The Effects of Increased Workload on Softball Pitching Mechanics, Range of Motion, and Strength

by

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A dissertation submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

Auburn, Alabama
August 7, 2021

Keywords: softball pitching, injury risk, workload, pitch types

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Abstract

Softball pitching is a dynamic motion that requires the entire kinetic chain and has been documented to result in whole body muscular fatigue. In addition to muscular fatigue, increased pain has been documented after a game, tournament, and season. However, there has been limited data researching the relationship between workload with trunk kinematics and clinical measures such as range of motion and strength. Furthermore, the current research investigates mechanics related to pain within a single pitch type, but recently mechanical differences between various pitch types have been found. Therefore, the purpose of the study was to examine the effects of workload on trunk mechanics, pitch types, and upper and lower extremity range of motion and strength between various time points. The results revealed no significant differences between time points for trunk kinematics for any of the pitch types, nor were there any significant differences in compensation mechanisms between pitch types. Results revealed that hip and shoulder range of motion and strength decreased as workload increased ($p < .001$). The results of decreased range of motion and strength congruent with increased workload even with a given break indicate that softball pitching may result in residual effects that could ultimately increase injury risk. Further research will need to be done to fully understand the impact of workload on injury risk in these athletes.

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CHAPTER I

INTRODUCTION

Over the past decade softball participation has significantly increased and concurrently, so have injury rates. Furthermore, numerous studies have shown similar or higher injury rates in softball athletes compared to baseball.[48,68,71] Among softball pitchers, the upper extremity, specifically the shoulder, has been documented as being injured the most compared to positional players who primarily injury their lower extremity.[82,84] Likewise, research has also shown high reports of pain in softball pitchers. Sauers et al. reported that 60% of pitchers reported mild to severe upper extremity pain late in their season.[78] In conjunction, Skillington et al. also documented an increase in shoulder pain and fatigue throughout a typical weekend tournament in high school softball pitchers.[83] However, despite their pain, these athletes were continuing to fully participate.

Whole body muscular fatigue has been documented in softball pitchers after a pitching bout and over a season.[17] The ability to efficiently transfer energy from the distal, lower extremity to the more proximal, upper extremity is imperative for optimal performance and decreased injury risk.[15,45,46] Inefficiencies within the kinetic chain may result from decreased range of motion within the hip and glenohumeral joints. Previous research has shown that pitchers demonstrate decreased hip and glenohumeral range of motion following a pitching bout and throughout a season.[11,12,26,73] Decreased range of motion has been shown to alter pitching mechanics and has been correlated with pain in pitchers.[47,80,87] Unfortunately, most of the range of motion literature has been conducted in baseball pitchers requiring further research to determine if similar adaptations occur in windmill softball pitchers.

While softball literature may be lacking studies investigating range of motion and pain, multiple studies have been conducted analyzing pitching mechanics and pain. Oliver et al. has distinguished kinematic and kinetic differences between pitchers with and without pain.[62,63] During the riseball pitch collegiate pitchers identified as having upper extremity pain presented a longer stride length, a posteriorly shifted center of mass (COM), and trunk rotation towards the pitching arm side indicated by a regression model.[62] In the same population but during the change-up, the pain group at foot contact and ball release exhibited significantly greater shoulder horizontal abduction and less trunk lateral flexion towards the pitching arm, respectively.[63] Additionally, the pain group displayed less compression force than the no pain group, hypothesized to be a result of an inability to resist the raised distraction force the shoulder experiences during the pitch.[63]

Kinematic differences associated with increased workload have also been found in youth softball pitchers. While pitching a simulated game, pitchers displayed significantly less trunk rotation toward the pitching arm side between the first and last inning in the fastball.[23] While the aforementioned studies have identified mechanical differences between pain and no pain groups and some mechanical differences with an increased workload, there was an inconsistency in the type of pitch thrown. Downs et al. recently conducted a study and found kinematic differences between the fastball, changeup, dropball, and curveball pitch.[22] Therefore, it is unknown if the mechanical differences between pain groups and/or if the mechanical differences associated with fatigue and increased workload are consistent across varying pitch types. It could be hypothesized that since kinematic differences exist between pitch types, compensations resulting from pain or fatigue may be unique to a specific pitch.

In the world of travel league softball and even in collegiate conferences, tournament play is prevalent. Tournament play means that teams play multiple games within a day and throughout the season with sometimes little to no rest between games. Due to the lack of required rest days or pitch count regulations softball pitchers may be expected to pitch back-to-back games, otherwise known as a doubleheader. Kinematic studies have only analyzed mechanics by taking three trials with minimal studies analyzing a simulated game. No studies to date, however, have been done to simulate doubleheaders. Thus, the risk of pitching back-to-back games and injury susceptibility is currently unknown. Understanding the biomechanical and musculoskeletal adaptations and demands of pitching a doubleheader can provide valuable information for designing interventions and strength and conditioning programs.

Purpose

The purpose of this research was to examine the effects of workload on trunk mechanics, pitch types, and upper and lower extremity range of motion and strength between various time points. A secondary purpose was to simulate pitching the first inning of a doubleheader. After the simulated game, the pitcher was given a rest break, ranging 30 minutes, and then was required to pitch three trials of each of their pitch types. This second round of pitching was referred to as the pre doubleheader round and all variables were re-assessed during this round.

Research Questions

RQ1: Do trunk kinematics (extension, rotation, lateral flexion) significantly differ at events between various time points (1st inning simulated game, last inning simulated game, pre double header) at each pitching event for the fastball, changeup, curveball, and dropball?

- Trunk kinematics for each pitch type were measured at three pitching events (top of pitch, foot contact, ball release). The analysis compared differences within a pitch type at events between the time points.

RQ2: As workload increases do pitch types display similar or different trunk mechanic (extension/flexion, rotation, lateral flexion) alterations?

- Analysis calculated the absolute difference at events between time points and then compared between pitch types.

RQ3: Do hip and shoulder range of motion dominant and non-dominant IR and ER) significantly differ between time points (pre simulated game to post simulated game; post simulated game to pre double header; post simulated game to post double header; pre simulated game to pre double header; pre simulated game to post double header; and pre double header to post double header)?

RQ4: Do hip and shoulder isometric strength dominant and non-dominant IR and ER) significantly differ between time points(pre simulated game to post simulated game; post simulated game to pre double header; post simulated game to post double header; pre simulated game to pre double header; pre simulated game to post double header; and pre double header to post double header)?

Hypothesis

H_1: As time increased (1st inning simulated game to last inning simulated game to pre-double header) there will be less trunk rotation towards the pitching arm side, an increase in trunk flexion, and an increase in trunk lateral flexion toward the glove arm side.

H_2: Pitch types will display different trunk mechanic alterations as workload increases

H_3: Hip and shoulder range of motion will decrease pre simulated game to post simulated game, pre simulated game to pre double header, and pre simulated game to post double header.

H_4: Hip and shoulder isometric strength will decrease pre simulated game to post simulated game, pre simulated game to pre double header, and pre simulated game to post double header.

Limitations

1. Variability in skill level in age group
2. Experience variability in pitching different pitch types

Delimitations

1. Will be comparing within pitcher not between pitcher
2. Will not have to “hit” certain strike zone locations

Chapter 2

Review of Literature

The purpose of this research was to examine the effects of workload on trunk mechanics, pitch types, and upper and lower extremity range of motion and strength between various time points. A secondary purpose was to simulate pitching a doubleheader. After the simulated game the pitcher was given a rest break, ranging 30 minutes, and then required to pitch three trials of each of their pitch types. This second round of pitching will be referred to as the pre doubleheader round and all variables were re-assessed during this round. The current study's objectives were to identify if repeated bouts of pitching place softball pitchers at increased risk of injury as a result of altered mechanics, range of motion, or strength. In addition, another objective of the study was to determine if the aforementioned altered mechanics vary by pitch type and the influence of various pitch type mechanics on injury risk. Therefore, the following chapter has been broken down into five sections each discussing relevant literature to the purpose of the study. The five sections include 1) injury risk 2) influence of fatigue and pain on pitching performance and mechanics 3) influence of fatigue and pain on shoulder and hip range of motion and strength 4) mechanical differences between pitch types.

Injury Risk

Congruent with the increasing participation rates, injury rates are rising in softball athletes.[53,68] Interestingly, epidemiological studies have found that injuries differ by position in softball athletes.[84,90] Positional players have been found to have higher lower extremity injury rates, while pitchers have higher upper extremity injury rates, but the cause of injuries in both positions is the result of overuse.[68,79,84,85,90] Softball athletes have lower elbow injury rates than baseball athletes, likely due to different stress on the elbow between the pitching motions, however when comparing when comparing injury rates irrespective of body location, softball athletes have a higher injury rate.[71] Not only do injury rates differ between sports and positions, the injuries have also been found to vary by competition level.[90] Using an online database Wasserman et al. found that college softball athletes' total injury rate was higher than high school athletes.[90] One explanation for this discrepancy is the exposure high school athletes have to their athletic trainer (AT). Typically, at the college level, the team has an AT dedicated to them. In contrast, at the high school level, an AT is responsible for all sports at the school, so the number of opportunities to report an injury may be decreased at the high school level. Indicating the need for more investigation of high school softball injuries as current data may not be supplying the full picture.

In softball epidemiology data, an injury is typically identified if it is endured due to participation in the respective sport and results in time loss or discontinuation of a practice or game for at least one day.[68,71,84] Based on this definition, softball pitchers are more likely to sustain an injury during the first six weeks of competition, which has been hypothesized as a repercussion of an improper post and preseason conditioning.[84] Another, more subjective measure of softball epidemiology data is reported pain. The International Association for the Study of Pain, defines pain as "an unpleasant sensory and emotional experience associated with actual or potential tissue damage described in terms of such damage".[49] In softball pitchers, pain typically increases with workload and time in season.[78,83] Specifically, in high school and college softball pitchers, it has been found that 60% of pitchers reported mild to severe upper extremity pain late in their season and 60% of pitchers reported mild to severe shoulder pain at rest.[78] Additionally, health-related quality of life was examined, and the reported pain was also correlated with decreased health-related quality of life scores. In the only study to date tracking fatigue and pain through a softball season, Yang et al. found an increase in fatigue and pain measures pre to post during the first and last game of a season.[100] Interestingly, pain and fatigue were not significantly correlated with pitch count.[100] However, a relationship between workload, fatigue, and pain may still exist as increased reports of pain and fatigue were found in those who pitched more than 10 games compared to those who didn't.[100] Additionally, there was a study that reported a significant increase in pain and fatigue for a single day and over multiple days during a typical weekend softball tournament, with follow-up testing values never returning to baseline, indicating inadequate rest days and/or residual effects.[83]

The aforementioned studies regarding pain may indicate a "playing through pain" mentality in softball pitchers. This mentality, while probably an attempt to avoid time loss, may ultimately result in decreased performance, injury, and decreased health related quality of life. This section highlights the needs to identify mechanisms in which softball pitchers may be increasing their pain or injury rates in order to properly develop intervention strategies.

Influence of Fatigue and Pain on Pitching Performance and Mechanics

Numerous studies in baseball and softball have documented kinematic and kinetic changes in pitching mechanics as pitchers increase in fatigue level, workload, and between those with and without pain. Multiple studies have found a decrease in pitch velocity, and two studies documented a decrease in pitching performance as indicated by a decrease in strike percentage and an increase in earned run average (ERA).[5,23,30,38,44,55,60,98] In baseball pitchers, kinematic differences within the lumbopelvic hip complex (LPHC) as a result of fatigue and workload have been documented.[14,29,30,43] Particularly, there was a 50% decrease in hip to shoulder separation as pitch count increased, and a 4° and 3.5° change in pelvis lateral tilt at maximum external rotation and ball release respectfully.[29,43] Yet, in the examination of trunk flexion and fatigue, there are contradicting results where one study reported a decrease in trunk flexion angle while another reported an increase.[14,30] However, it should be noted that the differences in trunk flexion could be a result of the populations examined. Those with a decrease in trunk flexion were collegiate pitchers, and those with an increase were high school pitchers. While softball literature regarding LPHC mechanics and fatigue is scarce, Downs et al. identified a significant positive correlation between the number of pitches thrown in the last inning of a simulated game and trunk flexion in youth pitchers.[23] Similar to the previous baseball studies, competition level may have influenced results, as the trunk flexion angles were smaller than the values reported in older softball competition levels. Thus, compensation strategies, like altered trunk kinematics, may vary by competition and skill level. Downs et al. also identified a significant decrease in trunk rotation towards the pitching arm side between the first and last inning of a simulated game. The relationship between fatigue and LPHC mechanical differences may be the result of inadequate strength within the LPHC musculature.

The LPHC is the key link connecting the lower and upper extremity, transferring energy between the two extremities.[45,46] Though the pitching motions between baseball and softball are different, they both require the kinetic chain to transfer energy.[15] In both motions, energy utilized from the lower extremities must be transferred distally up the kinetic chain and finally into the ball. As a result of the kinetic chain theory and the summation of speed principle any segment within the chain can influence more distal segments.[46] An unstable LPHC, characterized by musculature weakness, limited range of motion, or sub-optimal mechanics can decrease performance and increase injury risk directly or indirectly by altering more distal segments.[15,45,46] Hence, LPHC kinematics is an important variable of interest in overhead athletes due to the impact the LPHC can have on performance and injury.

As discussed in the previous section, research shows that softball pitchers are pitching with pain and a relationship between kinematics and pain has been found. Prior research has reported that in collegiate pitchers' pain was associated with a posteriorly shifted center of mass (COM), longer stride length, and increased trunk rotation towards the pitching arm side in the riseball pitch.[62] In the changeup, pitchers with pain had increased shoulder horizontal abduction at foot contact and decreased trunk lateral flexion towards the pitching arm at ball release.[63] Though an increased stride length is associated with increased pitch speed, there may be a tipping point where too much is not advantageous if a pitcher cannot maintain their COM in the middle of their base of support.[62,67] The inability to control COM, trunk rotation, and trunk lateral flexion may be the result of LPHC instability and an inability to perform proper segmental sequencing.[61,62] Nonetheless, it is unknown if these mechanical alterations are the result or the cause of pain.

