accelerations were in line with previous research performed on similar age participants[17] and appeared reasonable when compared to previous literature examining younger participants.[108,126] However, the hypothesis that as the weight in the glove hand increases among participants, segmental velocities and accelerations of the pelvis, trunk, humerus, and forearm would increase was rejected. Also, the second part of the hypothesis that as the weight in the glove hand increases, timing between maximal segmental velocities and accelerations would occur in a proximal to distal sequence with more time in between subsequent segment maximums was rejected. These findings, seen in Tables 22-25, agreed with previous research on the order of maximal segmental velocity and acceleration during the pitching motion suggesting that the humerus and forearm do not achieve maximal velocity and acceleration in a proximal to distal fashion.[21,126] Please see Figures 8 and 9 (below) for further insight in the timing within pitching motion that segmental velocities and accelerations were reached.

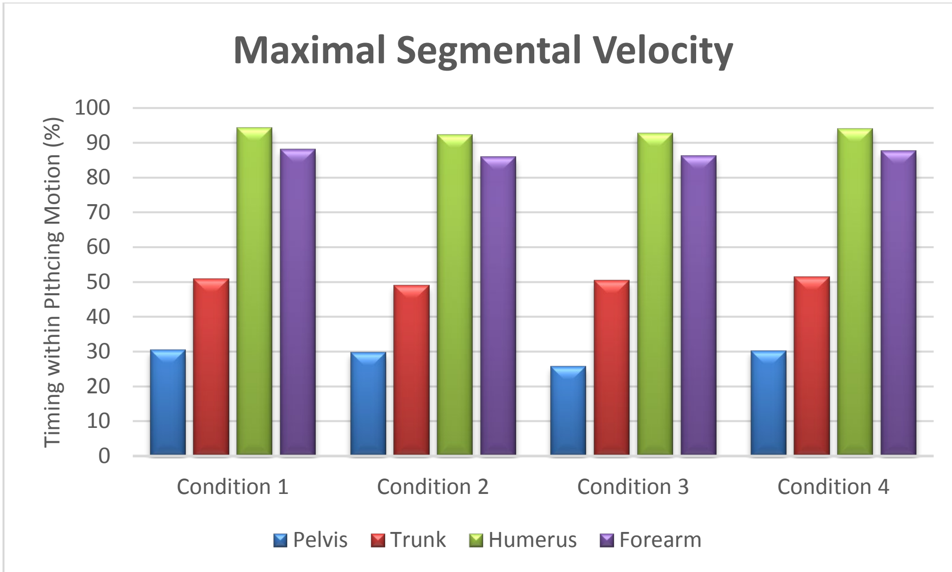

Figure 8: Timing within pitching motion that maximal segmental velocity of the pelvis, trunk, pitching arm humerus, and pitching arm forearm was reached. *Note: Foot contact was 0 % while ball release was 100%.*

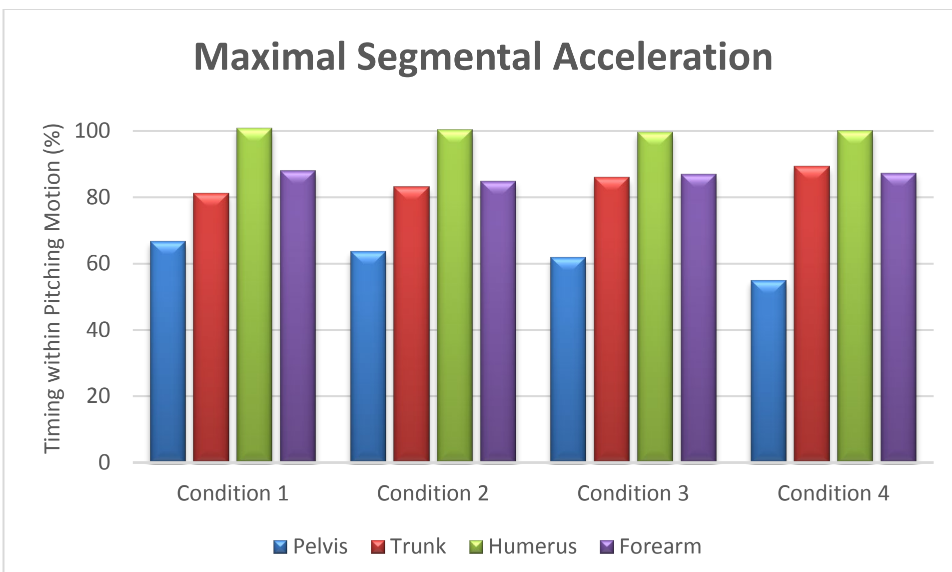

Figure 9: Timing within pitching motion that maximal segmental acceleration of the pelvis, trunk, pitching arm humerus, and pitching arm forearm was attained. *Note: Foot contact was 0 % while ball release was 100%.*

Results revealed that the weight in the glove hand had a significant effect on the overall magnitude of the angular velocities and accelerations for the pelvis, trunk, humerus, and forearm during the baseball pitching motion. However, increased weight in the glove hand does not lead to increased angular velocities and accelerations of the pelvis, trunk, pitching arm humerus, or pitching arm forearm. In regard to segmental sequencing, weight in the glove hand appears to have an effect on the maximal segmental acceleration timing during the baseball pitch.

With the current study, no significant univariate results were found when examining maximal segmental angular velocities and accelerations. However, when examining the descriptive statistics following the significant multivariate effect, it appears maximal segmental velocities occurred with the normal glove. Although the study controlled for the testing effect by randomizing all four glove conditions, these results call into question how much the unfamiliarity of pitching with either no glove, a 0.68 kg training glove, or 1.36 kg training glove impacts the segmental sequencing. Future studies should look to control for this unfamiliarity by introducing the participants to the varying glove weights days prior to actual testing.

The second MANOVA revealed no significance between weight in the glove hand and timing of segmental maximal velocities and accelerations. However, descriptive statistics of the timing between segmental angular accelerations reveal increased time between maximal angular acceleration of the pelvis and torso as the weight in the glove hand increased. This concurs with Ishida and Hirano who examined the effect of an unused glove arm and suggested that the timing of torso rotational velocity rotation was affected more than the overall magnitude.[32] Future studies should follow up and specifically examine the influence glove weight has on pelvis and torso separation.

Limitations to this research question include examining only peak magnitude of angular velocity and accelerations. Since the baseball pitching motion is a combination of linear and angular motion, linear velocities and accelerations should not be neglected. Future studies should analyze the impact that glove weight has on linear segmental velocities and accelerations. The findings in the current study suggest that participants generate more angular velocity with their normal glove compared to the other conditions. Coaches should allow pitchers to use a glove in which they are most comfortable or familiar in order to optimize angular segmental velocity during the baseball motion.

RQ5: Does the amount of weight in the glove hand during a fastball baseball pitch alter the muscle activation peak magnitude and timing to peak magnitude during the baseball pitching motion for the following muscles: glove side latissimus dorsi, throwing side gluteus maximus, throwing side gluteus medius, throwing side lower trapezius, bilateral serratus anterior, and bilateral external oblique?

The hypothesis that as the weight in the glove hand increases among participants, the timing of peak activation of the latissimus dorsi, lower trapezius, and serratus anterior would occur sooner while the gluteus maximus, gluteus medius, and external oblique peak contraction will occur later in the pitching motion was rejected. Additionally, the hypothesis that as the weight in the glove hand increases, the latissimus dorsi, gluteus maximus, gluteus medius, and external oblique would display an increase in muscle activation, while the lower trapezius and serratus anterior would display a decrease in muscle activation was also rejected. Results revealed no significant differences in muscle activation or muscle timing based on the weight of the glove.