A common complaint of pain in softball pitchers is anterior shoulder pain.[4,75] Anterior shoulder pain is likely because of the eccentric contraction the biceps tendon undergoes during the acceleration phase of the windmill pitch to counteract the elbow extension force.[66,75] Owning to the fact that a common complaint in softball pitchers is anterior shoulder pain and the biceps' high muscle activity, two studies have been published investigating biceps tendon measures pre and post a simulated game and the association between those measures and pitching kinematics.[3,60] Throughout the simulated game youth softball pitchers experienced biceps tendon changes associated with trunk kinematics. Specifically, there was an increase in biceps tendon transverse and longitudinal thickness.[3] While one cannot conclude that pitchers with an increase in biceps tendon thickness had pain, this increase in thickness may represent an acute inflammatory response.[3] The pitchers who exhibited increased biceps tendon thickness had less change in overall trunk rotation and decreased trunk flexion throughout the simulated game than those who did not have increased biceps tendon thickness.[60] These studies agree with previous literature that indicates different compensation mechanisms, warranting further research to identify if these mechanisms are the result or cause of future pain or injury. Due to the significant relationship between biceps tendon thickness and trunk positioning, it is postulated that trunk positioning may alter the line of the pull of the shoulder and humeral musculature, ultimately influencing the amount of stress on those muscles. Emphasizing the necessity of a strong LHPC to control the position of the trunk in order to produce optimal mechanics and timing of segmental sequencing.[60]

Similar to kinematics, kinetic changes have also been associated with fatigue and pain in overhead throwing athletes. In professional baseball pitchers a decrease in shoulder distraction force, elbow distraction force, and horizontal abduction torque at ball release from the first to last inning has been reported.[55] The authors predicted that because higher kinetic values are associated with increased injury risk, as the pitchers got fatigued, they may have altered their mechanics to decrease kinetics, in a subconscious response to decrease injury risk.[55] In youth softball pitchers, conflicting results were found as no kinetic changes were reported from the first to last inning in a simulated game.[60] These differences may be the result of the different skill levels and populations used between the two studies.

Though no kinetic differences were found in relation to workload in softball pitchers, a relationship between kinetics and pain has been found. It has been reported that collegiate softball pitchers with pain had decreased shoulder compression values than those without pain.[63] The decreased kinetic values were most likely the result of an unstable humeral head and an indicator that the pitchers were unable to withstand or counteract the high forces experienced during the windmill pitching motion. In conclusion, fatigue and pain can alter kinematics and kinetics in baseball and softball pitchers. However, mechanical compensations may vary by skill level and population. Though extensive work is still needed in this area, current research emphasizes the importance of an efficient kinetic chain and LPHC to achieve maximal pitching performance and decrease risk of injury.

Influence of Fatigue and Pain on Shoulder and Hip Range of Motion and Strength

Musculoskeletal adaptions, such as range of motion (ROM) and strength, in the glenohumeral and hip joints are another area within the kinetic chain that may negatively influence pitching performance if deficiencies exist.[15,45,46] Glenohumeral ROM adaptations in overhead athletes are likely due to soft tissue and osseous alterations attributable to the repetitive throwing motion.[2,7,18,35,54,72,81] Specifically, the throwing arm demonstrates less internal rotation (IR) and greater external rotation (ER) than the non-throwing arm.[2,18,27,54,73,94] The decreased IR and increased ER is classified as glenohumeral internal rotation deficit, otherwise known as GIRD. Glenohumeral internal rotation deficit is an expected adaptation of repetitive throwing. Too much GIRD, specifically, an ER gain of more than 20° has been associated with increased injury susceptibility.[8] Interestingly, the total ROM (TROM), is typically similar between the two arms. However, like GIRD, there is an optimal range where too much of a bilateral difference, >5°, in TROM can place athletes at increased risk of injury.[93,94] These deficits in glenohumeral ROM have been associated with altered pitching mechanics and glenohumeral strength ratios.[13,39] Despite the associated injury risk, minimal differences in glenohumeral ROM have been documented between those with and without pain.[47,87]

While numerous studies have analyzed glenohumeral ROM at a specific point in time, minimal studies have tracked glenohumeral ROM across various time points. Tracking glenohumeral ROM across various time points may provide further insight into identifying glenohumeral ROM adaptations associated with workload and differences between positions. For example, in major league baseball pitchers, no differences in glenohumeral ROM pre to post season were found. However, starting pitchers had a significant increase in IR and TROM while relief pitchers had a significant worsening of GIRD pre and post the season.[35] The results of that study indicates that stretching may not be the only influence on ROM. Other factors such as the structure of practice or length of warm-up before games may also impact glenohumeral ROM.[35] Glenohumeral ROM differences between baseball positional players and pitchers throughout a season have also been found.[12] Though both players showed an increase in glenohumeral ROM, specifically ER and humeral adduction during the season, pitchers showed a significant TROM increase.[12] Differences between positions suggest that when designing programs playing position should be accounted for and specific programs should be designed for each position.

Furthermore, ROM differences in a little as immediately and 24 hours post baseball pitching have also been documented. Particularly a decrease in dominant arm IR and TROM was found in baseball pitchers immediately, and 24hr post pitching with no changes in non-dominant ROM.[73] These decreases in glenohumeral ROM are likely the result of the adaptations of the soft-tissue musculature owning to the high eccentric contractions endured during the baseball pitching motions.[41,70,73]

Compared to baseball, glenohumeral ROM research in softball is lacking. In a study tracking both baseball and softball pitchers and positional players during a season, no change in IR was found, but there was a significant increase in dominant and non-dominant ER and TROM.[26] A limitation of the study was that the authors analyzed both sports and positions together. This is a limitation as differences in glenohumeral ROM between playing positions has been found in both sports.[12,35,37] In an experimental study comparing glenohumeral ROM in softball pitchers pre and post pitching to fatigue, no differences in shoulder IR or ER were found but, there was a significant decrease in horizontal adduction.[19] Consequently, the authors could not compare results to other softball studies as they are the first to assess glenohumeral ROM directly with pitching performance. It is plausible that because of the different pitching motions and the point in which maximum stress is endured, the clinical values identified for at-risk baseball pitchers may be different for softball pitchers.[4,19] Further research is needed in order to identify if different clinical values and measures are needed to properly identify at-risk softball pitchers.

Similar to glenohumeral ROM, overhead throwing athletes also demonstrate altered glenohumeral strength profiles when comparing bilaterally. Overhead throwing athletes typically have greater IR strength in the throwing arm with fairly symmetrical ER strength values bilaterally.[1,2,6,16,21,40,42,87,92] Due to the unilateral throwing motion, IR and ER strength profiles within the throwing arm are also examined. This unilateral examination is typically measured using ratios or percentages. Research has found that normative values for external rotation strength should be between 66%-75% of IR strength within the dominant arm in baseball pitchers.[42,92,96] During the deceleration phase of the baseball pitch, the external rotators must contract eccentrically to slow down and dissipate the energy generated from the previous phases. This eccentric contraction is commonly associated with muscle degradation, so weak ER is common in overhead throwing athletes. Although weak ER is a common adaptation, it is not considered positive as overstrengthened IR combined with weak ER within the dominant arm places overhead throwers at increased risk of injury. This profile is associated with increased IR torque, shoulder musculature damage, pain, and injury.[9,57,87-89]

Unfortunately, again, limited research has been done solely in softball pitchers examining glenohumeral strength. One study compared ER strength in youth tennis, baseball, and softball athletes and found no differences in glenohumeral ER strength between softball and baseball athletes or between positions (pitchers vs positional) both between and within sports.[58] Though the study did not directly compare ER strength bilaterally within sports or position, the results represented similar trends between dominant and non-dominant glenohumeral ER strength consistent with previous literature. The lack of significant differences between softball and baseball provides evidence that limited differences in glenohumeral strength may exist at the youth level. Nonetheless, further research into the strength profiles of softball pitchers is needed to confirm that hypothesis.

With respect to fatigue and pain, several studies have analyzed glenohumeral strength in relation to fatigue and pain within baseball and softball pitchers. Notably, significant decreases in shoulder strength post the fatiguing protocol or pitching performance were found.[17,83] One study, in particular, measured glenohumeral strength in softball pitchers throughout a tournament and found that strength significantly decreased over a single day and throughout the tournament, with values never returning to baseline.[83] Understanding the glenohumeral strength demands, workload, and how the body responds is imperative for developing sufficient strength and conditioning programs and injury prevention interventions.

Due to the kinetic chain theory, and the distal segment's influence on more proximal segments in overhead throwing athletes, hip ROM and strength have recently started to gain popularity in the literature. Therefore, there is less agreement on normative values for hip ROM and strength in overhead throwing athletes. Although in recent years, hip ROM and strength changes in association with fatigue, workload, pitching performance, and pain have been found, laying the foundation for normative values. Overall research has found a significant decrease in stride and drive hip ROM during a season or pitching bout in overhead throwing athletes.[11,12,101] Surprisingly the association between hip ROM and workload is unclear as two studies found no correlation,[12,101] with one study finding a significant negative correlation between drive hip IR and total pitches and number of innings pitched, and drive hip ER and pitch velocity.[11]

A handful of studies have analyzed the relationship between hip ROM and injuries in baseball players finding decreased hip IR in those with pain and finding a significant correlation with injury.[10,47,51,76,80] Too much or too little hip ROM can alter lower extremity mechanics which in response, results in altered mechanics of the distal segments.[15,46,50] For example, improper alignment of the pelvis as a repercussion of hip ROM deficiencies can result in early trunk rotation, increased forces and torques at the arm, inefficient energy transfer, and decreased ball velocity.[20,50,86,91,95]

Mechanical Differences between Pitch Types

There is disagreement in the baseball literature if certain pitch types, particularly breaking ball pitches, increase injury risk more than other pitch types such as the fastball or changeup. Recommendations advise youth pitchers against throwing breaking ball pitches until proper fastball mechanics have been learned, as a result of the positive association between arm pain and breaking ball pitches.[52,99] However, multiple follow-up biomechanical studies have been conducted to investigate why pain was associated with breaking ball pitches, but no results indicated that the curveball was more harmful than the fastball based on mechanical differences.[25,28,31,34,56,77] The mechanical differences found were thought to result from the mechanics required to achieve the desired pitch outcome and not indicators of injury risk.[25,28,31,34,56,77] Hence, it is still unknown why breaking ball pitches were associated with pain in baseball pitchers. The studies comparing pitch type differences were done with the pitcher only throwing a couple of trials per pitch type within a single point in time. While the study finding pain with breaking ball pitches asked their series of questions before, during, and after a season. Due to the previously established mechanical differences associated with fatigue and workload, one could speculate that different pitch types have different compensation mechanisms or that the compensation mechanisms previously identified have different effects on various pitch types due to the mechanical differences. This hypothesis may explain the lack of significance between pitch types and injury in biomechanical studies.

All of the aforementioned studies analyzing pitch types have been in baseball pitchers. Alternatively, softball research has analyzed mechanics within a single pitch type and their relationship to pain.[62,63] Only two studies to date have compared kinematic and kinetic differences between pitch types in softball pitchers.[22,59] Trunk kinematics (flexion, rotation, lateral flexion) and COM differences between the fastball, changeup, curveball, and dropball pitch in collegiate pitchers were found.[22] Specifically, softball pitchers had more trunk extension in the fastball and more trunk flexion in the dropball. Additionally, the dropball had a more posteriorly shifted COM than the curveball. Based on prior significant association between specific mechanics and pain, the significant differences found between pitch types would place certain pitches at increased pain or injury risk than others.

In comparing kinetics between pitch types in collegiate softball pitchers, the results agree with what is in the baseball literature.[59] The fastball and curveball had higher kinetic values than the changeup, but no significant differences were found between the fastball and curveball in collegiate softball pitchers. The higher kinetic values of shoulder distraction force and anterior elbow force are likely to result from the higher pitch speed in the fastball and curveball than the changeup. Based on kinetics one may consider the fastball and curveball as having a higher injury risk than the changeup as higher kinetic values have previously been associated with increase injury risk in other studies. If this hypothesis holds true it is very unlikely that softball pitchers will be willing to decrease injury risk by means of decreasing pitch speed. Clinicians and researchers must identify other means of lowering kinetics than through pitch speed.

Summary

A single softball pitcher is expected to pitch multiple games within a single day and over the course of multiple days with sometimes little rest between games. Unfortunately, no studies to date have been conducted simulating tournament play or a double header. Focus has primarily been done simulating a single game. However, pitching research indicates residuals effects on ROM and strength within the glenohumeral and hip joints, which can ultimately influence mechanics. Since tournament play is normal in the game of softball, understanding how the body adapts to the increased demands is imperative for injury prevention and performance enhancement strategies.

During a game, a softball pitcher uses an arsenal of pitch types to deceive the batter. It has been documented that these pitch types have various kinematic differences that may increase pain or injury risk. It is important to know how mechanics within various pitch types adapt to fatigue as coaches and players can use that information to potentially decrease injury risk by only calling certain pitches as a pitcher approaches fatigue. Therefore, the data from this study can provide a more inclusive picture of the demands and adaptations from pitching multiple games that can be used to develop various programs and ultimately decrease injury.

CHAPTER 3

METHODS

Objectives of the current study were to identify if increased bouts of pitching place softball pitchers at increased risk of injury due to potential changes in mechanics, range of motion, or strength as a result of the increased workload. In addition, another objective of the study was to determine if the aforementioned altered mechanics vary by pitch type and the influence of various pitch type mechanics on injury risk. This chapter provides the methodology of the study in the following order: participants, setting, instrumentation, design and procedures, and data analysis.

Research Questions

RQ1: Do trunk kinematics (extension, rotation, lateral flexion) significantly differ at events between various time points (1st inning simulated game, last inning simulated game, pre double header) at each pitching event for the fastball, changeup, curveball, and dropball?

RQ2: As workload increases do pitch types display similar or different trunk mechanical (extension, rotation, lateral flexion) alterations?

RQ3: Do hip and shoulder range of motion (dominant and non-dominant IR and ER) significantly differ between time points (pre simulated game to post simulated game; post simulated game to pre double header; post simulated game to post double header; pre simulated game to pre double header; pre simulated game to post double header; and pre double header to post double header)?

RQ4: Do hip and shoulder isometric strength (dominant and non-dominant IR and ER) significantly differ between time points (pre simulated game to post simulated game;

post simulated game to pre double header; post simulated game to post double header; pre simulated game to pre double header; pre simulated game to post double header; and pre double header to post double header)?

Participants

Thirty (14.8 ± 1.9yrs, 162.5 ± 18.3cm, 71.79 ± 16.03kg) adolescent softball pitchers were recruited to participate in this study. Inclusion criteria consisted of being deemed injury and surgery free for the past six months and currently active on a team's roster at the position of a pitcher. In addition, participants must feel comfortable and have experiencing pitching the fastball, changeup, curveball, and dropball in a game setting. Prior to participation all testing procedures were thoroughly explained and any questions were answered. Following explanation of testing procedures participants signed an informed consent document that was approved by Auburn University Institutional Review Board (Appendix A). Participants under the age of 19 also had parental assent obtained (Appendix A).

Setting

All testing procedures took place at the Sports Medicine and Movement Laboratory at Auburn University. This location provided sufficient space, equipment, and tools to successfully complete all objectives of the study.

Instrumentation

Range of Motion

Range of motion measurements were assessed using a Baseline Digital Inclinometer (Fabrication Enterprises, Inc., White Plains, NY) and recorded on a trial sheet.

Isometric Strength

Isometric strength measurements were assessed using a handheld dynamometer (Lafayette Instruments, Lafayette, IN) and recorded on a trial sheet.

Ball Velocity

Ball velocity was assessed using a radar gun (Stalker Pro II Speed Sensor Radar, Applied Concepts, Inc./Stalker Radar, Richardson, TX) positioned directly behind the catcher.

Kinematics

Kinematic data were collected using The MotionMonitor (Innovative Sports Training, Chicago, IL) XGen software synced with an electromagnetic tracking system, The Flock of Birds (trakSTAR Wide-Range, Ascension Technology Corp., Burlington, VT). Position and orientation error of electromagnetic sensers are 0.01 meters and 3° respectively. All kinematic data were sampled at a 240Hz and filtered using a 4th order Butterworth filter with a cutoff frequency of 13.4Hz, as per previous studies examining the pitching motion.[32,33,89] Stride foot contact was determined as an event marker using a force plate (Bertec Corp, Columbus, OH) sampled at a rate of 1200Hz.

Design and Procedures

Before arrival, participants were asked what type of pitches they typically throw in a game. Only fastball, changeup, curveball, and dropball pitch types were used in the study. The order of pitches thrown in the simulated game was pre-determined using a random number generator (fastball = 1, changeup = 2, curveball = 3, and dropball = 4). A pitch count of 100 was used for the simulated game with each inning consisting of 25 pitches, thus a total of 4 innings was pitched for the simulated game.

Participants were asked to arrive to the lab wearing loose-fitting shirts, sports bra, athletic shorts, and athletic shoes.[23] After consent forms were signed, participants' bilateral IR and ER hip and shoulder ROM and isometric strength were measured (pre simulated game). Hip ROM was assessed with the participant seated with legs flexed at 90° hanging off an athletic training table with a rolled towel placed under their distal femur (Figure 1).[24,50] For IR a digital inclinometer was placed on the shaft of the fibula just proximal to the lateral malleolus and for ER a digital inclinometer was placed just proximal to the medial malleolus. A firm capsular end-feel, or tissue resistance without accessory hip movement, was used to determine IR and ER ROM measurements.[24,50,65,74] Excellent intra-rater reliability was reported with an intra-class correlation coefficients (ICC) of (.903-.928).

Hip isometric strength was assessed with the participant in the same position as hip ROM. A handheld dynameter was placed in the same position as the digital inclinometer for IR and ER respectively (Figure 1). Participants were asked to push against the examiner for three seconds to perform a maximal isometric contraction for both IR and ER isometric strength.[24] Measurement was taken from their neutral sitting position. Moderate to excellent intra-rater reliability was reported with an $ICC_{(3,1)}$ of (.726-.913).

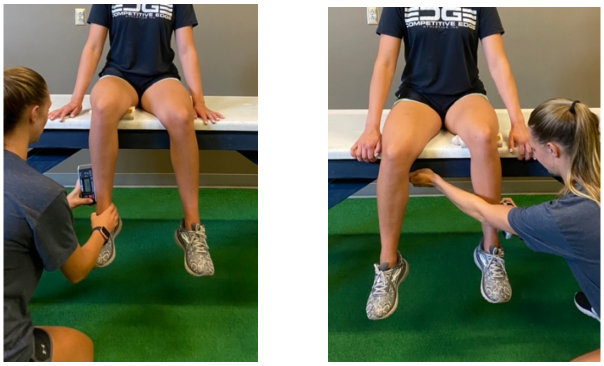

Figure 1: Hip Range of Motion and Strength Protocol

Glenohumeral IR and ER ROM was assessed with the participant laying supinated on an athletic training table with their arm in 90° abduction and elbow flexed 90° with a rolled towel placed under the distal humerus. For IR one hand is placed under the scapula and the other hand is used to hold the digital inclinometer on the dorsum of the forearm just below the olecranon and styloid process of the ulna (Figure 2). The arm was then passively rotated into IR and the identification of scapulothoracic movement during IR was used to determine IR measurement.[24,26] Firm capsular end-feel, or tissue resistant was used to determine ER, with the digital inclinometer placed on the ventral side of the forearm.[24,26] Good to excellent intra-rater reliability was reported with an $ICC_{(3,1)}$ of 0.80-0.98.

Shoulder isometric strength was assessed with the participant in the same position as ROM. The handheld dynamometer was placed in the same position as the digital inclinometer and participants were asked perform a maximal isometric contraction against the examiner for three seconds in the direction of IR and ER (Figure 2).[24] Strength measurements were taken with the arm in 90° abduction and elbow flexed 90°. Good to excellent intra-rater reliability was reported with an $ICC_{(3,1)}$ of 0.86-0.97. All isometric strength measurements were normalized to body mass.

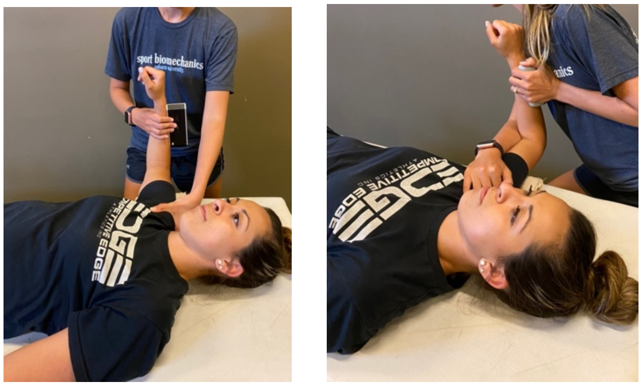

Figure 2: Shoulder Range of Motion and Strength Protocol

Following collection of ROM and isometric strength participants were given an unlimited amount of time to perform a dynamic warmup. Once the participant deemed themself ready, 14 electromagnetic sensors were affixed to the participant at the following anatomical locations (Figure 3): 1) dorsal aspect of the second metatarsal of the stride foot; 2-3) bilateral lateral aspect of the shank; 4-5) bilateral lateral aspect of the femur; 6) sacrum between left and right posterior superior iliac spines (PSIS); 7) posterior aspect of trunk at first thoracic vertebrae spinous process; 8-9) bilateral scapula on the flat broad portion of acromion 10-11) bilateral lateral aspect of the humerus 1-2cm proximal the elbow; 12-13) bilateral lateral aspect of the distal forearm; 14) dorsal aspect of the throwing hand on the third metacarpal. A 15th moveable sensors was used to digitize bony landmarks to build a linked segment model and estimate joint centers for the ankle, knee, hip, spinal column, and shoulder (Table 1).[97]

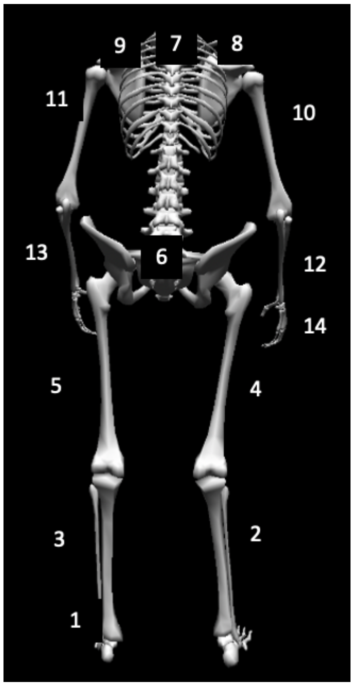

Figure 3: Electromagnetic Sensor Placement

Table 1: Description of Digitized Bony Landmarks

Bony Landmark	*Digitized Process*
Lower Extremity	
Foot	Second phalange metatarsal head
Lateral Ankle	Lateral malleolus
Medial Ankle	Medial malleolus
Lateral Knee	Distal aspect of the lateral femoral condyle
Medial Knee	Distal aspect of the medial femoral condyle
Pelvis	Bilateral anterior superior iliac spine Bilateral posterior superior iliac spine
Trunk	
Thoracic Vertebra (T12)	Space between T12 and lumbar vertebra 1 (L1)
Cervical Vertebra 7 (C7)	Space between C7 and thoracic vertebra 1 (T1)
Thoracic Vertebra 8 (T8)	Space between T8 and thoracic vertebra 9 (T9)
Xiphoid Process	Distal aspect of sternum
Jugular Notch	Proximal aspect of sternum
Upper Extremity	
Superior Angle of Scapula	Medial superior aspect of scapula
Inferior Angle of Scapula	Medial distal aspect of scapula
Acromion Angle of Scapula	Lateral aspect of acromion
Lateral Elbow	Lateral aspect of humeral epicondyle
Medial Elbow	Medial aspect of humeral epicondyle
Lateral Wrist	Lateral aspect of distal radius
Medial Wrist	Lateral aspect of distal ulna
Hand	Tip of third phalange Third metacarpal head

The axis system was defined as positive Y in the vertical direction, anterior/posterior to Y in the direction of movement was defined as positive X, and orthogonal to the X-Y axis to the right was defined as positive Z. Trunk kinematics are defined by the International Society of Biomechanics standards and conventions.[97] Specifically ZX'Y'' was used to define trunk kinematic sequence. Trunk flexion was defined about the Z, with flexion (-) and extension (+). Trunk lateral flexion was defined about the X' with lateral flexion toward the right (+) and toward the left (-). Trunk rotation was defined about the Y'' with rotation to the right (-0) and toward the left (+).

After digitizing was complete, participants were given an unlimited amount of time to complete their warm-up routine. They were instructed to warm-up like they would before a game. Total warm-up time for each participant was recorded. Once deemed warm the simulated game began, using the pre-determined pitch order. A rest break ranging 4-7 minutes, determined using a random number generator, was given between "innings", every 25 pitches, to simulate the pitcher's teams being on offense. All pitches were thrown to a catcher at regulation distance. Three trials thrown for a strike of each pitch type within the first and last inning were recorded, averaged, and used for analysis. Once the simulated game was over, participants bilateral hip and shoulder ROM and isometric strength were immediately reassessed following the procedures described above (post simulated game). Participants were then given a 30 minute break prior to the second round of testing. This break was used to simulate a typical break given to teams during a doubleheader or tournament play.

The second round of testing was to simulate the first inning of a double header, this round will be referred to as the pre double header. Pre double header testing consisted of participants bilateral IR and ER hip and shoulder ROM and isometric strength being collected before and after the pre double header pitching bout using the techniques previously described. These data were identified as pre double header and post double header. After the 30 minutes break was over participants were given unlimited amount of time to warm-up pitching again. Once warm the pre double header round began and participants were asked to pitch three trials of each pitch type for a strike to a catcher at regulation distance, to be saved, averaged, and used for analysis. A total of 12 pitches were pitched in the pre double header. Immediately following completion of the three trials for each pitch type, bilateral IR an ER hip and shoulder ROM and isometric strength were measured and the pre double header was deemed complete. A complete overview of data collection procedures can be found in Figure 4.

The pitching arm was defined as the arm used to pitch the ball and the glove arm was defined as the contralateral arm. The drive leg was defined ipsilateral to the pitching arm and the stride leg was defined contralateral to the pitching arm. Prior to analysis the pitching motion was broken down into three main pitching events: top of pitch (TOP), foot contact (FC), and ball release (BR). Top of pitch was defined as the humerus of the pitching arm positioned perpendicular to the ground. Foot contact was defined using the force place. Specifically, foot contact was identified by the first frame that a ground reaction force was greater than or equal to 20N. Ball release was defined as one frame after max hand angular velocity.[36]

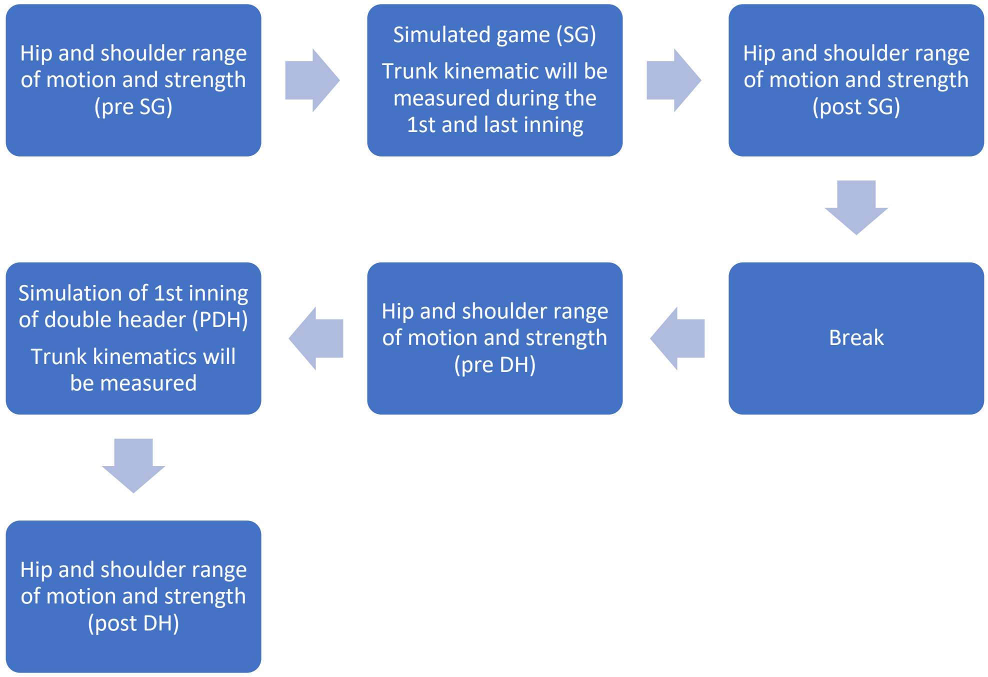

Figure 4: Overview of data collection procedures

Data Analysis and Processing

All statistical testing was completed in IBM SPSS Statistics (IBM corp. Armonk,NY). To answer research question 1, four (one for each pitch type) 3 (time) x 3 (pitching events) multivariate (three trunk variables) analysis of variance (MANOVA) were used to determine any significant differences between the various time points and pitching events. To answer research question two, the mean difference between time points for each trunk kinematic variable (extension/flexion, rotation, lateral flexion) at each event was calculated, and a 4 (pitch type) X 3 (time) X 3 (pitching event) MANOVA was performed to determine if trunk mechanic alterations between time points differ between pitch types.

To answer research questions 3 and 4 two 2 (side) X 2 (rotation) X 4 (time) MANOVA's (ROM and strength) were used to determine differences in hip and glenohumeral ROM and isometric strength between the various time points. A complete overview of all statistical analysis for each research question can be found in Table 2.