The thought that altered muscle activity would coincide with altered segmental sequencing was not proven in this study. While multivariate significance was found between weight in the glove hand and maximal segmental angular velocities and accelerations, no significance was seen when examining the influence glove weight has on muscle activation peak magnitude of the glove and throwing side serratus anterior, glove and throwing side external oblique, glove side latissimus dorsi, throwing side lower trapezius, throwing side gluteus maximus, and throwing side gluteus medius. If the body behaves as a dynamic coupling system indicated in previous research,[35] then combining the results for question 4 with question 5 indicate that the altered segmental velocities and accelerations were not directly affected by muscle dependent torque of the examined muscles.

Limitations of this question include only being able to test 8 muscles during the pitching motion. With the pitching motion being a full body motion, the muscle dependent torque generated during the motion come from many different muscles. Future studies should examine the impact that glove weight has on other muscles. With the conclusions reached by Murata that the non-throwing arm shoulder acts as a fulcrum on which torso rotation advances,[107] musculature around that region should be of interest. Specifically, future studies should examine the impact that glove weight has on the biceps brachii, triceps brachii, deltoid, and rotator cuff musculature of the non-throwing arm during the baseball pitching motion.

Additional limitations to this research question include the variability seen with the muscle activation peak magnitude normalized to a maximum voluntary isometric contraction (MVIC) trial. Reasons for this variability, particularly with the glove side external oblique, can be attributed to normalizing a dynamic movement to a static contraction and participant effort during the MVIC trial. In an attempt to combat this variability within the results, data were natural log transformed. Future studies should examine the benefits to dynamic normalization, especially when analyzing dynamic motion, for EMG variability. Also, there was increased muscle activation and variability within conditions other than normal glove with the glove side external oblique. Further research should be performed to analyze what influence that weight in the glove hand has on LPHC musculature.

Although no multivariate significance among timing of peak magnitude muscle activation was observed in this study, a trend of glove side peak magnitude muscle activation occurring sooner in the pitching motion can be seen in the descriptive statistics. Future studies should examine the relationship between timing to peak muscle activation on the glove side with the stability inclusion criteria used in this study. These results could help shed light on the impact that varying glove weights had on a stable participant’s pitching motion. The baseball community should be aware that pitcher’s able to dynamically stabilize their body will not have their muscular activation or timing to peak muscle activation significantly influenced when an altered external load in the glove hand is used.

Conclusions:

The results of this study revealed that weight in the glove hand has a significant influence on glove arm kinematics during all analyzed time points of the baseball pitching motion. Specifically, when examining glove arm kinematics, univariate significance was found between weight in the glove hand and glove arm elbow flexion at FC, phase 1, and phase 2 of the baseball pitching motion. Increased glove arm elbow flexion was found at all analyzed time points of the pitching motion as the weight in the glove hand increased. When participants held heavier weight in their glove hand, they tucked their glove closer to their chest during the baseball pitching motion. Accordingly, participants subconsciously shortened the moment arm of the trunk during the entire pitching motion when using a heavier external load in the glove hand. Future studies should include ball velocity to determine the extent that increased glove arm elbow flexion represents a mechanism to effect pitching motion efficiency.

Additionally, significance was found with weight in the glove hand impacting angular velocity and acceleration peak magnitude of the pelvis, trunk, humerus, and forearm. Interestingly, when examining the descriptive statistics of angular velocity and acceleration peak magnitude of various segments, the fastest velocities appeared during the normal glove condition. Whether familiarization with this condition influenced increased angular velocity and acceleration magnitudes is not known. Future research should allow familiarization of various glove weights to analyze if this finding holds true. Also, researchers should examine the impact that weight in the glove hand has for participants with an unstable LPHC. From this study, coaches and players within the baseball community should ensure that baseball pitchers with a stable LPHC use a glove that is comfortable to them. Further research is needed to determine the training effect of pitching with varying weights in the glove hand to determine if weight in the glove hand can be used to aid performance.

References:

1. Wolken D. Soccer could be more popular than baseball when World Cup comes to the U.S. in 2026. USA Today. https://www.usatoday.com/story/sports/2018/07/17/world-cup-could-soccer-surpass-baseball-popularity-2026-all-star-game/789223002/. Published 2018. Accessed September 24, 2018.
2. Gay J. Reports of Baseball's Popular Decline Are…Popular. Wall Street Journal. https://www.wsj.com/articles/reports-of-baseballs-popular-decline-arepopular-1529596455. Published 2018. Accessed September 24, 2018.
3. Brown M. Has MLB Been Passed By The NBA In Popularity? The Problems With The Gallup Poll. Forbes. https://www.forbes.com/sites/maurybrown/2018/01/12/has-mlb-been-passed-by-the-nba-in-popularity-the-problems-with-the-gallup-poll/#da8c8142cd34. Published 2018. Accessed September 24, 2018.
4. Elias R. *Baseball and the American Dream: Race, Class, Gender, and the National Pastime*. Routledge; 2016.
5. The National Federation of State High School Associations. 2017-18 HIGH SCHOOL ATHLETICS PARTICIPATION SURVEY. http://www.nfhs.org/ParticipationStatistics/PDF/2017-18 High School Athletics Participation Survey.pdf. Published 2018.
6. Baseball LL. Little League International Program Guide. https://ll-production-uploads.s3.amazonaws.com/uploads/2017/12/Baseball-Brochure.pdf. Accessed September 24, 2018.
7. Saper MG, Pierpoint LA, Liu W, Comstock RD, Polousky JD, Andrews JR. Epidemiology of Shoulder and Elbow Injuries Among United States High School Baseball Players: School Years 2005-2006 Through 2014-2015. *Am J Sports Med*. 2018. doi:10.1177/0363546517734172
8. DeFroda SF, Goodman AD, Gil JA, Owens BD. Epidemiology of Elbow Ulnar Collateral Ligament Injuries Among Baseball Players: National Collegiate Athletic Association Injury Surveillance Program, 2009-2010 Through 2013-2014. *Am J Sports Med*. 2018. doi:10.1177/0363546518773314
9. Rothermich MA, Conte SA, Aune KT, Fleisig GS, Cain EL, Dugas JR. Incidence of Elbow Ulnar Collateral Ligament Surgery in Collegiate Baseball Players. *Orthop J Sport Med*. 2018. doi:10.1177/2325967118764657
10. Cain EL, Andrews JR, Dugas JR, et al. Outcome of ulnar collateral ligament reconstruction of the elbow in 1281 athletes: Results in 743 athletes with minimum 2-Year follow-up. *Am J Sports Med*. 2010. doi:10.1177/0363546510378100
11. Camp CL, Conte S, D'Angelo J, Fealy SA. Epidemiology of ulnar collateral ligament reconstruction in Major and Minor League Baseball pitchers: comprehensive report of 1429 cases. *J Shoulder Elb Surg*. 2018. doi:10.1016/j.jse.2018.01.024
12. Erickson BJ, Nwachukwu BU, Rosas S, et al. Trends in medial ulnar collateral ligament reconstruction in the United States: A retrospective