Table 2: Overview of Statistical Analysis

RQ1: *Do trunk kinematics (extension, rotation, lateral flexion) significantly differ at events between various time points (1^{st} inning simulated game (SG), last inning SG, pre double header (PDH)) at each pitching event for the fastball, changeup, curveball, and dropball?*	
Fastball	3 X 3 MANOVA: Trunk flexion/extension, rotation, lateral flexion Time (3): 1^{st} inning SG, last inning SG, PDH Pitching Events (3): TOP, FC, BR
Changeup	3 X 3 MANOVA: Trunk flexion/extension, rotation, lateral flexion Time (3): 1^{st} inning SG, last inning SG, PDH Pitching Events (3): TOP, FC, BR
Curveball	3 X 3 MANOVA: Trunk flexion/extension, rotation, lateral flexion Time (3): 1^{st} inning SG, last inning SG, PDH Pitching Events (3): TOP, FC, BR
Dropball	3 X 3 MANOVA: Trunk flexion/extension, rotation, lateral flexion Time (3): 1^{st} inning SG, last inning SG, PDH Pitching Events (3): TOP, FC, BR
RQ2: *As workload increases do pitch types display similar or different trunk mechanic alterations?*	
1. Calculate change in position between time points for each pitch type for each trunk kinematic variable 2. 4 X 3 X 3 MANOVA; Trunk flexion/extension, rotation, lateral flexion Pitch type (4): fastball, changeup, curveball, dropball Time: 1^{st} inning to last inning, 1^{st} inning to PDH, last inning to PDH Pitching Events (3): TOP, FC, BR	
RQ3: *Do hip and shoulder range of motion significantly differ between time points*(dominant and non-dominant IR and ER) **RQ4**: *Do hip and shoulder isometric strength significantly differ between time points*(dominant and non-dominant IR and ER)	
Hip Joint	2 X 2 X 4 MANOVA; range of motion and isometric strength Side (2): dominant (drive), non-dominant (stride) Rotation (2): Internal rotation, external rotation Time (4): pre SG, post SG, pre PDH, post PDH
Glenohumeral Joint	2 X 2 X 4 MANOVA; range of motion and isometric strength Side (2): dominant, non-dominant Rotation (2): Internal rotation, external rotation Time (4): pre SG, post SG, pre PDH, post PDH

Chapter 4

Results

Objectives of the current study were to identify if increased bouts of pitching place softball pitchers at increased risk of injury due to potential changes in mechanics, range of motion, or strength as a result of the increased workload. In addition, another objective of the study was to determine if the aforementioned altered mechanics vary by pitch type and the influence of various pitch type mechanics on injury risk. This chapter provides the results for each research question and is sectioned accordingly:

Research Questions

RQ1: Do trunk kinematics (extension, rotation, lateral flexion) significantly differ at events between various time points (1st inning simulated game, last inning simulated game, pre double header) at each pitching event for the fastball, changeup, curveball, and dropball?

RQ2: As workload increase do pitch types display similar or different trunk mechanic (extension/flexion, rotation, lateral flexion) alterations?

RQ3: Do hip and shoulder range of motion (dominant and non-dominant IR and ER) significantly differ between time points (pre simulated game to post simulated game; post simulated game to pre double header; post simulated game to post double header; pre simulated game to pre double header; pre simulated game to post double header; and pre double header to post double header)?

RQ4: Do hip and shoulder isometric strength (dominant and non-dominant IR and ER) significantly differ between time points (pre simulated game to post simulated game; post simulated game to pre double header; post simulated game to post double header;

pre simulated game to pre double header; pre simulated game to post double header; and pre double header to post double header)?

RQ1: Do trunk kinematics (extension, rotation, lateral flexion) significantly differ at events between various time points (1st inning simulated game, last inning simulated game, pre double header) at each pitching event for the fastball, changeup, curveball, and dropball?

To answer research question one, four separate 3 (event) x 3 (time) multivariate analysis of variance (MANOVAs), one for each pitch type, were used to determine any trunk kinematic differences at pitching events between the three time points. Statistical significance was set a priori at $\alpha = .0125$. Results revealed that the only significant multivariate main effects for each of the pitch types was event. There were no significant main effects for time or for the time X event interaction. Descriptive statistics for each trunk variable at events across time points for each pitch type are shown below in Tables 3-6.

Follow-up testing for event revealed that for each pitch type there were significant differences between events for trunk extension, rotation, and lateral flexion. Specifically, for trunk extension there was a significant difference between top of pitch and foot contact and foot contact and ball release for the fastball, changeup, curveball, and dropball. Additionally, trunk rotation and trunk lateral flexion revealed a significant difference between all three events for all four pitch types.

Table 3: Descriptive Statistics for the Fastball

Fastball	**1st Inning**	**Last Inning**	**Pre-Double Header**
Top of Pitch			
Trunk Extension(°)	1.25 ± 11.41	.66 ± 13.51	1.58 ± 15.89
Trunk Rotation(°)	-65.15 ± 15.28	-65.11 ± 17.63	-66.57 ± 17.59
Trunk Lateral Flexion(°)	5.06 ± 11.04	5.95 ± 10.20	6.42 ± 11.76
Foot Contact			
Trunk Extension(°)	7.98 ± 12.70	7.02 ± 14.19	9.07 ± 16.88
Trunk Rotation(°)	-69.77 ± 13.81	-69.46 ± 17.52	-71.60 ± 15.49
Trunk Lateral Flexion(°)	9.94 ± 11.17	10.26 ± 10.35	11.28 ± 11.64
Ball Release			
Trunk Extension(°)	2.03 ± 9.82	.16 ± 8.72	1.88 ± 9.78
Trunk Rotation(°)	-35.71 ± 14.85	-37.11 ± 16.61	-38.11 ± 15.16
Trunk Lateral Flexion(°)	19.95 ± 8.03	19.08 ± 7.96	19.52 ± 9.92

Trunk extension (+) Trunk flexion (-); Trunk rotation towards glove arm side (+) Trunk rotation towards pitching arm (-); Trunk lateral flexion towards pitching arm side (+) Trunk lateral flexion towards glove arm side (-); ***A*** *denotes significant difference from 1st inning;*

Table 4: Descriptive Statistics for the Changeup

Changeup	**1st Inning**	**Last Inning**	**Pre-Double Header**
Top of Pitch			
Trunk Extension(°)	4.67 ± 11.06	2.74 ± 13.03	4.74 ± 13.04
Trunk Rotation(°)	-61.98 ± 15.46	-64.09 ± 16.81	-64.78 ± 16.48
Trunk Lateral Flexion(°)	4.29 ± 10.82	3.92 ± 10.38	4.42 ± 11.13
Foot Contact			
Trunk Extension(°)	11.34 ± 11.06	8.57 ± 13.31	11.19 ± 13.92
Trunk Rotation(°)	-67.28 ± 13.88	-69.47 ± 15.51	-69.69 ± 14.66
Trunk Lateral Flexion(°)	10.57 ± 11.48	9.33 ± 11.13	10.20 ± 11.35
Ball Release			
Trunk Extension(°)	48.92 ± 10.57	2.54 ± 9.27	4.07 ± 10.44
Trunk Rotation(°)	-35.96 ± 16.19	-37.58 ± 17.42	-38.27 ± 15.64
Trunk Lateral Flexion(°)	21.73 ± 10.40	20.94 ± 9.98	21.59 ± 11.22

Trunk extension (+) Trunk flexion (-); Trunk rotation towards glove arm side (+) Trunk rotation towards pitching arm (-); Trunk lateral flexion towards pitching arm side (+) Trunk lateral flexion towards glove arm side (-); ***A*** *denotes significant difference from 1st inning;*

Table 5: Descriptive Statistics for the Curveball

Curveball	**1st Inning**	**Last Inning**	**Pre-Double Header**
Top of Pitch			
Trunk Extension(°)	2.87 ± 11.73	.40 ± 14.03	.55 ± 15.29
Trunk Rotation(°)	-64.67 ± 15.01	-65.69 ± 17.48	-68.28 ± 18.31
Trunk Lateral Flexion(°)	5.38 ± 10.24	6.13 ± 10.44	6.03 ± 10.97
Foot Contact			
Trunk Extension(°)	10.73 ± 12.50	7.27 ± 14.77	7.86 ± 16.38
Trunk Rotation(°)	-68.22 ± 13.86	-69.0 ± 16.47	-71.51 ± 17.06
Trunk Lateral Flexion(°)	10.17 ± 10.28	9.99 ± 10.68	10.93 ± 10.92
Ball Release			
Trunk Extension(°)	1.41 ± 10.32	-1.01 ± 9.17	.27 ± 10.46
Trunk Rotation(°)	-33.82 ± 15.77	-34.98 ± 16.79	-35.59 ± 16.0
Trunk Lateral Flexion(°)	18.71 ± 8.63	18.04 ± 8.42	18.24 ± 9.49

*Trunk extension (+) Trunk flexion (-); Trunk rotation towards glove arm side (+) Trunk rotation towards pitching arm (-); Trunk lateral flexion towards pitching arm side (+) Trunk lateral flexion towards glove arm side (-); **A** denotes significant difference from 1st inning;*

Table 6: Descriptive Statistics for the Dropball

Dropball	**1st Inning**	**Last Inning**	**Pre-Double Header**
Top of Pitch			
Trunk Extension(°)	2.58 ± 10.14	1.48 ± 13.74	2.66 ± 13.44
Trunk Rotation(°)	-65.79 ± 15.71	-66.16 ± 18.35	-68.12 ± 17.82
Trunk Lateral Flexion(°)	5.03 ± 11.44	4.77 ± 10.51	4.43 ± 11.59
Foot Contact			
Trunk Extension(°)	10.08 ± 11.29	8.24 ± 14.97	10.09 ± 15.02
Trunk Rotation(°)	-70.21 ± 14.07	-70.16 ± 17.26	-72.51 ± 15.89
Trunk Lateral Flexion(°)	9.51 ± 11.21	9.34 ± 11.17	9.96 ± 11.62
Ball Release			
Trunk Extension(°)	1.10 ± 9.80	-0.87 ± 9.42	0.43 ± 9.81
Trunk Rotation(°)	-37.66 ± 15.34	-38.39 ± 17.37	-38.86 ± 15.58
Trunk Lateral Flexion(°)	18.98 ± 8.77	18.40 ± 8.40	18.82 ± 10.05

*Trunk extension (+) Trunk flexion (-); Trunk rotation towards glove arm side (+) Trunk rotation towards pitching arm (-); Trunk lateral flexion towards pitching arm side (+) Trunk lateral flexion towards glove arm side (-); **A** denotes significant difference from 1st inning;*

RQ2: As workload increases do pitch types display similar or different trunk mechanical (extension, rotation, lateral flexion) alterations?

The absolute change between time points (1st inning simulated game to last inning simulated game (time 1), last inning simulated to pre double header (time 2), 1st inning simulated game to pre double header (time 3)) was calculated for each pitch type. Then a 4 (pitch type) X 3 (time point) X 3 (event) MANOVA was used to investigate any potential differences between pitch types, time, and/or events for trunk extension, trunk rotation, and trunk lateral flexion. Statistical significance was set a priori at α = .05. Results revealed a significant effect for event (p = .005), no other main effects or interactions were statistically significant (Table 9). Descriptive statistics can be found in Table 7 and data trends can be found in Figure 5-7.

Follow-up testing for event revealed significant univariate results for trunk extension (p < .001) and trunk rotation (p < .001). Specifically for trunk extension and trunk rotation there was a significant differences between ball release and top of pitch and foot contact (Table 8).

Table 7 : Statistical Results

	Pitch Type	Time	Event	Pitch Type X Time Interaction	Pitch Type X Event Interaction	Time X Event Interaction
Wilks' I	.488	.686	.427	.370	.223	.530
F	(9.0, 17.0) = 1.984	(6.0, 20.0)= 1.524	(6.0, 20.0)= 4.482	(18.0, 8.0) = .757	(18.0, 8.0) = 1.545	(12.0, 14.0)= 1.036
Significance	.107	.221	.005*	.705	.271	.469
Partial η^2	.512	.314	.573	.630	.777	.470

* *Denotes statical significance*

Table 8: Post-Hoc Results for Event

	Top of Pitch		Foot Contact		Ball Release	
	Mean	Standard Error	Mean	Standard Error	Mean	Standard Error
Trunk Extension(°)	5.54	.55	5.98	.72	3.37[AB]	.39
Trunk Rotation(°)	10.73	1.47	9.49	1.26	5.91[AB]	.80
Trunk Lateral Flexion(°)	4.57	.59	3.95	.55	3.61	.44

[A] denotes statistical differences from Top of Pitch; [B] denotes statistical differences from Foot Contact

Table 9: Descriptive Statistics

	1st inning to last inning			Last inning to pre double header			1st inning to pre double header		
	Trunk Extension (°)	Trunk Rotation (°)	Trunk Lateral Flexion (°)	Trunk Extension (°)	Trunk Rotation (°)	Trunk Lateral Flexion (°)	Trunk Extension (°)	Trunk Rotation (°)	Trunk Lateral Flexion (°)
Top of Pitch									
Fastball	5.00 ± 5.19	11.30 ± 12.0	3.28 ± 3.22	6.29 ± 4.37	10.44 ± 8.37	4.90 ± 3.80	5.64 ± 4.07	10.72 ± 8.94	5.33 ± 4.33
Changeup	5.66 ± 4.73	11.33 ± 10.46	4.02 ± 3.57	5.55 ± 4.17	9.49 ± 8.90	4.59 ± 3.65	5.56 ± 4.55	9.47± 9.46	5.10 ± 5.42
Curveball	4.65 ± 4.48	10.45 ± 12.35	3.52 ± 3.29	5.53 ± 3.58	9.66 ± 8.07	3.87 ± 3.36	5.21 ± 3.44	11.48 ± 10.02	5.08 ± 5.10
Dropball	5.29 ± 6.07	13.07 ± 14.21	4.66 ± 3.93	6.09 ± 4.72	10.99 ± 9.73	4.88 ± 4.65	5.99 ± 3.31	10.33 ± 11.11	5.61 ± 5.63
Foot Contact									
Fastball	5.69 ± 6.53	10.94 ± 10.96	3.15 ± 2.58	5.47 ± 5.63	8.63 ± 6.72	3.88 ± 3.76	6.00 ± 4.48	9.86 ± 9.11	4.84 ± 4.96
Changeup	6.69 ± 5.18	9.74 ± 9.47	4.35 ± 2.80	5.67 ± 5.10	7.30 ± 5.90	3.22 ± 2.51	6.30 ± 5.20	7.74 ± 7.19	4.40 ± 4.50
Curveball	5.63 ± 5.59	10.69 ± 10.58	3.47 ± 3.02	6.04 ± 4.21	8.77 ± 7.29	3.35 ± 3.02	6.00 ± 4.80	9.84 ± 9.85	4.75 ± 5.44
Dropball	6.03 ± 6.97	11.67 ± 12.63	3.85 ± 3.50	5.88 ± 5.79	9.26 ± 8.58	3.61 ± 3.33	6.35 ± 3.86	9.36± 9.97	4.54 ± 5.12
Ball Release									
Fastball	3.76 ± 3.26	5.46 ± 6.24	2.75 ± 2.56	2.96 ± 2.84	6.23 ± 5.37	3.52 ± 2.48	3.56 ± 2.65	6.31 ± 5.45	4.33 ± 3.67
Changeup	3.59 ± 3.54	5.16 ± 5.35	3.19 ± 3.73	3.50 ± 3.30	5.57 ± 6.16	2.96 ± 2.85	3.81 ± 3.31	5.70 ± 4.64	4.83 ± 4.10
Curveball	3.03 ± 3.71	5.70 ± 6.49	3.03 ± 3.26	3.41 ± 3.33	6.32 ± 5.47	2.96 ± 2.47	3.12 ± 3.04	6.29 ± 5.90	4.58 ± 3.73
Dropball	3.38 ± 3.43	5.98 ± 6.49	2.97 ± 3.32	3.33 ± 2.94	6.81 ± 5.56	3.55 ± 2.67	3.02 ± 3.86	5.45 ± 5.02	4.67 ± 3.64