review of a large private-payer database from 2007 to 2011. *Am J Sports Med*. 2015. doi:10.1177/0363546515580304
13. Limpisvasti O, ElAttrache NS, Jobe FW. Understanding shoulder and elbow injuries in baseball. *J Am Acad Orthop Surg*. 2007. doi:10.5435/00124635-200703000-00003
14. Lyman S, Fleisig GS, Andrews JR, Osinski ED. Effect of pitch type, pitch count, and pitching mechanics on risk of elbow and shoulder pain in youth baseball pitchers. *Am J Sports Med*. 2002. doi:10.1177/03635465020300040201
15. Byram IR, Bushnell BD, Dugger K, Charron K, Harrell FE, Noonan TJ. Preseason shoulder strength measurements in professional baseball pitchers: Identifying players at risk for injury. *Am J Sports Med*. 2010. doi:10.1177/0363546509360404
16. Escamilla RF, Yamashiro K, Paulos L, Andrews JR. Shoulder muscle activity and function in common shoulder rehabilitation exercises. *Sport Med*. 2009. doi:10.2165/00007256-200939080-00004
17. Fleisig GS, Barrentine SW, Zheng N, Escamilla RF, Andrews JR. Kinematic and kinetic comparison of baseball pitching among various levels of development. *J Biomech*. 1999. doi:10.1016/S0021-9290(99)00127-X
18. Cook G, Burton L, Hoogenboom B. Pre-participation screening: the use of fundamental movements as an assessment of function - part 1. *N Am J Sports Phys Ther*. 2006. doi:10.1055/s-0034-1382055
19. Putnam CA. Sequential motions of body segments in striking and throwing skills: Descriptions and explanations. *J Biomech*. 1993;26:125-135. doi:10.1016/0021-9290(93)90084-R
20. Bunn J. *Scientific Principles of Coaching*. Englewood Cliffs, NJ: Prentice-Hall; 1972.
21. Kaizu Y, Watanabe H, Yamaji T. Correlation of upper limb joint load with simultaneous throwing mechanics including acceleration parameters in amateur baseball pitchers. *J Phys Ther Sci*. 2018;30(2):223-230.
22. Hirashima M, Kudo K, Watarai K, Ohtsuki T. Control of 3D Limb Dynamics in Unconstrained Overarm Throws of Different Speeds Performed by Skilled Baseball Players. *J Neurophysiol*. 2007. doi:10.1152/jn.00348.2006
23. Reinold MM, Macrina L, Fleisig GS, Aune KT, Andrews JR. Effect of a 6-Week Weighted Baseball Throwing Program on Pitch Velocity, Pitching Arm Biomechanics, Passive Range of Motion, and Injury Rates. *Sports Health*. 2018;10(9):327-333.
24. Fleisig GS, Diffendaffer AZ, Aune KT, Ivey B, Laughlin WA. Biomechanical Analysis of Weighted-Ball Exercises for Baseball Pitchers. *Sports Health*. 2017. doi:10.1177/1941738116679816
25. Oliver G, Henning L, Plummer H, Cheatham S. Scapula muscle activations during overhead throwing holds. *Int J Athl Ther Train*. 2016. doi:10.1123/ijatt.2015-0038
26. Anz AW, Bushnell BD, Griffin LP, Noonan TJ, Torry MR, Hawkins RJ. Correlation of torque and elbow injury in professional baseball pitchers. *Am*

J Sports Med. 2010. doi:10.1177/0363546510363402
27. Fleisig GS, Andrews JR. Prevention of Elbow Injuries in Youth Baseball Pitchers. *Sports Health*. 2012. doi:10.1177/1941738112454828
28. Fleisig GS, Andrews JR, Dillman CJ, Escamilla RF. Kinetics of Baseball Pitching with Implications About Injury Mechanisms. *Am J Sports Med*. 1995. doi:10.1177/036354659502300218
29. Oyama S. Baseball pitching kinematics, joint loads, and injury prevention. *J Sport Heal Sci*. 2012. doi:10.1016/j.jshs.2012.06.004
30. Fortenbaugh D, Fleisig GS, Andrews JR. Baseball pitching biomechanics in relation to injury risk and performance. *Sports Health*. 2009. doi:10.1177/1941738109338546
31. Chalmers PN, Wimmer MA, Verma NN, et al. The Relationship Between Pitching Mechanics and Injury: A Review of Current Concepts. *Sports Health*. 2017. doi:10.1177/1941738116686545
32. Ishida K, Hirano Y. Effects of Non-throwing Arm on Trunk and Throwing Arm Movements in Baseball Pitching. *Int J Sport Heal Sci*. 2004. doi:10.5432/ijshs.2.119
33. Barfield JW, Anz AW, Andrews JR, Oliver GD. Relationship of Glove Arm Kinematics With Established Pitching Kinematic and Kinetic Variables Among Youth Baseball Pitchers. *Orthop J Sport Med*. 2018;6(7).
34. Hamill J, Knutzen KM, Derrick TR. *Biomechanical Basis of Human Movement: Fourth Edition*.; 2014.
35. Naito K, Takagi T, Kubota H, Maruyama T. Multi-body dynamic coupling mechanism for generating throwing arm velocity during baseball pitching. *Hum Mov Sci*. 2017. doi:10.1016/j.humov.2017.05.013
36. Kibler W Ben, Press J, Sciascia A. The role of core stability in athletic function. *Sports Med*. 2006. doi:10.2165/00007256-200636030-00001
37. Hodges PW, Richardson CA. Feedforward contraction of transversus abdominis is not influenced by the direction of arm movement. *Exp Brain Res*. 1997. doi:10.1007/PL00005644
38. Willson JD, Dougherty CP, Ireland ML, Davis IMC. Core stability and its relationship to lower extremity function and injury. *J Am Acad Orthop Surg*. 2005. doi:10.5435/00124635-200509000-00005
39. Chaudhari AMW, McKenzie CS, Pan X, Oñate JA. Lumbopelvic control and days missed because of injury in professional baseball pitchers. *Am J Sports Med*. 2014. doi:10.1177/0363546514545861
40. McGill SM, Grenier S, Kavcic N, Cholewicki J. Coordination of muscle activity to assure stability of the lumbar spine. *J Electromyogr Kinesiol*. 2003. doi:10.1016/S1050-6411(03)00043-9
41. Clark M, Lucett S, Kirkendall D. *NASM's Essentials of Sports Performance Training.* Lippincott Williams & Wilkins; 2010.
42. Yamazaki J, Muneta T, Ju YJ, Sekiya I. Differences in kinematics of single leg squatting between anterior cruciate ligament-injured patients and healthy controls. *Knee Surgery, Sport Traumatol Arthrosc*. 2009. doi:10.1007/s00167-009-0892-z
43. Crossley KM, Zhang WJ, Schache AG, Bryant A, Cowan SM. Performance