Trunk extension (+) Trunk flexion (-); Trunk rotation towards glove arm side (+) Trunk rotation towards pitching arm (-); Trunk lateral flexion towards pitching arm side (+) Trunk lateral flexion towards glove arm side (-);

Figure 5: *Change in number of degrees between time points; Time 1: 1st inning simulated game to last inning simulated game; Time 2: last inning simulated game to pre double header; Time 3: 1st inning simulated game to pre double header*

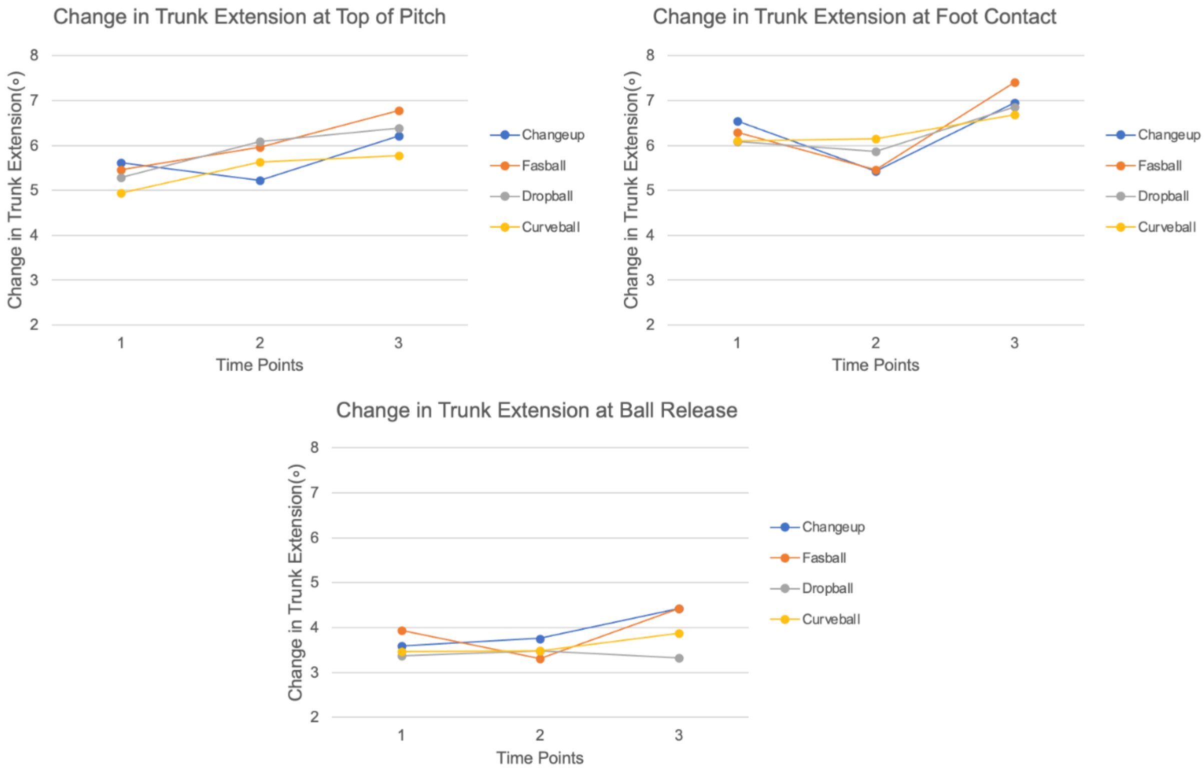

Figure 6: *Change in number of degrees between time points; Time 1: 1st inning simulated game to last inning simulated game; Time 2: last inning simulated game to pre double header; Time 3: 1st inning simulated game to pre double header*

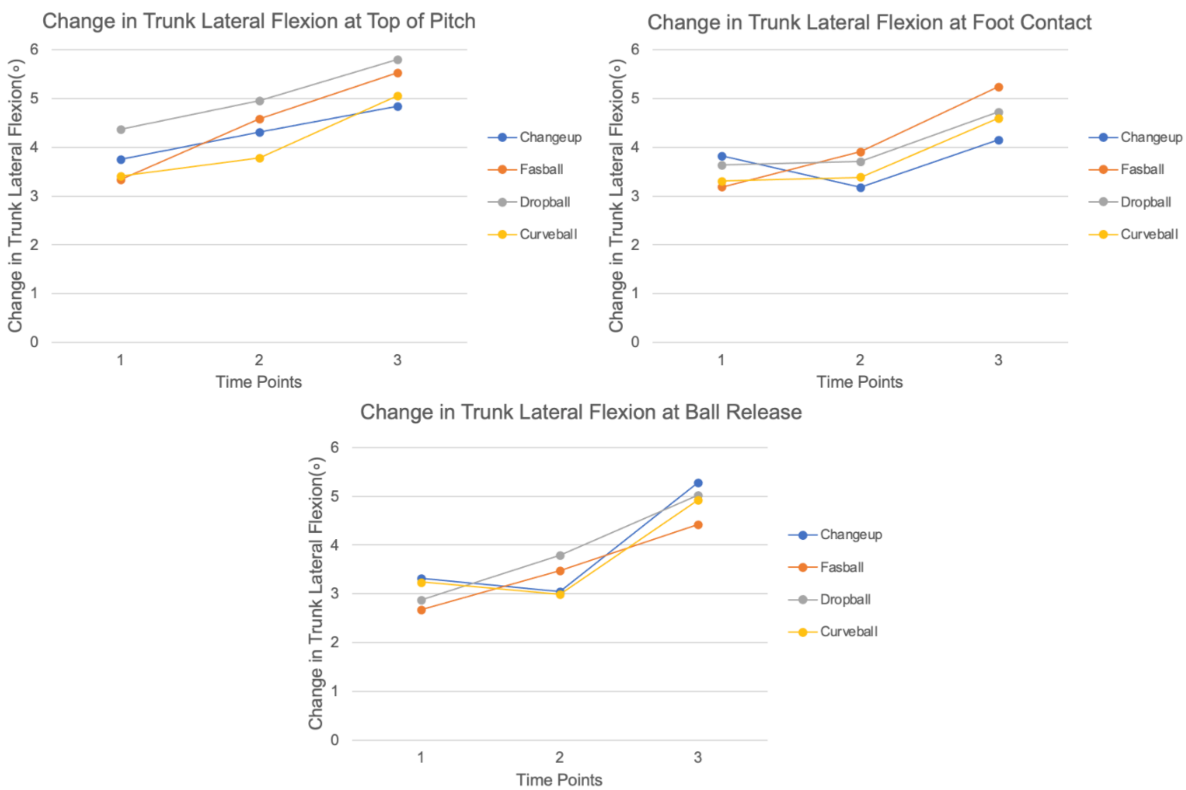

Figure 7: *Change in number of degrees between time points; Time 1: 1st inning simulated game to last inning simulated game; Time 2: last inning simulated game to pre double header; Time 3: 1st inning simulated game to pre double header*

RQ3: Do hip and shoulder range of motion (dominant and non-dominant IR and ER) **significantly differ between time points (pre simulated game to post simulated game; post simulated game to pre double header; post simulated game to post double header; pre simulated game to pre double header; pre simulated game to post double header; and pre double header to post double header)?**

Two separate 2 (side) X 2 (rotation) X 4 (time) MANOVAs, one for the hip and one for the shoulder, were used to determine differences in range of motion (ROM) of the hip and shoulder joint across time points. Statistical significance was set a priori at $\alpha = .025$. All statistically significant multivariate effects were followed up with post-hoc testing using a Bonferroni adjustment to determine specific differences. Results can be found in Tables 10 and 11 below.

Table 10: Statistical Results for Hip Range of Motion and Isometric Strength

	Side	Rotation	Time	Side X Rotation Interaction	Side X Time Interaction	Rotation X Time Interaction	Side X Rotation X Time Interaction
Wilks' l	.771	.258	.346	.716	.785	.699	.722
F	(2.0, 31.0) = 4.602	(2.0, 31.0) = 44.599	(6.0, 27.0) = 8.515	(2.0, 31.0) = 6.156	(6.0, 27.0) = 1.233	(6.0, 27.0) = 1.938	(6.0, 27.0) = 1.735
Significance	.018*	< .001*	< .001*	.006*	.321	.111	.151
Partial η^2	.299	.742	.654	.284	.215	.301	.278

* p < .025

Table 11: Hip Range of Motion Descriptive Statistics Over Time

	Drive Leg IR(°)	Drive Leg ER(°)	Stride Leg IR(°)	Stride Leg ER(°)
Pre SG	29.7 ± 6.3	29.8 ± 6.5	28.3 ± 7.3	31.7 ± 6.0
Post SG	28.3 ± 6.9	27.6 ± 7.0	26.7 ± 8.2	30.2 ± 6.0
Pre PDH	26.2 ± 6.6	25.5 ± 5.8	26.3 ± 7.2	28.1 ± 5.8
Post PDH	26.6 ± 7.2	24.6 ± 6.3	24.7 ± 7.0	28.0 ± 5.5

IR: Internal Rotation; ER: External Rotation; SG: Simulated Game; PDH: Pre Double Header

For the hip joint, MANOVA results revealed statistically significant ROM main effect finding for time ($p < .001$) and a side X rotation interaction ($p < .001$). Time follow-up testing revealed that for the average overall ROM, hip ROM decreased over time (Figure 8). Specifically, pre simulated game ROM was significantly greater than post simulated game ($p = .007$), pre double header ($p < .001$), and post double header ($p < .001$). Additionally, post simulated game ROM was significantly more than pre double header ($p = .005$) and post double header ($p = .008$).

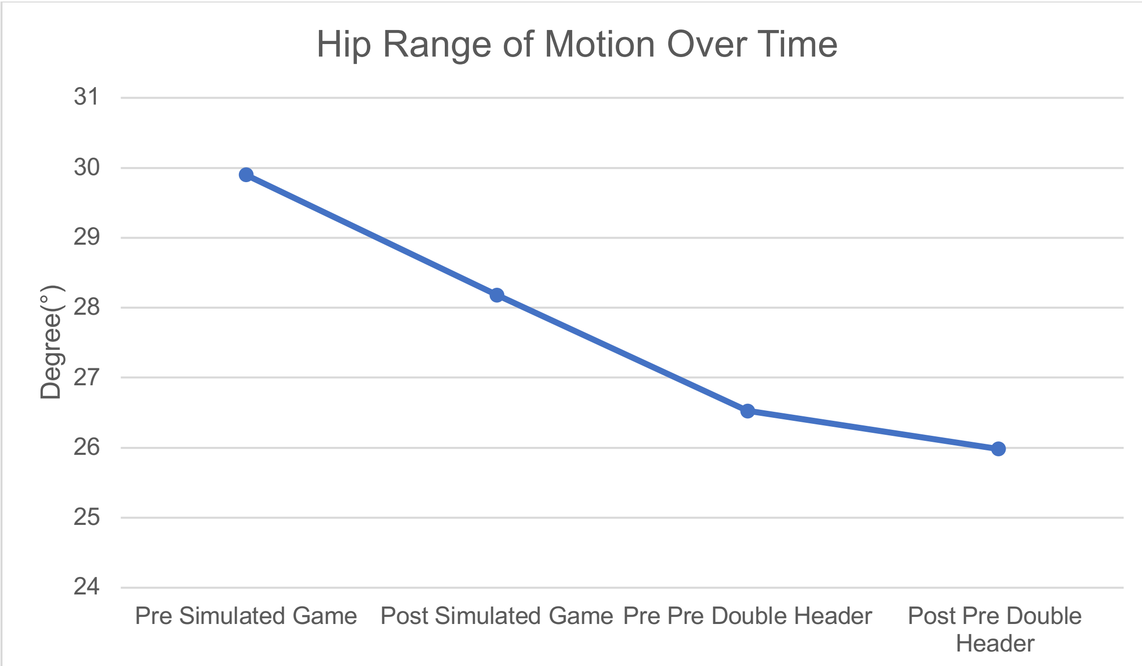

Figure 8: Overall Average Hip Range of Motion Over Time

The side X rotation interaction revealed that for the stride leg there was statistically more external rotation (ER) than internal rotation (IR) ($p = .030$) (Figure 9 and Table 12). There were no other statistically significant differences between side, rotation, or time or any side, rotation, time interactions for the hip joint.

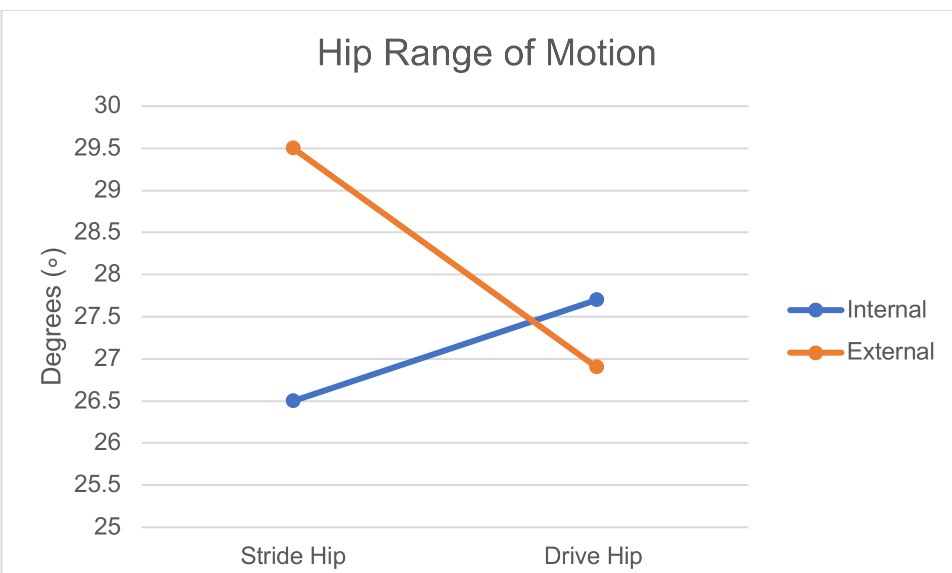

Figure 9: Hip Range of Motion Side X Rotation Interaction

Table 12: Mean and Standard Error for Hip Range of Motion Side X Rotation Interaction

Side	Rotation	Mean(°)	Standard Error
Stride Hip	Internal Rotation	26.5*	1.2
	External Rotation	29.5*	0.9
Drive Hip	Internal Rotation	27.7	1.0
	External Rotation	26.9	1.0

* *denotes statistically significant difference*

For the shoulder joint, the MANOVA revealed a statistically significant main effect finding for side (p = .021), rotation (p < .001), and time (p < .001) (Table 13). Follow-up testing for rotation found that ER for the shoulder joint was statistically greater than IR (p < .001). Descriptive results can be found in Table 14 below.

Table 13: Statistical Results for Shoulder Range of Motion and Isometric Strength

	Side	Rotation	Time	Side X Rotation Interaction	Side X Time Interaction	Rotation X Time Interaction	Side X Rotation X Time Interaction
Wilks' l	.779	.051	.342	.922	.741	.892	.824
F	(2.0, 31.0) = 4.385	(2.0, 31.0) = 288.636	(6.0, 27.0) = 8.648	(2.0, 31.0) = 1.316	(6.0, 27.0) = 1.574	(6.0, 27.0) = .544	(6.0, 27.0) = .963
Significance	.021*	< .001*	< .001*	.283	.193	.770	.468
Partial η^2	.221	.949	.658	.078	.259	.108	.176

* p < .025

Table 14: Shoulder Range of Motion Descriptive Statistics Over Time

	Dominant Shoulder IR(°)	Dominant Shoulder ER(°)	Non-Dominant Shoulder IR(°)	Non-Dominant Shoulder ER(°)
Pre SG	47.9 ± 4.3	104.9 ± 13.5	46.9 ± 5.3	106.0 ± 13.4
Post SG	46.1 ± 5.1	103.8 ± 13.9	45.2 ± 7.2	102.0 ± 12.2
Pre PDH	46.1 ± 4.1	102.5 ± 14.3	45.4 ± 5.4	102.5 ± 14.4
Post PDH	44.9 ± 4.5	102.2 ± 14.6	43.8 ± 5.3	100.0 ± 12.9

IR: Internal Rotation; ER: External Rotation; SG: Simulated Game; PDH: Pre Double Header

Time follow-up testing for the shoulder revealed that the average overall ROM decreased over time (Figure 10). Specifically, pre simulated game ROM was significantly greater than post simulated game ($p = .001$), pre double header ($p = .005$), and post double header ($p < .001$). Additionally, pre double header was significantly greater than post double header ($p = .033$). There were no other statistically significant differences between side, rotation, time, or any side, rotation, time interactions for the shoulder joint.

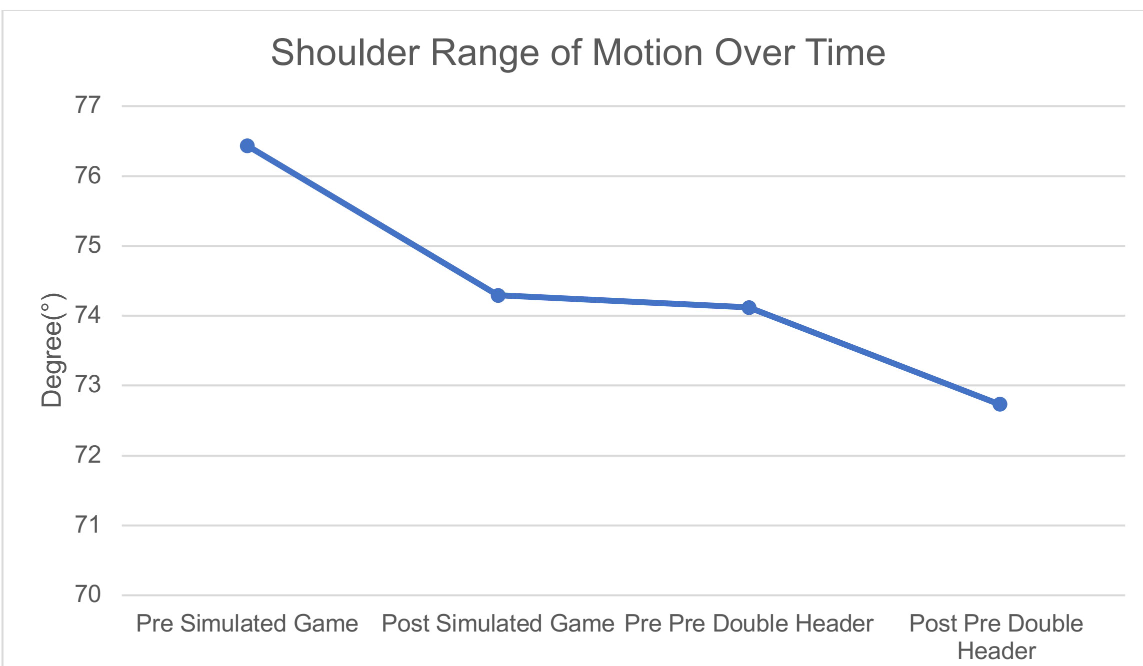

Figure 10: Overall Average Shoulder Range of Motion Over Time

RQ4: Do hip and shoulder isometric strength (dominant and non-dominant IR and ER) significantly differ between time points (pre simulated game to post simulated game; post simulated game to pre double header; post simulated game to post double header; pre simulated game to pre double header; pre simulated game to post double header; and pre double header to post double header)?

Two separate 2 (side) X 2 (rotation) X 4 (time) MANOVAs, one for the hip and one for the shoulder, were used to determine differences in isometric strength of the hip and shoulder joint across time points. Statistical significance was set a priori at $\alpha = .025$. Any multivariate significant results were followed up with post-hoc testing using a Bonferroni adjustment to determine specific differences. Results for hip and shoulder isometric strength can be found in Tables 10 and 13 above. Results revealed for the hip joint, isometric strength had a significant main effect for time ($p < .001$), and side X rotation interaction ($p < .006$).

Table 10: Statistical Results for Hip Range of Motion and Isometric Strength

	Side	Rotation	Time	Side X Rotation Interaction	Side X Time Interaction	Rotation X Time Interaction	Side X Rotation X Time Interaction
Wilks' l	.771	.258	.346	.716	.785	.699	.722
F	(2.0, 31.0) = 4.602	(2.0, 31.0) = 44.599	(6.0, 27.0) = 8.515	(2.0, 31.0) = 6.156	(6.0, 27.0) = 1.233	(6.0, 27.0) = 1.938	(6.0, 27.0) = 1.735
Significance	.018*	< .001*	< .001*	.006*	.321	.111	.151
Partial η^2	.299	.742	.654	.284	.215	.301	.278

* p < .025

Time follow-up testing revealed that overall isometric strength for the hip decreased over time (Figure 11). Specifically, pre simulated game isometric strength was significantly greater than post simulated game ($p < .001$), pre double header ($p = .004$), post double header ($p = .015$). There were no other differences between time points for hip isometric strength.

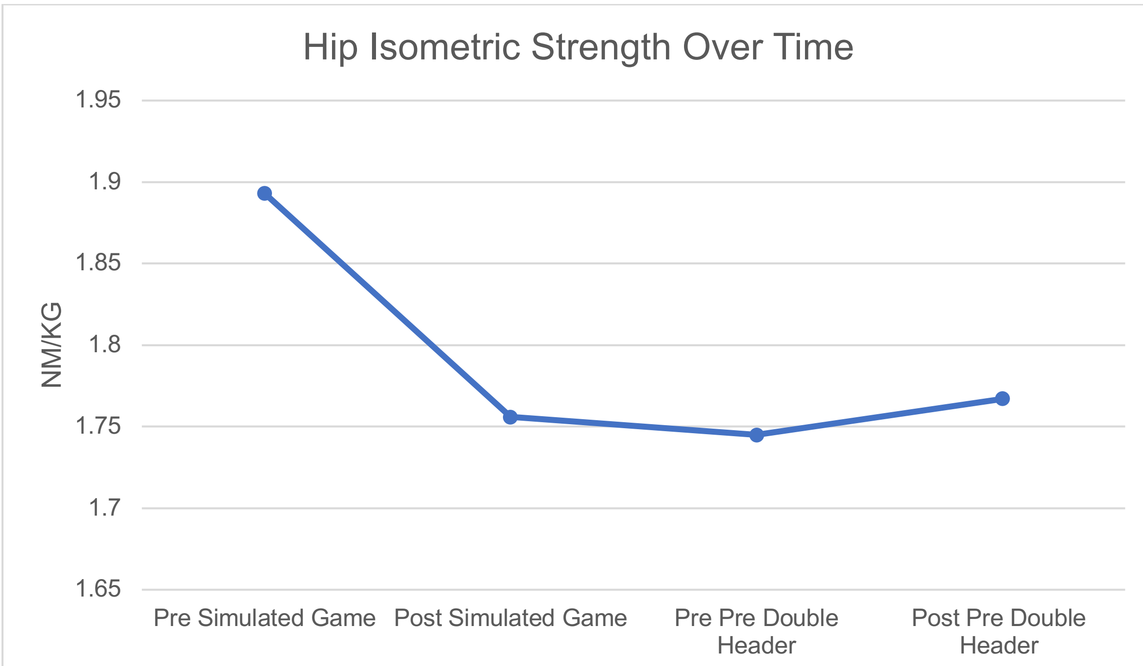

Figure 11: Overall Average Hip Isometric Strength Over Time

The side X rotation interaction follow-up testing revealed that the drive and stride leg had greater IR than ER isometric strength ($p < .001$). There were no other significant differences between side, rotation, time, or side, rotation, time interactions. Descriptive results for hip isometric strength can be found in Table 15.

Table 15: Hip Isometric Strength Descriptive Statistics Over Time

	Drive Leg IR(Nm/kg)	Drive Leg ER(Nm/kg)	Stride Leg IR(Nm/kg)	Stride Leg ER(Nm/kg)
Pre SG	2.1 ± .5	1.7 ± .4	2.1 ± .6	1.7 ± .3
Post SG	2.0 ± .6	1.6 ± .4	1.9 ± .5	1.5 ± .3
Pre PDH	2.0 ± .5	1.6 ± .4	.9 ± .5	1.5 ± .3
Post PDH	2.0 ± .6	1.6 ± .4	1.0 ± .6	1.5 ± .3

IR: Internal Rotation; ER: External Rotation; SG: Simulated Game; PDH: Pre Double Header

For the shoulder joint the MANOVA revealed a significant main effect for isometric strength for side (p = .021) and time (p < .001). Follow-up testing revealed that overall the dominant shoulder was signficantly stronger than the non-dominant shoulder.Time follow-up testing revealed that shoulder isometric strength decreased as time increased (Figure 12). Specifically, pre simulated game shoulder isometric strength was significantly greater than post simulated game (p < .001), pre double header (p < .001), and post double header (p < .001). There were no other significant differences between side, rotation, time or side, rotation, time interactions for shoulder isometric strength. Descriptive results for shoulder isometric strength can be found in Table 16.

Table 13: Statistical Results for Shoulder Range of Motion and Isometric Strength

	Side	Rotation	Time	Side X Rotation Interaction	Side X Time Interaction	Rotation X Time Interaction	Side X Rotation X Time Interaction
Wilks' l	.779	.051	.342	.922	.741	.892	.824
F	(2.0, 31.0) = 4.385	(2.0, 31.0) = 288.636	(6.0, 27.0) = 8.648	(2.0, 31.0) = 1.316	(6.0, 27.0) = 1.574	(6.0, 27.0) = .544	(6.0, 27.0) = .963
Significance	.021*	< .001*	< .001*	.283	.193	.770	.468
Partial η^2	.221	.949	.658	.078	.259	.108	.176

* p < .025

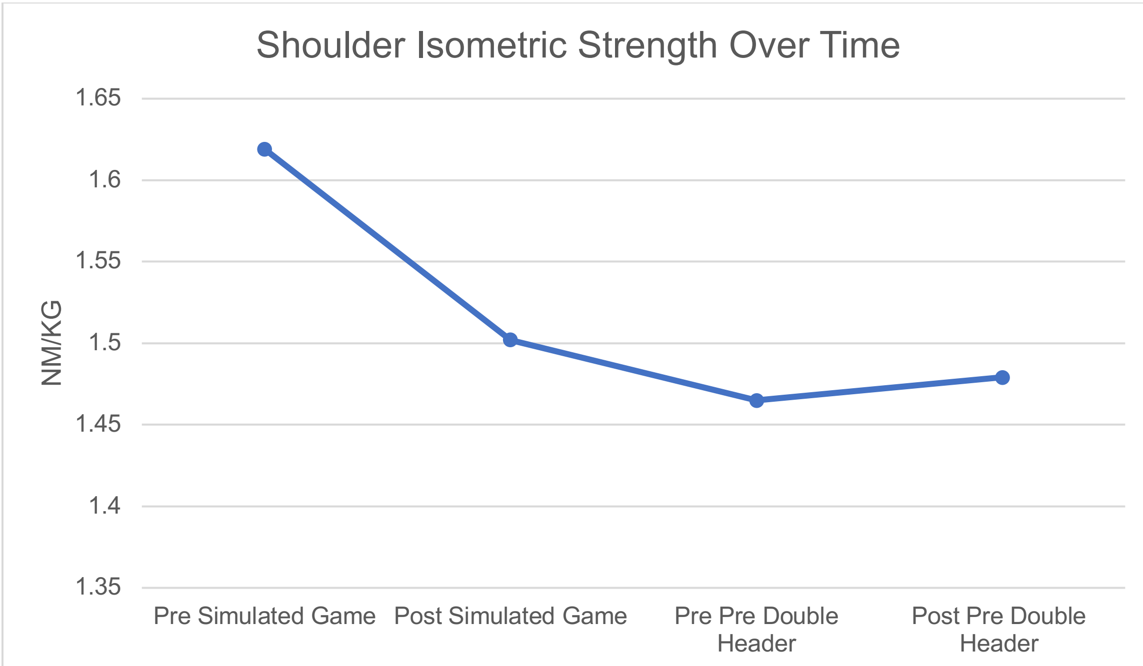

Figure 12: Overall Average Shoulder Isometric Strength Over Time

Table 16: Shoulder Isometric Strength Descriptive Statistics Over Time

	Dominant Shoulder IR(°)	Dominant Shoulder ER(°)	Non-Dominant Shoulder IR(°)	Non-Dominant Shoulder ER(°)
Pre SG	1.6 ± .4	1.7 ± .4	1.6 ± .4	1.6 ± .4
Post SG	1.5 ± .5	1.5 ± .3	1.5 ± .4	1.5 ± .4
Pre PDH	1.5 ± .4	1.5 ± .3	1.4 ± .4	1.5 ± .4
Post PDH	1.5 ± .4	1.5 ± .4	1.4 ± .4	1.5 ± .4

IR: Internal Rotation; ER: External Rotation; SG: Simulated Game; PDH: Pre Double Header

Chapter 5

Discussion

Objectives of the current study were to identify if increased bouts of pitching place softball pitchers at increased risk of injury as a result of changes in mechanics, range of motion (ROM), or strength because of the increased workload. In addition, another objective of the study was to determine if the aforementioned altered mechanics vary by pitch type and the influence on injury risk. This chapter discusses the findings of each research question and the application these results have to softball pitchers.

RQ1: Do trunk kinematics (extension, rotation, lateral flexion) significantly differ at events between various time points (1st inning simulated game, last inning simulated game, and pre double header) at each pitching event for the fastball, changeup, curveball, and dropball?

The aim of this question was to investigate the influence of workload on trunk kinematics for various pitch types. It was hypothesized that as time increased (1st inning simulated game to last inning simulated game, last inning simulated game to pre double header, and 1st inning simulated game to pre double header) there would be less trunk rotation towards the pitching arm side, an increase in trunk flexion, and an increase in trunk lateral flexion toward the glove arm side for each of the pitch types. Results showed that there were no significant differences at any of the defined pitching event between the time points for any of the trunk kinematic variables.