on the single-leg squat task indicates hip abductor muscle function. *Am J Sports Med*. 2011. doi:10.1177/0363546510395456
44. Claiborne TL, Armstrong CW, Gandhi V, Pincivero DM. Relationship between hip and knee strength and knee valgus during a single leg squat. *J Appl Biomech*. 2006. doi:10.1123/jab.22.1.41
45. Stickler L, Finley M, Gulgin H. Relationship between hip and core strength and frontal plane alignment during a single leg squat. *Phys Ther Sport*. 2015. doi:10.1016/j.ptsp.2014.05.002
46. Graci V, Salsich GB. Trunk and lower extremity segment kinematics and their relationship to pain following movement instruction during a single-leg squat in females with dynamic knee valgus and patellofemoral pain. *J Sci Med Sport*. 2015. doi:10.1016/j.jsams.2014.04.011
47. Ugalde V, Brockman C, Bailowitz Z, Pollard CD. Single leg squat test and its relationship to dynamic knee valgus and injury risk screening. *PM R*. 2015. doi:10.1016/j.pmrj.2014.08.361
48. Agresta C, Church C, Henley J, Duer T, O'Brien K. Single-leg squat performance in active adolescents aged 8-17 years. *J Strength Cond Res*. 2017. doi:10.1519/JSC.0000000000001617
49. Gianola S, Castellini G, Stucovitz E, Nardo A, Banfi G. Single leg squat performance in physically and non-physically active individuals: A cross-sectional study. *BMC Musculoskelet Disord*. 2017. doi:10.1186/s12891-017-1660-8
50. Raisanen AM, Pasanen K, Krosshaug T, et al. Association between frontal plane knee control and lower extremity injuries: a prospective study on young team sport athletes. *BMJ open Sport Exerc Med*. 2018. doi:10.1136/bmjsem-2017-000311
51. Gilmer GG, Washington JK, Oliver GD. Assessment of lumbopelvic-hip complex instability and segmental sequencing amongst softball athletes. *Int Biomech*. 2018:1-10.
52. Plummer HA, Oliver GD, Powers CM, Michener LA. Trunk Lean During a Single-leg Squat is Associated with Trunk Lean During Pitching. *Int J Sports Phys Ther*. 2018. doi:10.26603/ijspt20180058
53. Goldbeck TG, Davies GJ. Test-Retest Reliability of the Closed Kinetic Chain Upper Extremity Stability Test: A Clinical Field Test. *J Sport Rehabil*. 2000. doi:10.1123/jsr.9.1.35
54. Ellenbecker T, Manske R, Davies GJ. Closed kinetic chain testing techniques of the upper extremities. *Orthop Phys Ther Clin North Am*. 2000;9(2):219-230.
55. Tucci HT, Felicio LR, McQuade KJ, Bevilaqua-Grossi D, Camarini PM, Oliveira AS. Biomechanical Analysis of Closed Kinetic Chain Upper Extremity Stability Test. *J Sport Rehabil*. 2015. doi:10-1123/jsr.2015-0071
56. Roush JR, Kitamura J, Waits MC. Reference Values for the Closed Kinetic Chain Upper Extremity Stability Test (CKCUEST) for Collegiate Baseball Players. *N Am J Sports Phys Ther*. 2007.
57. Lee D-R, Kim LJ. Reliability and validity of the closed kinetic chain upper extremity stability test. *J Phys Ther Sci*. 2015. doi:10.1589/jpts.27.1071

58. Tucci HT, Martins J, Sposito GDC, Camarini PMF, De Oliveira AS. Closed Kinetic Chain Upper Extremity Stability test (CKCUES test): A reliability study in persons with and without shoulder impingement syndrome. *BMC Musculoskelet Disord*. 2014. doi:10.1186/1471-2474-15-1
59. de Oliveira VMA, Pitangui ACR, Nascimento VYS, da Silva HA, Dos Passos MHP, de Araújo RC. Test-Retest Reliability of the Closed Kinetic Chain Upper Extremity Stability Test (Ckcuest) in Adolescents: Reliability of Ckcuest in Adolescents. *Int J Sports Phys Ther*. 2017. doi:10.1123/jsr.9.1.35
60. Sciascia A, Uhl T. Reliability of Strength and Performance Testing Measures and Their Ability to Differentiate Persons With and Without Shoulder Symptoms. *Int J Sports Phys Ther*. 2015.
61. Borms D, Cools A. Upper-Extremity Functional Performance Tests: Reference Values for Overhead Athletes. *Int J Sports Med*. 2018.
62. Audenaert D, Baele J, Christiaens J. A normative database of functional (shoulder) tests within healthy male overhead athletes. 2017.
63. Pontillo M, Huffman G, Sennett BJ. Profile of Upper Extremity Rotator Cuff Strength and Function in Division 1 Collegiate Athletes. *J Orthop Sport Phys Ther*. 2011;41(1):A45.
64. Taylor JB, Wright AA, Smoliga JM, DePew JT, Hegedus EJ. Upper-Extremity Physical-Performance Tests in College Athletes. *J Sport Rehabil*. 2016. doi:10.1123/jsr.2014-0296
65. Pontillo M, Spinelli BA, Sennett BJ. Prediction of In-Season Shoulder Injury From Preseason Testing in Division I Collegiate Football Players. *Sports Health*. 2014. doi:10.1177/1941738114523239
66. Sekiguchi T, Hagiwara Y, Momma H, et al. Coexistence of Trunk or Lower Extremity Pain with Elbow and/or Shoulder Pain among Young Overhead Athletes: A Cross-Sectional Study. *Tohoku J Exp Med*. 2017. doi:10.1620/tjem.243.173
67. Kageyama M, Sugiyama T, Takai Y, Kanehisa H, Maeda A. Kinematic and kinetic profiles of trunk and lower limbs during baseball pitching in collegiate pitchers. *J Sport Sci Med*. 2014.
68. Oi T, Takagi Y, Tanaka H, Inui H, Nobuhara K, Yoshiya S. Three-dimensional kinematic analysis of throwing motion focusing on pelvic rotation at stride foot contact. *J Orthop Res*. 2016. doi:10.1002/jor.23247
69. Stodden DF, Fleisig GS, McLean SP, Lyman SL, Andrews JR. Relationship of pelvis and upper torso kinematics to pitched baseball velocity. *J Appl Biomech*. 2001. doi:10.1123/jab.17.2.164
70. Graaf E van der, Hoozemans M, Nijhoff M, Davidson M, Hoezen M, Veeger D. Timing of Peak Pelvis and Thorax Rotation Velocity in Baseball Pitching. *J Phys Fit Sport Med*. 2018;7(5):269-277.
71. Urbin MA, Fleisig GS, Abebe A, Andrews JR. Associations between timing in the baseball pitch and shoulder kinetics, elbow kinetics, and ball speed. *Am J Sports Med*. 2013. doi:10.1177/0363546512467952
72. Southard D. Throwing pattern: Changes in timing of joint lag according to age between and within skill level. *Res Q Exerc Sport*. 2009.

doi:10.1080/02701367.2009.10599555
73. Southard D. Change in throwing pattern: Critical values for control parameter of velocity. *Res Q Exerc Sport*. 2002. doi:10.1080/02701367.2002.10609039
74. Wasser JG, Zaremski JL, Herman DC, Vincent HK. Prevalence and proposed mechanisms of chronic low back pain in baseball: part i. *Res Sport Med*. 2017. doi:10.1080/15438627.2017.1282361
75. Luera MJ, Dowling B, Magrini MA, Muddle TWD, Colquhoun RJ, Jenkins NDM. Role of Rotational Kinematics in Minimizing Elbow Varus Torques for Professional Versus High School Pitchers. *Orthop J Sport Med*. 2018. doi:10.1177/2325967118760780
76. Saeterbakken AH, Tillaarr R Van Den, Seiler S. E Ffect of C Ore S Tability T Raining on T Hrowing. *J Strength Cond Res*. 2011. doi:10.1519/JSC.0b013e3181cc227e
77. Kageyama M, Sugiyama T, Kanehisa H, Maeda A. Difference between adolescent and collegiate baseball pitchers in the kinematics and kinetics of the lower limbs and trunk during pitching motion. *J Sport Sci Med*. 2015.
78. Gilmer GG, Gascon SS, Oliver GD. Classification of lumbopelvic-hip complex instability on kinematics amongst female team handball athletes. *J Sci Med Sport*. 2018. doi:10.1016/j.jsams.2017.12.009
79. Oliver GD, Keeley DW. Gluteal muscle group activation and its relationship with pelvis and torso kinematics in high-school baseball pitchers. *J Strength Cond Res*. 2010. doi:10.1519/JSC.0b013e3181c865ce
80. Chowdhary AG, Challis JH. The biomechanics of an overarm throwing task: A simulation model examination of optimal timing of muscle activations. *J Theor Biol*. 2001. doi:10.1006/jtbi.2001.2332
81. Aguinaldo AL, Buttermore J, Chambers H. Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. *J Appl Biomech*. 2007. doi:10.1123/jab.23.1.42
82. Dowling B, Pearl C, Laughlin WA, Tubbs T, Fleisig GS. Relationship of pelvic and trunk kinematics to ball velocity in professional baseball pitchers. *40th Annu Meet Am Soc Biomech*. 2016.
83. Hazar Z, Ulug N, Yuksel I. Is there a relation between shoulder dysfunction and core instability? *Orthop J Sport Med*. 2014. doi:10.1177/2325967114S00173
84. Laudner KG, Latal JR, Wong RH, Meister K. Descriptive Profile of Lumbopelvic Control in Collegiate Baseball Pitchers. *J Strength Cond Res (Lippincott Williams Wilkins)*. 2018.
85. Escamilla RF, Slowik JS, Diffendaffer AZ, Fleisig GS. Differences Among Overhand, Three-Quarter, and Sidearm Pitching Biomechanics in Professional Baseball Players. *J Appl Biomech*. 2018. doi:10.1123/jab.2017-0211
86. Oyama S, Yu B, Blackburn JT, Padua DA, Li L, Myers JB. Effect of excessive contralateral trunk tilt on pitching biomechanics and performance in high school baseball pitchers. *Am J Sports Med*. 2013. doi:10.1177/0363546513496547