A previous study examining youth softball pitchers found a significant decrease in trunk rotation toward the pitching arm side between the first and last inning of a simulated game in the fastball at the top of backswing.[23] The results of the current study are not in agreement with the aforementioned study as the current study did not find significant differences. Discrepancies in results may be explained by the age of the participants used in the two studies. The average age in the study conducted by Downs et al was 12.4yrs while the current study had an average of 14.8.[23] Assuming age is positively correlated with pitching experience, the age difference may explain the difference in results. Older softball pitchers would be expected to represent with increased strength and muscular endurance, due to the increased repetitions and experience compared to a younger population. These reasonings may furthermore be why the curveball and dropball too lacked significant differences. Further research should evaluate varying age ranges and years of experience pitching various pitch types to investigate if there is a correlation between mechanical alterations, workload, and experience.

Additionally, the lack of significant differences may result from the methods not being able to fully replicate the demands of tournament play. While the current study did implement a total pitch count of 112 pitches, reports have documented pitchers achieving a pitch count of 191 within a single day and up to 381 during a typical weekend tournament.[83] Lastly, pitchers were excluded if they experienced an injury that required them to cease participation. The current study did not exclude individuals if they were experiencing pain. Varying results may be found if pain free and pitchers with pain were to be analyzed separately, rather than as a whole, as kinematic differences between pain and pain free pitchers have previously been documented.[62,63] Participants pitching with pain would not be unexpected as previous literature has indicated that softball pitchers are playing with/through pain.[78,83,100] Additionally, these reported pain values have been show to increase over the course of a tournament and competitive season.

RQ2: As workload increases do pitch types display similar or different trunk mechanical (extension, rotation, lateral flexion) alterations?

Research question two aimed to investigate the influence of workload on trunk mechanics between various pitch types. It was hypothesized that pitch types would display different trunk mechanical alterations as workload increased. The results, however, were not in agreement with the hypothesis. There were no statistically significant differences between pitch types in the change of trunk rotation, trunk extension, or trunk lateral flexion between the three time points (*Time 1: 1st inning simulated game to last inning simulated game; Time 2: last inning simulated to pre double header; Time 3: 1st inning simulated game to pre double header).*

Previous research has identified differences in trunk extension and trunk lateral flexion between the fastball, changeup, curveball, and dropball at various pitching events.[22] The current research question did not investigate differences in trunk kinematics at events between pitch types but rather the change in mechanics between time points to investigate if pitch types display similar or different compensation strategies as workload increased. Nonetheless, the lack of significance for the main effect or interaction of time is intriguing. One would have hypothesized that the break given to participants mechanics between the first inning of the simulated game and the pre double header (time 3) would have the least amount of change in mechanics, indicating that the rest given was enough for pitchers to recover and return to baseline mechanics. Interestingly, trunk extension and trunk lateral flexion time point 3 trended to have the largest change in mechanics and for trunk rotation time point 3 had the second largest change in mechanics. Though the differences between time points lacked statistical significance, data trends warrant further research into the influence of tournament play on mechanics.

Though results did not reveal differences between pitch types some interesting trends within the data that are worth discussing. In particular, the change in trunk rotation at the top of pitch and foot contact for all pitch types follow the similar trend of time point 1 (1st inning simulated game to last inning simulated game) being the largest change, time point two (last inning simulated game to pre double header) being the smallest change, and time point 3 (1st inning simulated game to pre double header) in the middle (Figure 13). However, at ball release, the dropball trends in the opposite direction for time point 2, making time point 2 the largest change, while the other pitch types follow the previously mentioned trend (Figure 13). Thus, variations in trunk rotation mechanics have been documented to be associated with pain and workload in softball pitchers.[23,62] Further research will be needed to determine if the change in trunk rotation for the dropball continues to trend in the opposite direction of other pitch types as workload continue and the impact of that change on injury risk.

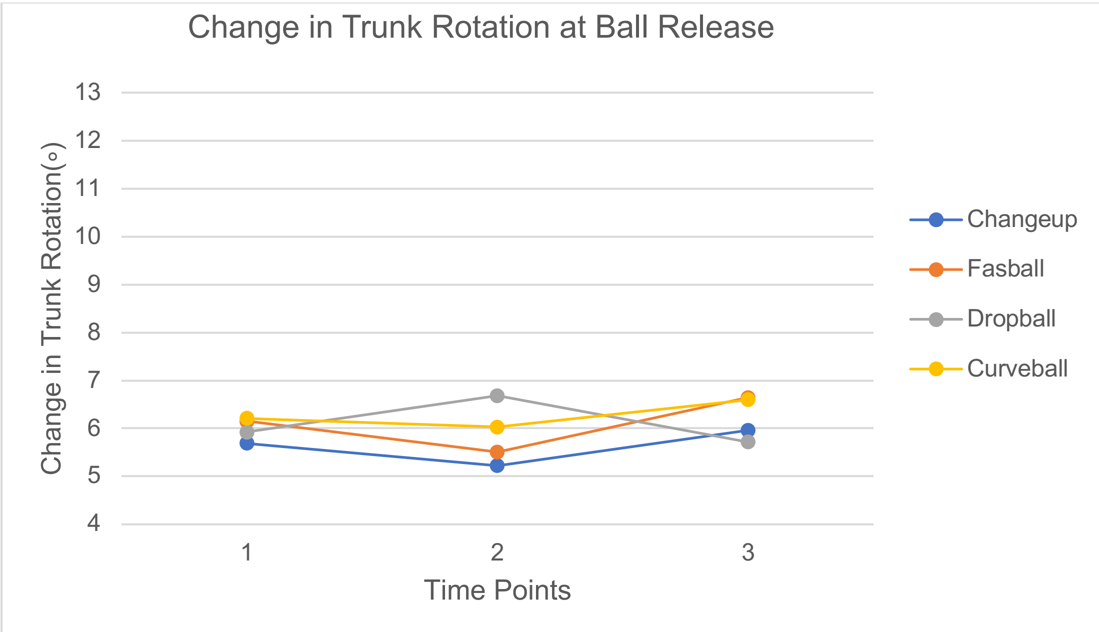

Figure 13: *Time 1: 1st inning simulated game to last inning simulated game; Time 2: last inning simulated game to pre double header; Time 3: 1st inning simulated game to pre double header*

Trunk lateral flexion at ball release for the fastball and dropball represent similar trends, while the changeup and curveball represent similar trends. Specifically, the fastball and dropball exhibit a linear trend between time points (Figure 14), while the changeup and curveball exhibit a small decrease between time points 1(1st inning simulated game to last inning simulated game) and 2 (last inning simulated game to pre double header) and then an increase between time points 2 and 3 (1st inning simulated game to pre double header). Future studies should increase the workload and determine if the trends found in the current study continue.

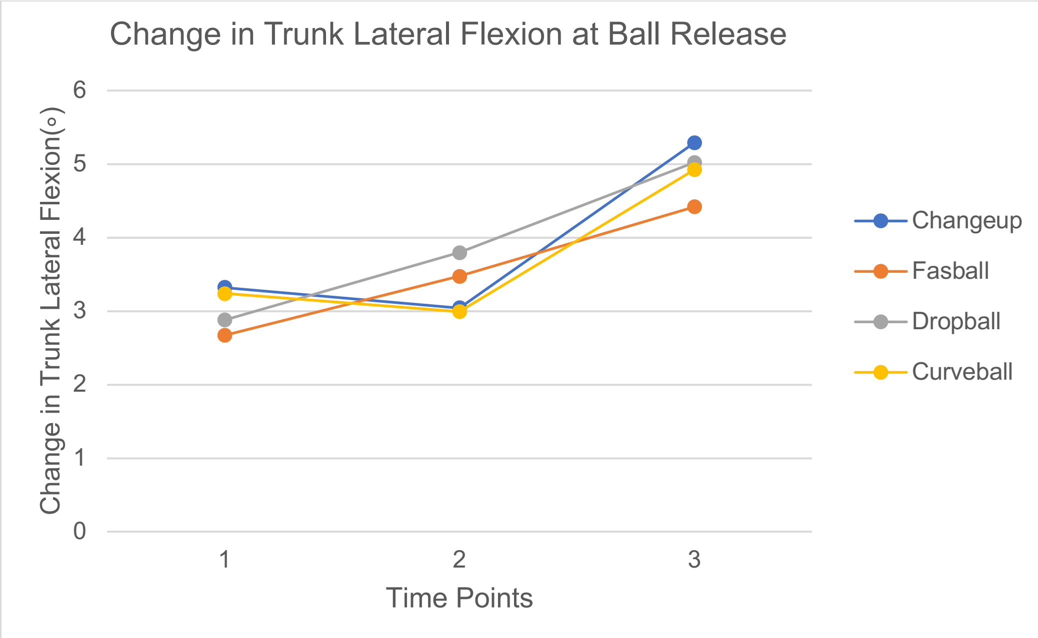

Figure 14: *Time 1: 1st inning simulated game to last inning simulated game; Time 2: last inning simulated game to pre double header; Time 3: 1st inning simulated game to pre double header*

This research question, however, is not without its limitations. The current study calculated the change between time points and then used the absolute value for analysis. The direction in which participants' trunk mechanics changed between time points is important. A change in one direction versus another may be harmful or protective. Splitting participants into groups, for example those who increased trunk rotation towards their pitching arm and those who decreased trunk rotation towards their pitching arm, may provide a more holistic picture of an athletes' injury risk and the relationship of specific compensations on pitching performance.

RQ3: Do hip and shoulder range of motion dominant and non-dominant IR and ER) significantly differ between time points (pre to post simulated game; post simulated game to pre double header; post simulated game to post double header; pre simulated game to pre double header; pre simulated game to post double header; and pre double header to post double header)?

The aim of this question was to investigate the influence of workload on hip and shoulder range of motion (ROM). It was hypothesized that hip and shoulder ROM will decrease pre simulated game to post simulated game, pre simulated game to pre double header, and pre simulated game to post double header. The results confirmed the hypothesis for both the hip and shoulder joint. As time points increased the average overall ROM decreased when compared to the pre simulated game values. This decrease in hip ROM was significant between pre simulated game and post simulated game, pre double header, and post double header. Additionally, pre double header and post double header hip ROM were significantly lower than post simulated game. These results are in agreement with prior baseball literature finding a decrease in hip ROM after pitching and/or repeated pitching bouts.[11,12,101] The results of the current study add important information to softball research as it shows that even after a typical rest break, softball pitchers hip ROM do not return to baseline values (pre simulated game), and in fact actually decreased below post simulated game values. The continual decline in hip ROM as time and workload increased may indicate inadequate rest and that softball pitching may result in residual effects in hip ROM. Though hip ROM was not assessed, Skillington et al, found similar results with fatigue and strength over the course a typical weekend tournament.[83] The aforementioned study found that over the course of the tournament strength and fatigue values never returned to baseline, indicating inadequate rest and residual effects.

Decreased hip ROM may negatively impact softball pitcher's mechanics and increase their injury risk. Prior literature has emphasized the impact hip ROM can have on altering pitching mechanics, in baseball and softball, such as hip and trunk position and increasing upper extremity kinetics.[15,20,46,50,86,91,95] The current study represents the first study, to the authors knowledge, to most closely replicate a back-to-back game scenario. Based on the finding of decreased hip ROM as time increased softball pitchers who pitch back-to-back games may be placing themselves at increased risk of injury, even with a given rest break. These results warrant further research into investigating adequate rest time in softball pitchers and the impact tournament play has on these athletes.

Moving distally up the kinetic chain to the shoulder, similar results were found. Pre simulated game average overall shoulder ROM was greater than post simulated game, pre double header, and post double header. Additionally, pre double header was significantly greater than post double header. Again, shoulder ROM decreased across time points and never returned to baseline values. Further emphasizing the previous hypothesis of inadequate rest and residual effects. Prior literature investigating shoulder ROM and its relationship with pitching has varying results. One study conducted in baseball pitchers did find a significant decrease in shoulder ROM immediately and 24hrs post pitching.[73] However, other studies have found no differences in shoulder ROM pre and post pitching and over the course of a season in baseball and softball athletes.[19,26] Only one study to date, besides the current study, has tracked shoulder ROM in softball pitchers. Dashottar et al found no difference in shoulder IR or ER ROM after pitching to fatigue but did find a significant decrease in shoulder horizontal adduction.[19] The current study however is the only study to track shoulder ROM while implementing a back-to-back game scenario, most similar to what pitcher's experience during a double header or tournament play.

Though previous research has documented an increase in shoulder ER and a decrease in IR in the dominant arm in baseball pitchers over the course of a season, is it unknown if this shift in total ROM is as advantageous for softball pitchers. Friesen et al found that compared to softball positional players, pitchers had decreased ER.[37] The difference in total ROM between baseball and softball pitches may be the result of the different pitching motions. Further research is needed to determine if previously established at-risk values for baseball pitchers can be applied to softball pitchers.

It is worth noting that while the differences between pre simulated game and post simulated game, pre double header, and post double header are statistically significant they may not be clinically significant as they only vary by a few degrees. Mean detectable change may be a more beneficial from of analysis from a clinical perspective. However, that does not take away from the significance of the findings of the current study. The trends represented with hip and shoulder ROM lay an important foundation for future research and warrant further investigation into the topic.

RQ4: Do hip and shoulder isometric strength dominant and non-dominant IR and ER) significantly differ between time points (pre simulated game to post simulated game; post simulated game to pre double header; post simulated game to post double header; pre simulated game to pre double header; pre simulated game to post double header; and pre double header to post double header)?

The aim of this question was to investigate the influence of workload on hip and shoulder range of motion. It was hypothesized that hip and shoulder isometric strength will decrease pre simulated game to post simulated game, pre simulated game to pre double header, and pre simulated game to post double header. The hypothesis for hip and shoulder isometric strength was confirmed. Results revealed that for overall hip average isometric strength as time points increased isometric strength decreased. Corben et al, to the authors knowledge, is the only other study to track hip strength before and after pitching in softball pitchers.[17] The results of the current study are similar to Corben who found a decrease in hip strength after a single pitching bout.[17] The results of the current study add to current literature by also finding the hip isometric strength did not return to baseline value after the given break.

In softball pitching, energy is transferred from the lower extremity up the kinetic chain to the distal upper extremity. Having a strong lower extremity is imperative for optimal performance and decreasing injury risk in softball pitchers. In a study comparing pitchers with and without upper extremity pain, those with pain had decreased drive hip ER strength and stride hip IR strength than pitchers without upper extremity pain.[64] Hip strength, specifically drive hip ER strength, has also been associated with increased net energy outflow from the trunk to humerus and from the humerus to the forearm during the acceleration phase of the softball pitching motion.[69] The results of current study lay the groundwork however, further research is needed to fully understand the optimal range of hip strength and the influence of workload.

The current study found that shoulder isometric strength was greatest at pre simulated game and shoulder strength values never returned as time increased. These results are similar to the results found by Skillington et al who also found that shoulder strength values decreased over the course of a weekend tournament and never returned to baseline value even after each day.[83] Shoulder strength is important for slowing down and dissipating the energy in the throwing shoulder after ball release.