87. Oyama S, Waldhelm AG, Sosa AR, Patel RR, Kalinowski DL. Trunk Muscle Function Deficit in Youth Baseball Pitchers with Excessive Contralateral Trunk Tilt during Pitching. *Clin J Sport Med*. 2017. doi:10.1097/JSM.0000000000000396
88. Oliver GD, Keeley DW. Pelvis and torso kinematics and their relationship to shoulder kinematics in high-school baseball pitchers. *J Strength Cond Res*. 2010. doi:10.1519/JSC.0b013e3181cc22de
89. Hong DA, Cheung TK, Roberts EM. A three-dimensional, six-segment chain analysis of forceful overarm throwing. *J Electromyogr Kinesiol*. 2001. doi:10.1016/S1050-6411(00)00045-6
90. Reinold MM, Gill TJ, Wilk KE, Andrews JR. Current concepts in the evaluation and treatment of the shoulder in overhead throwing athletes, part 2: Injury prevention and treatment. *Sports Health*. 2010. doi:10.1177/1941738110362518
91. Laudner K, Wong R, Meister K. The Influence of Lumbopelvic Control on Shoulder and Elbow Kinetics in Elite Baseball Pitchers. *J Shoulder Elb Surg*. 2018.
92. Pytiak A V., Kraeutler MJ, Currie DW, McCarty EC, Comstock RD. An Epidemiological Comparison of Elbow Injuries Among United States High School Baseball and Softball Players, 2005-2006 Through 2014-2015. *Sports Health*. 2018. doi:10.1177/1941738117736493
93. Chalmers PN, Sgroi T, Riff AJ, et al. Correlates with History of Injury in Youth and Adolescent Pitchers. *Arthrosc - J Arthrosc Relat Surg*. 2015. doi:10.1016/j.arthro.2015.03.017
94. Silfies SP, Ebaugh D, Pontillo M, Butowicz CM. Critical review of the impact of core stability on upper extremity athletic injury and performance. *Brazilian J Phys Ther*. 2015. doi:10.1590/bjpt-rbf.2014.0108
95. Endo Y, Sakamoto M. Correlation of Shoulder and Elbow Injuries with Muscle Tightness, Core Stability, and Balance by Longitudinal Measurements in Junior High School Baseball Players. *J Phys Ther Sci*. 2014. doi:10.1589/jpts.26.689
96. Douoguih WA, Dolce DL, Lincoln AE. Early cocking phase mechanics and upper extremity surgery risk in starting professional baseball pitchers. *Orthop J Sport Med*. 2015. doi:10.1177/2325967115581594
97. Davis JT, Limpisvasti O, Fluhme D, et al. The effect of pitching biomechanics on the upper extremity in youth and adolescent baseball pitchers. *Am J Sports Med*. 2009. doi:10.1177/0363546509340226
98. Sabick MB, Torry MR, Lawton RL, Hawkins RJ. Valgus torque in youth baseball pitchers: A biomechanical study. *J Shoulder Elb Surg*. 2004. doi:10.1016/j.jse.2004.01.013
99. Werner SL, Murray TA, Hawkins RJ, Gill TJ. Relationship between throwing mechanics and elbow valgus in professional baseball pitchers. *J Shoulder Elb Surg*. 2002. doi:10.1067/mse.2002.121481
100. Stodden DF, Fleisig GS, McLean SP, Andrews JR. Relationship of biomechanical factors to baseball pitching velocity: Within pitcher variation. *J Appl Biomech*. 2005. doi:10.1123/jab.21.1.44

101. Aguinaldo AL, Chambers H. Correlation of throwing mechanics with elbow valgus load in adult baseball pitchers. *Am J Sports Med*. 2009. doi:10.1177/0363546509336721
102. Ramappa AJ, Chen PH, Hawkins RJ, et al. Anterior shoulder forces in professional and little league pitchers. *J Pediatr Orthop*. 2010. doi:10.1097/BPO.0b013e3181c87ca2
103. Takagi Y, Oi T, Tanaka H, et al. Increased horizontal shoulder abduction is associated with an increase in shoulder joint load in baseball pitching. *J Shoulder Elb Surg*. 2014. doi:10.1016/j.jse.2014.03.005
104. Dick R, Sauers EL, Agel J, Keuter G, Marshall SW, McCarty, KennethMcFarland E. Descriptive Epidemiology of Collegiate Men's Baseball Injuries : National Collegiate Athletic Association Injury Surveillance System , 1988 – 1989 Through 2003 – 2004. *J Athl Train*. 2007. doi:10.1016/S0276-1092(08)79204-6
105. Sutter GE, Orenduff J, Fox WJ, Myers J, Garrigues GE. Predicting Injury in Professional Baseball Pitchers From Delivery Mechanics: A Statistical Model Using Quantitative Video Analysis. *Orthopedics*. 2018;41(1):43-53.
106. Oyama S, Yu B, Blackburn JT, Padua DA, Li L, Myers JB. Improper trunk rotation sequence is associated with increased maximal shoulder external rotation angle and shoulder joint force in high school baseball pitchers. *Am J Sports Med*. 2014. doi:10.1177/0363546514536871
107. Murata A. Shoulder joint movement of the non-throwing arm during baseball pitch-comparison between skilled and unskilled pitchers. *J Biomech*. 2001. doi:10.1016/S0021-9290(01)00154-3
108. Fleisig GS, Diffendaffer AZ, Ivey B, et al. Changes in Youth Baseball Pitching Biomechanics: A 7-Year Longitudinal Study. *Am J Sports Med*. 2018. doi:10.1177/0363546517732034
109. Hirashima M, Kadota H, Sakurai S, Kudo K, Ohtsuki T. Sequential muscle activity and its functional role in the upper extremity and trunk during overarm throwing. *J Sports Sci*. 2002. doi:10.1080/026404102753576071
110. Siff MC, Verkhoshansky YV. Supertraining. In: *Supertraining*. ; 2009.
111. Bernstein NA. *The Coordination and Regulation of Movement*. London: Pergamon Press; 1967.
112. Grezios AK, Gissis IT, Sotiropoulos AA, Nikolaidis D V., Souglis AG. Muscle-contraction properties in overarm throwing movements. *J Strength Cond Res*. 2006. doi:10.1519/R-15624.1
113. Escamilla RF, Andrews JR. Shoulder muscle recruitment patterns and related biomechanics during upper extremity sports. *Sports Med*. 2009. doi:4 [pii]
114. Trakis JE, McHugh MP, Caracciolo PA, Busciacco L, Mullaney M, Nicholas SJ. Muscle strength and range of motion in adolescent pitchers with throwing-related pain: Implications for injury prevention. *Am J Sports Med*. 2008. doi:10.1177/0363546508319049
115. Basmajian J V, De Luca CJ. *Muscles Alive*.; 1985.
116. Cram JR, Criswell E. *Cram's Introduction to Surface Electromyography*.; 2011.

117. Oliver GD, Weimar WH, Henning LE. Effects of a Simulated Game on Muscle Activation in Youth Baseball Pitchers. *J Strength Cond Res*. 2016. doi:10.1519/JSC.0000000000001130
118. Oliver GD, Stone AJ, Plummer H. Electromyographic examination of selected muscle activation during isometric core exercises. *Clin J Sport Med*. 2010. doi:10.1097/JSM.0b013e3181f7b0ef
119. Oliver GD, Weimar WH, Plummer HA. Gluteus medius and scapula muscle activations in youth baseball pitchers. *J Strength Cond Res*. 2015. doi:10.1519/JSC.0000000000000797
120. McGill S, Juker D, Kropf P. Appropriately placed surface EMG electrodes reflect deep muscle activity (psoas, quadratus lumborum, abdominal wall) in the lumbar spine. *J Biomech*. 1996. doi:10.1016/0021-9290(96)84547-7
121. Blackburn JT, Padua DA. Sagittal-plane trunk position, landing forces, and quadriceps electromyographic activity. *J Athl Train*. 2009. doi:10.4085/1062-6050-44.2.174
122. Kendall F., McCreary EK, Provance PG, Rodgers MM, Romani WA. *Muscles: Testing an DFunction, with Posture and Pain*. Philadelphia: Lippincottt Williams & Wilkins; 2005.
123. Wu G, Siegler S, Allard P, et al. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion—part I: ankle, hip, and spine. *J Biomech*. 2002. doi:10.1016/S0021-9290(01)00222-6
124. Wu G, Van Der Helm FCT, Veeger HEJ, et al. ISB recommendation on definitions of joint coordinate systems of various joints for the reporting of human joint motion - Part II: Shoulder, elbow, wrist and hand. *J Biomech*. 2005. doi:10.1016/j.jbiomech.2004.05.042
125. Veeger HEJ. The position of the rotation center of the glenohumeral joint. *J Biomech*. 2000. doi:10.1016/S0021-9290(00)00141-X
126. Washington JK, Gilmer GG, Barfield JW, et al. Differences in Segmental Speeds as a Function of Maturation in Youth Baseball Pitchers. *Int J Sports Med*. 2018;39(6). doi:10.1055/s-0044-102134
127. Wicke J, Keeley DW, Oliver GD. Comparison of pitching kinematics between youth and adult baseball pitchers: A meta-analytic approach. *Sport Biomech*. 2013. doi:10.1080/14763141.2013.838692
128. Winter D a D a. D a. *BIOMECHANICS AND MOTOR CONTROL OF*.; 2009. doi:10.1002/9780470549148
129. Chandler RF, Clauser CE, McConville JT, Reynolds HM, Young JW. Investigation of inertial properties of the human body. *US Dep Commer*. 1975. doi:10.1017/CBO9781107415324.004
130. Zatsiorsky VM, Raitsin LM, Seluyanov VN, Aruin AS, Prilutzky BJ. Biomechanical characteristics of the human body. *Biomech Perform Sport*. 1983:71-83.
131. Escamilla RF, Barrentine SW, Fleisig GS, et al. Pitching biomechanics as a pitcher approaches muscular fatigue during a simulated baseball game. *Am J Sports Med*. 2007. doi:10.1177/0363546506293025
132. Chu Y, Fleisig GS, Simpson KJ, Andrews JR. Biomechanical comparison

between elite female and male baseball pitchers. *J Appl Biomech*. 2009. doi:10.1123/jab.25.1.22
133. Feltner ME, Dapena J. Dynamics of the Shoulder and Elbow Joints of the Throwing Arm During a Baseball Pitch. *J Appl Biomech*. 1986. doi:10.1039/C2CS35323G
134. Feltner ME. Three-Dimensional Interactions in a Two-Segment Kinetic Chain . Part II : Application to the Throwing Arm in Baseball Pitching. *J Appl Biomech*. 1989.
135. Fleisig G, Chu Y, Weber A, Andrews J. Variability in baseball pitching biomechanics among various levels of competition. *Sport Biomech*. 2009. doi:10.1080/14763140802629958
136. Escamilla RF, Fleisig GS, Barrentine SW, Andrews JR. Kinematic comparison between American and Korean professional baseball pitchers. *Med Sci Sport Exerc*. 1999. doi:10.1097/00005768-199905001-00009
137. Fleisig GS, Phillips R, Shatley A, et al. Kinematics and kinetics of youth baseball pitching with standard and lightweight balls. *Sport Eng*. 2006. doi:10.1007/BF02844117
138. Fleisig GS, Kingsley DS, Loftice JW, et al. Kinetic comparison among the fastball, curveball, change-up, and slider in collegiate baseball pitchers. *Am J Sports Med*. 2006. doi:10.1177/0363546505280431
139. Gagnon D, Gagnon M. The influence of dynamic factors on triaxial net muscular moments at the L5 S1 joint during asymmetrical lifting and lowering. *J Biomech*. 1992. doi:10.1016/0021-9290(92)90229-T

Appendix A

AUBURN UNIVERSITY

COLLEGE OF EDUCATION

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

Parental Permission/Minor Assent

Effect of weight in the non-throwing hand on the baseball pitching motion

CONSENT TO PARTICIPATE IN RESEARCH

Explanation and Purpose of the Research

We need your permission, as your child is under the age of 19, for your child's participation in a research study for the Sports Medicine & Movement Lab in the School of Kinesiology. Before agreeing to participate in this study, it is vital that you and your child understand certain aspects of what might occur. This statement describes the purpose, methodology, benefits, risks, discomforts, and precautions of this research. This statement describes your right to confidentiality and your child's right to discontinue their participation at any time during the course of this research without penalty or prejudice. No assurances or guarantees can be made concerning the results of this study.

This study is designed to examine the influence of weight in the non-throwing hand on the baseball pitching motion among pitchers of various ages (9-29) without injury or surgery for the past 6 months. To investigate this, pitching kinematics, kinetics, and muscle activity will be measured. Your child will be equipped with fourteen electromagnetic sensors, approximately the size of a pencil eraser to obtain pitching kinematics and kinetics. In order to obtain muscle activation information, your child will be equipped with eight sensors the size of a quarter.
Following sensor attachment, your child will perform 3 single leg squats on each leg and a closed kinetic chain upper extremity stability test. Once the stability assessments are complete, ample time to warm-up until game ready will be provided. Your child will throw 3 fastballs and 3 breaking balls using each condition of weight in the non-throwing hand (no glove, normal glove,
0.68 kgs, and 1.36 kgs).

Research Procedures

To be considered for this study, your child must be pain, injury, and surgery free for at least the past 6 months. In addition, your child must be currently playing at a competitive level. Your child must also not have an allergy to adhesive tape and have not participated in full effort pitching in the 72 hours prior to data collection.

Testing in this research will require your child to be dressed in shorts, t-shirt, and tennis shoes. Height, body mass, and age will be documented. Height and mass will be measured with a common Standiometer (scale with height ruler) and will be recorded to the nearest tenth of a kilogram and centimeter. Age will be determined from this consent form and will be recorded to the nearest month.

Once these measurements have been collected, fourteen electromagnetic sensors, approximately the size of a pencil eraser, will be attached to the skin with double-sided tape and

Participant Initials_______ Parent Initials ______ cover roll. The sensors will be placed bilaterally at the following locations: acromioclavicular joint (tip of the shoulder), deltoid tuberosity of the humerus (superior lateral aspect of the upper arm), and the distal radioulnar joint (superior aspect of the wrist). The remaining sensors will be placed on the back of the throwing hand, C7 spinal vertebrae, on the sacrum (low back), on the middle of the lateral aspect of each thigh, on the middle of the lateral aspect of each lower leg, and on the top of stride leg shoe (superior to the tip of the second toe). Eight electromyographic electrodes will be placed on the following muscles: glove side latissimus dorsi (middle back), throwing side gluteus maximus, bilateral external obliques (side abdominal region), bilateral serratus anterior (outside ribcage underneath armpit), throwing arm side lower trapezius (middle back), and throwing arm side gluteus medius. Following the placement of all sensors, a fifteenth electromagnetic sensor attached to a stylus will be used to digitize various bony landmarks on the thorax (middle of torso), scapula (shoulder blade), humerus (upper arm), radius and ulna (lower arm), femur (thigh), tibia and fibula (lower leg), and foot. Manual muscle testing will be performed to establish baseline muscle activity in which all data will be compared.

Your child will randomly be assigned the order of the single-leg squat (SLS) and closed kinetic chain upper extremity stability test (CKCUEST). For the SLS, your child will perform 3 repetitions for each leg. For the CKCUEST, your child will start in the push up position and perform alternate hand- touching for 15 seconds. The CKCUEST is a stability test performed for 3 sets with 45 seconds rest between sets. All exercises are body weight and are designed to test your child's core or lumbopelvic hip (LPHC) stability.

Following both stability assessments, your child will be allotted an unlimited time to warm-up. Your child will be asked to throw three maximal effort fastballs and three maximal effort breaking balls using each non-throwing hand weight condition. We estimate that the data collection session will take one hour and fifteen minutes to complete.

Potential Risks

As with any movement research, certain risks and discomforts may arise. The possible risks and discomforts associated with this study are no greater than those involved in competitive baseball and softball and may include: death, muscle strain, muscle soreness, ligament and tendon damage, and general overuse injury to the throwing athlete. Every effort will be made to minimize these risks and discomforts. It is your child's responsibility, as a participant, to inform the investigators if they notice any indications of injury or fatigue, or feel symptoms of any other possible complications that might occur during testing.

To reduce the risk of injury, certain precautions will be taken. During data collection, a board certified athletic trainer will be present to monitor your child as he throws. Ample warm-up and cool-down periods will be required of your child, water will be provided as needed, and ice will be made available after testing.

The researcher will try to prevent any problem that could happen because of this research. If at any time there is a problem you or your child should let the researcher know and he will help you. Should an emergency arise, we will call 911 and follow our Emergency Action Plan. In the unlikely event that your child sustains an injury from participation in this study, the investigators have no current plans to provide funds for any medical expenses or other costs you may incur.

Confidentiality

All information gathered in completing this study will remain confidential. Your child's individual performance will not be made available for public use, and will not be disclosed to any person(s) outside of the research team. The results of this study may be published as

Participant Initials ________________

Parent Initials_________

scientific research. Your child's name or identity shall not be revealed should such publication occur. Upon termination of this study, the samples collected for this study will be stored for up to 10 years to research scientific questions specifically related to the baseball pitching motion. The participant will continue to be the owner of the samples and retain the right to have the sample material destroyed at any time during this study by contacting the study principal investigator.
During this study the samples will be stored with number identifiers only; however, the number identifier will be linked to a specific name and will be kept on file in the possession of the principal investigator. The linked file will be encrypted with password protection and stored on a password protected computer. A backup file will be made and will be encrypted with password protection and stored on a password protected flash drive. No other individuals will have access to these identifying materials unless the principal investigator is required by law to provide such identifying information. Data will not be publicly available and participants will not be identified or linked to the samples in publication. If a commercial product is developed from this research project, I will not profit financially from such a product.

Participation and Benefits

Participation in this research is strictly voluntary and refusal to participate will result in no penalty. If you or your child change your minds about participating, you can withdraw at any time during the study. Your child's participation is completely voluntary. If you choose to withdraw, your child's data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your child's future relations with Auburn University or the School of Kinesiology.

Questions Regarding the Study

If you have questions about this study, please ask them now. If you have questions later you may contact Jeff Barfield at (334)-707-7204 or jzb0123@auburn.edu, or Dr. Gretchen Oliver at (334)844-1497 or goliver@auburn.edu.

If you have any questions about your child's rights as a research participant, you may contact the Auburn University Office of Research Compliance or the Institutional Review Board by phone (334)-844-5966 or email at irbadmin@auburn.edu or IRBChair@auburn.edu.

The Auburn University Institutional Review Board has approved this Document for use from
__12/14/2018___to__12/13/2019___
Protocol # ___18-440 EP 1812______

Participant Initials________ Parent Initials ______

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH FOR YOUR CHILD TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO ALLOW YOUR CHILD'S PARTICIPATION.

____________________________________ __________
Printed Name of Parent Participant Date of Birth

____________________________________ ______________
Signature of Parent Date

____
Printed Name of Participant

____________________________________ ______________
Signature of Participant Date

The above consent form was read, discussed, and signed in my presence. In my opinion, the person signing said consent form did so freely and with full knowledge of its contents.

____________________________________ ______________
Signature of Investigator, Jeff Barfield Date

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SCHOOL OF
KINESIOLOGY
301 Wire Road
Auburn, AL 36849
(334) 884-4483

AUBURN UNIVERSITY

COLLEGE OF EDUCATION

(NOTE: DO NOT SIGN THIS DOCUMENT UNLESS AN IRB APPROVAL STAMP WITH CURRENT DATES HAS BEEN APPLIED TO THIS DOCUMENT.)

INFORMED CONSENT for a Research Study entitled

Effect of weight in the non-throwing hand on the baseball pitching motion

Auburn University

CONSENT TO PARTICIPATE IN RESEARCH

Explanation and Purpose of the Research

You are being asked to participate in a research study for the Sports Medicine & Movement Lab in the School of Kinesiology. Before agreeing to participate in this study, it is vital that you understand certain aspects of what might occur. This statement describes the purpose, methodology, benefits, risks, discomforts, and precautions of this research. This statement describes your right to confidentiality and your right to discontinue your participation at any time during the course of this research without penalty or prejudice. No assurances or guarantees can be made concerning the results of this study.

This study is designed to examine the influence of weight in the non-throwing hand on the baseball pitching motion among pitchers of various ages (9-29) without injury or surgery for the past 6 months. To investigate this, pitching kinematics, kinetics, and muscle activity will be measured. You will be equipped with fourteen electromagnetic sensors, approximately the size of a pencil eraser to obtain pitching kinematics and kinetics. In order to obtain muscle activation information, you will be equipped with eight sensors the size of a quarter. Following sensor attachment, you will perform 3 single leg squats on each leg and a closed kinetic chain upper extremity stability test. Once the stability assessments are complete, ample time to warm-up until game ready will be provided. You will throw 3 fastballs and 3 breaking balls using each condition of weight in the non-throwing hand (no glove, normal glove, 0.68 kgs, and 1.36 kgs).

Research Procedures

To be considered for this study, you must be pain, injury, and surgery free for at least the past 6 months. In addition, you must be currently playing at a competitive level. You must also not have an allergy to adhesive tape and have not participated in full effort pitching in the 72 hours prior to data collection.

Testing in this research will require you to be dressed in shorts, t-shirt, and tennis shoes. Your height, body mass, and age will be documented. Height and mass will be measured with a common Standiometer (scale with height ruler) an

Participant Initials __________

The Auburn University Institutional Review Board has approved this Document for use from __12/14/2018___to__12/13/2019____ Protocol # ___18-440 EP 1812______ kilogram and centimeter. Age will be determined from this consent form and will be recorded to the nearest month.

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To reduce the risk of injury, certain precautions will be taken. During data collection, a board certified athletic trainer will be present to monitor you as you complete the stability assessments and throw. Ample warm-up and cool-down periods will be required of you, water will be provided to you as needed, and ice will be made available after testing.

The researcher will try to prevent any problem that could happen because of this research. If at any time there is a problem you should let the researcher know and he will help you. Should an emergency arise, we will call 911 and follow our Emergency Action Plan. In the unlikely event that you sustain an injury from participation in this study, the investigators have no current plans to provide funds for any medical expenses or other costs you may incur.

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Participation in this research is strictly voluntary and refusal to participate will result in no penalty. If you change your mind about participating, you can withdraw at any time during the study. Your participation is completely voluntary. If you choose to withdraw, your data can be withdrawn as long as it is identifiable. Your decision about whether or not to participate or to stop participating will not jeopardize your future relations with Auburn University or the School of Kinesiology.

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Participant Initials __________

HAVING READ THE INFORMATION PROVIDED, YOU MUST DECIDE WHETHER OR NOT YOU WISH TO PARTICIPATE IN THIS RESEARCH STUDY. YOUR SIGNATURE INDICATES YOUR WILLINGNESS TO PARTICIPATE.

____ ______yr.______mo.
Printed Name of Participant Age of Participant

____ __________________
Signature of Participant Date

The above consent form was read, discussed, and signed in my presence. In my opinion, the person signing said consent form did so freely and with full knowledge of its contents.

____ __________________
Signature of Investigator, Jeff Barfield Date

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Protocol # ___18-440 EP 1812______

Appendix B

HEALTH and SPORT HISTORY QUESTIONNAIRE

Part 1. Participant Information

(Please print)

ID Number: ________________

Age: _______ State: ___________________ Phone: ___________________

Email: _____________________

Height: _____ft _____in Weight: ________lbs

Part 2. Athletic Participation

(Circle or fill in your responses)

1. Are you currently cleared to participate in baseball? **YES** **NO**

2. What is your dominant throwing arm? **RIGHT** **LEFT**

3. What position is your primary position? **Infield** **Outfield** **Catcher** **Pitcher**

4. At what age did you begin playing competitive baseball? __________

5. At what competition level are you currently playing? [Please circle]

Professional **NCAA Div. I** **NCAA Div. II** **NCAA Div. III**
Junior College **High School** **Junior High** **Youth League,**
Other________________

6. For how many years have you been participating at this level? ________

7. Is baseball your primary sport? **YES** **NO**

List all sports you play competitively

____

8. During the season, how many hours per week do you spend performing the following?

   a. Playing baseball: _____**hrs./week**

   b. Sport Specific training/conditioning: _____**hrs./week**

   c. What is the average number of games you play per week? ________

   d. What is the average number of days between games? ______

9. During the off-season, how many hours per week do you spend performing the following?

a. Playing baseball: _____**hrs./week**

b. Sport Specific training/conditioning: _____**hrs./week**

10. Estimate the typical number of throws you perform at or greater than 90% of maximal effort during the following:

a. Practice: _______**throws**

b. Competition/Game: _______**throws**

Part 3. Medical History

11. Are you allergic to adhesive tape or other adhesive products? **YES** **NO**
If **YES, explain:**

____

12. Have you ever had surgery before? **YES** **NO**
If **YES, explain:**

____

____

If YES, how long ago? ______ **Years** ______ **Months**

13. In the past year, have you had any injury to your upper or lower extremities that has caused you to miss a practice or game? **YES** **NO**
If **YES, explain:**

____

____

If YES, on what part(s)?

FOOT/ANKLE **KNEE** **HIP** **BACK** **SHOULDER**
ELBOW **WRIST** **HAND/FINGER**

14. Do you currently experience pain/stiffness before, during or after throwing or pitching? **YES** **NO**

If **YES, please explain** and continue onto question 15:

____

____

If **NO, please sign on page 3.**

15. For how long have you been experiencing pain? (Indicate a number next to one category) _____Years _____Months _____ Days

16. When you do experience pain, how would you describe the onset of pain? (Circle one)

SUDDEN **GRADUAL**

17. When you do experience pain, how is it related to activity? (Circle one)

ASSOCIATED WITH USE **INTERMITTENT** **ALL THE TIME**

18. Have you changed your training/competition habits because of upper extremity pain?
YES **NO**
If YES, explain:

____

____

19. Have your activities of daily living been effected by your pain? **YES** **NO**
If YES, explain:

____

____

20. Has your pain disrupted your sleep? **YES** **NO**
If YES, explain:

____

____

21. Have you sought medical consultation because of your pain? **YES** **NO**
If YES, explain:

____

____

22. Have you been given treatment for your pain? **YES** **NO**
If YES, explain:

____

____

23. When you do experience pain, what is the intensity of the pain (1 = NO pain; 10 = unbearable pain)?

NO PAIN **UNBEARABLE PAIN**

1 2 3 4 5 6 7 8 9 10

I hereby state, to the best of my knowledge, my answers to the above questions are complete and correct.

Signature of Participant (or parent/guardian): _______________________

Appendix C:

The spatial motion of each segment will be first defined by a general equation governing the center of mass translation of a segment:

1. $\Sigma F = m\ddot{r}$.

Expansion of this equation (A1), yields the following three scalar equations to solve for the spatial translational equilibrium of the *Nth* segment:

2. $F_{PX} + F_{DX} = m\ddot{r}_X$
3. $F_{PY} + F_{DY} – mg = m\ddot{r}_Y$
4. $F_{PZ} + F_{DZ} = m\ddot{r}_Z$

For a coordinate system corresponding to the fixed coordinate system and having as origin the center of mass C of the segment, the spatial rotational equilibrium will be defined by the following equation:

5. $\Sigma M_C = \dot{H}_C$.

The expansion of this equation (A5), yields the following three scalar equations to solve the spatial rotational equilibrium of segment *N*:

6. $M_{PX} + M_{DX} + r_{PY}F_{PZ} – r_{PZ}F_{PY} + r_{DY}F_{DZ} – r_{DZ}F_{DY} = I_x\alpha_X – (I_Y – I_Z)\omega_Y\omega_Z$
7. $M_{PY} + M_{DY} + r_{PZ}F_{PX} – r_{PX}F_{PZ} + r_{DZ}F_{DX} – r_{DX}F_{DZ} = I_Y\alpha_Y – (I_Z – I_X)\omega_Z\omega_X$
8. $M_{PZ} + M_{DZ} + r_{PX}F_{PY} – r_{PY}F_{PX} + r_{DX}F_{DY} – r_{DY}F_{DZ} = I_Z\alpha_Z – (I_X – I_Y)\omega_X\omega_Y$

Note: Taken from Gagnon and Gagnon.[139]