Decreased shoulder strength may decrease the ability of the shoulder musculature to eccentrically control the throwing arm and place undue stress on the upper extremity. Understanding the physiologically demands of softball pitching can help researchers, clinicians, and coaches develop sport specific training regimens to help improve performance.

Summary

The overall purpose of this study was to investigate the influence of workload on pitching mechanics, pitch types, range of motion and strength between various time points. The results of this study did not show any significant differences between time points for trunk kinematics nor any differences in compensation mechanisms between pitch types. Alternatively, it was found that overall hip and shoulder ROM and isometric strength significantly decreased as time/workload increased. Previous research has identified significant relationships between decreased ROM and strength with altered pitching mechanics, decreased performance, and increased injury risk. Though no significant differences in trunk kinematics were found, it may be hypothesized that pitching mechanics may be altered after a certain degree of musculature adaptions (decreased ROM and strength) occur. Limited research currently exist investigating the influence of workload in softball pitching; thus, this study lays an important foundation for the field. Future research should investigate whole body kinematic and kinetic changes with an increased workload.

REFERENCES

1. Alderink GJ, Kuck DJ. lsokinetic Shoulder Strength of High School and College-Aged Pitchers*. *The Journal of orthopaedic and sports physical therapy.* 1986;7(4):163-172.
2. Anloague PA, Spees V, Smith J, Herbenick MA, Rubino LJ. Glenohumeral range of motion and lower extremity flexibility in collegiate-level baseball players. *Sports health.* 2012;4(1):25-30.
3. Barfield JW, Plummer HA, Anz AW, Andrews JR, Oliver GD. Biceps Tendon Changes in Youth Softball Pitchers Following an Acute Bout of Pitching. *Int J Sports Med.* 2018;39(14):1063-1067.
4. Barrentine SW, Fleisig GS, Whiteside JA, Escamilla RF, Andrews JR. Biomechanics of windmill softball pitching with implications about injury mechanisms at the shoulder and elbow. *The Journal of orthopaedic and sports physical therapy.* 1998;28(6):405-415.
5. Bradbury JC, Forman SL. The impact of pitch counts and days of rest on performance among major-league baseball pitchers. *The Journal of Strength & Conditioning Research.* 2012;26(5):1181-1187.
6. Brown LP, Niehues SL, Harrah A, Yavorsky P, Hirshman HP. Upper extremity range of motion and isokinetic strength of the internal and external shoulder rotators in major league baseball players. *The American journal of sports medicine.* 1988;16(6):577-585.
7. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: Spectrum of pathology part I: Pathoanatomy and biomechanics. *Arthroscopy: The Journal of Arthroscopic & Related Surgery.* 2003;19(4):404-420.
8. Burkhart SS, Morgan CD, Kibler WB. The disabled throwing shoulder: spectrum of pathology. Part II: evaluation and treatment of SLAP lesions in throwers. *Arthroscopy : the journal of arthroscopic & related surgery : official publication of the Arthroscopy Association of North America and the International Arthroscopy Association.* 2003;19(5):531-539.
9. Byram IR, Bushnell BD, Dugger K, et al. Preseason shoulder strength measurements in professional baseball pitchers: identifying players at risk for injury. *The American journal of sports medicine.* 2010;38(7):1375-1382.
10. Camp CL, Spiker AM, Zajac JM, et al. Decreased Hip Internal Rotation Increases the Risk of Back and Abdominal Muscle Injuries in Professional Baseball Players: Analysis of 258 Player-seasons. *J Am Acad Orthop Surg.* 2018;26(9):e198-e206.
11. Camp CL, Zajac JM, Pearson D, et al. The Impact of Workload on the Evolution of Hip Internal and External Rotation in Professional Baseball Players Over the Course of the Season. *Orthopaedic journal of sports medicine.* 2018;6(2):2325967117752105-2325967117752105.
12. Chan JM, Zajac J, Erickson BJ, et al. Upper Extremity and Hip Range of Motion Changes Throughout a Season in Professional Baseball Players. *The American journal of sports medicine.* 2020;48(2):481-487.

13. Chou PP-H, Chou Y-L, Wang Y-S, Wang R-T, Lin H-T. Effects of glenohumeral internal rotation deficit on baseball pitching among pitchers of different ages. *Journal of shoulder and elbow surgery.* 2018;27(4):599-605.
14. Chou PP-H, Huang Y-P, Gu Y-H, et al. Change in pitching biomechanics in the late-inning in Taiwanese high school baseball pitchers. *The Journal of Strength & Conditioning Research.* 2015;29(6):1500-1508.
15. Chu SK, Jayabalan P, Kibler WB, Press J. The Kinetic Chain Revisited: New Concepts on Throwing Mechanics and Injury. *PM & R : the journal of injury, function, and rehabilitation.* 2016;8(3 Suppl):S69-77.
16. Cook EE, Gray VL, Savinar-Nogue E, Medeiros J. Shoulder Antagonistic Strength Ratios: A Comparison between College-Level Baseball Pitchers and Nonpitchers. *The Journal of orthopaedic and sports physical therapy.* 1987;8(9):451-461.
17. Corben JS, Cerrone SA, Soviero JE, et al. Performance Demands in Softball Pitching: A Comprehensive Muscle Fatigue Study. *The American journal of sports medicine.* 2015;43(8):2035-2041.
18. Crockett HC, Gross LB, Wilk KE, et al. Osseous adaptation and range of motion at the glenohumeral joint in professional baseball pitchers. *The American journal of sports medicine.* 2002;30(1):20-26.
19. Dashottar A. Acute effects of softball pitching to fatigue on the glenohumeral internal rotation range of motion. *Physiotherapy-The Journal of Indian Association of Physiotherapists.* 2019;13(1):23.
20. Dillman CJ, Fleisig GS, Andrews JR. Biomechanics of pitching with emphasis upon shoulder kinematics. *The Journal of orthopaedic and sports physical therapy.* 1993;18(2):402-408.
21. Donatelli R, Ellenbecker TS, Ekedahl SR, et al. Assessment of shoulder strength in professional baseball pitchers. *The Journal of orthopaedic and sports physical therapy.* 2000;30(9):544-551.
22. Downs J, Bordelon N, Friesen K, David S, Oliver G. Kinematic Differences Exist Between the Fastball, Change-up, Curveball, and Drop-ball Pitch in Collegiate Softball Pitchers. *American Journal of Sports Medicine.* 2020.
23. Downs J, Friesen K, A WA, et al. Effects of a Simulated Game on Pitching Kinematics in Youth Softball Pitcher. *Int J Sports Med.* 2020;41(3):189-195.
24. Downs J, Wasserberger K, Oliver GD. Influence of a Pre-throwing Protocol on Range of Motion and Strength in Baseball Athletes. *Int J Sports Med.* 2020.
25. Dun S, Loftice J, Fleisig GS, Kingsley D, Andrews JR. A biomechanical comparison of youth baseball pitches: is the curveball potentially harmful? *The American journal of sports medicine.* 2008;36(4):686-692.
26. Dwelly PM, Tripp BL, Tripp PA, Eberman LE, Gorin S. Glenohumeral rotational range of motion in collegiate overhead-throwing athletes during an athletic season. *Journal of Athletic Training.* 2009;44(6):611-616.
27. Ellenbecker TS, Roetert EP, Bailie DS, Davies GJ, Brown SW. Glenohumeral joint total rotation range of motion in elite tennis players and baseball pitchers. *Medicine and science in sports and exercise.* 2002;34(12):2052-2056.

28. Elliott B, Grove JR, Gibson B, Thurston B. A three-dimensional cinematographic analysis of the fastball and curveball pitches in baseball. *Journal of Applied Biomechanics.* 1986;2(1):20-28.
29. Erickson BJ, Sgori T, Chalmers PN, et al. The impact of fatigue on baseball pitching mechanics in adolescent male pitchers. *Arthroscopy: The Journal of Arthroscopic & Related Surgery.* 2016;32(5):762-771.
30. Escamilla RF, Barrentine SW, Fleisig GS, et al. Pitching biomechanics as a pitcher approaches muscular fatigue during a simulated baseball game. *The American journal of sports medicine.* 2007;35(1):23-33.
31. Escamilla RF, Fleisig GS, Groeschner D, Akizuki K. Biomechanical Comparisons Among Fastball, Slider, Curveball, and Changeup Pitch Types and Between Balls and Strikes in Professional Baseball Pitchers. *The American journal of sports medicine.* 2017;45(14):3358-3367.
32. Escamilla RF, Fleisig GS, Zheng N, Barrentine SW, Andrews JR. Kinematic comparisons of 1996 Olympic baseball pitchers. *J Sports Sci.* 2001;19(9):665-676.
33. Fleisig GS, Escamilla RF, Andrews JR, et al. Kinematic and kinetic comparison between baseball pitching and football passing. *Journal of Applied Biomechanics.* 1996;12(2):207-224.
34. Fleisig GS, Kingsley DS, Loftice JW, et al. Kinetic comparison among the fastball, curveball, change-up, and slider in collegiate baseball pitchers. *The American journal of sports medicine.* 2006;34(3):423-430.
35. Freehill MT, Ebel BG, Archer KR, et al. Glenohumeral range of motion in major league pitchers: changes over the playing season. *Sports health.* 2011;3(1):97-104.
36. Friesen K. The Effects of Body Composition on Female Softball Pitching Biomechanics. 2020.
37. Friesen K, Downs J, Wasserberger K, Shannon D, Oliver GD. Glenohumeral and Hip Range of Motion in Youth Softball Athletes. *Int J Sports Med.* 2020;41(1):59-64.
38. Gandhi J, ElAttrache NS, Kaufman KR, Hurd WJ. Voluntary activation deficits of the infraspinatus present as a consequence of pitching-induced fatigue. *Journal of shoulder and elbow surgery.* 2012;21(5):625-630.
39. Guney H, Harput G, Colakoglu F, Baltaci G. The Effect of Glenohumeral Internal-Rotation Deficit on Functional Rotator-Strength Ratio in Adolescent Overhead Athletes. *J Sport Rehabil.* 2016;25(1):52-57.
40. Hinton RY. Isokinetic evaluation of shoulder rotational strength in high school baseball pitchers. *The American journal of sports medicine.* 1988;16(3):274-279.
41. Jamurtas AZ, Theocharis V, Tofas T, et al. Comparison between leg and arm eccentric exercises of the same relative intensity on indices of muscle damage. *Eur J Appl Physiol.* 2005;95(2-3):179-185.
42. Kaplan KM, Elattrache NS, Jobe FW, et al. Comparison of shoulder range of motion, strength, and playing time in uninjured high school baseball pitchers who reside in warm- and cold-weather climates. *The American journal of sports medicine.* 2011;39(2):320-328.

43. Record #716 is using an undefined reference type. If you are sure you are using the correct reference type, the template for that type will need to be set up in this output style.
44. Keeley WD, Oliver DG, Torry RM, Wicke J. Validity of pitch velocity and strike percentage to assess fatigue in young baseball pitchers. *International Journal of Performance Analysis in Sport.* 2014;14(2):355-366.
45. Kibler WB, Press J, Sciascia A. The role of core stability in athletic function. *Sports medicine (Auckland, NZ).* 2006;36(3):189-198.
46. Kibler WB, Wilkes T, Sciascia A. Mechanics and pathomechanics in the overhead athlete. *Clinics in sports medicine.* 2013;32(4):637-651.
47. Kim YO, Jo YJ, Kim SH, Park KN. Shoulder Pain and Rotational Range of Motion of the Trunk, Shoulder, and Hip in Baseball Players. *Journal of Athletic Training.* 2019;54(11):1149-1155.
48. Krajnik S, Fogarty KJ, Yard EE, Comstock RD. Shoulder injuries in US high school baseball and softball athletes, 2005-2008. *Pediatrics.* 2010;125(3):497-501.
49. Kumar KH, Elavarasi P. Definition of pain and classification of pain disorders. *Journal of Advanced Clinical and Research Insights.* 2016;3(3):87-90.
50. Laudner KG, Moore SD, Sipes RC, Meister K. Functional Hip Characteristics of Baseball Pitchers and Position Players. *The American journal of sports medicine.* 2009;38(2):383-387.
51. Li X, Ma R, Zhou H, et al. Evaluation of Hip Internal and External Rotation Range of Motion as an Injury Risk Factor for Hip, Abdominal and Groin Injuries in Professional Baseball Players. *Orthop Rev (Pavia).* 2015;7(4):6142.
52. 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. *The American journal of sports medicine.* 2002;30(4):463-468.
53. M F. Softball Slides into the 21st century: growth in popularity of softball in schools. *Parks Recreation.* 1995;30(4):36.
54. Meister K, Day T, Horodyski M, et al. Rotational Motion Changes in the Glenohumeral Joint of the Adolescent/Little League Baseball Player. *The American journal of sports medicine.* 2005;33(5):693-698.
55. Murray TA, Cook TD, Werner SL, Schlegel TF, Hawkins RJ. The effects of extended play on professional baseball pitchers. *The American journal of sports medicine.* 2001;29(2):137-142.
56. Nissen CW, Westwell M, Ounpuu S, et al. A biomechanical comparison of the fastball and curveball in adolescent baseball pitchers. *The American journal of sports medicine.* 2009;37(8):1492-1498.
57. Noffal GJ. Isokinetic eccentric-to-concentric strength ratios of the shoulder rotator muscles in throwers and nonthrowers. *The American journal of sports medicine.* 2003;31(4):537-541.
58. Oliver G, Downs J, Barbosa G, Camargo P. Descriptive Profile of Shoulder Range of Motion and Strength in Youth Athletes Participating in Overhead Sports. *The International Journal of Sports Physical Therapy.* 2020;15(6).

59. Oliver G, Downs J, Friesen K. NCAA Division I Collegiate Softball Pitchers Have Decreased Shoulder and Elbow Joint Loads in Changeup Compared to Fastball and Curveball. 2020.
60. Oliver GD, Downs JL, Friesen KB, et al. Biceps Tendon Changes and Pitching Mechanics in Youth Softball Pitchers. *Int J Sports Med.* 2020.
61. Oliver GD, Dwelly PM, Kwon YH. Kinematic motion of the windmill softball pitch in prepubescent and pubescent girls. *Journal of strength and conditioning research.* 2010;24(9):2400-2407.
62. Oliver GD, Friesen K, Barfield JW, et al. Association of Upper Extremity Pain With Softball Pitching Kinematics and Kinetics. *Orthop J Sports Med.* 2019;7(8):2325967119865171.
63. Oliver GD, Gilmer GG, Anz AW, et al. Upper Extremity Pain and Pitching Mechanics in National Collegiate Athletic Association (NCAA) Division I Softball. *Int J Sports Med.* 2018;39(12):929-935.
64. Oliver GD, Gilmer GG, Friesen KB, et al. Functional differences in softball pitchers with and without upper extremity pain. *J Sci Med Sport.* 2019;22(10):1079-1083.
65. Oliver GD, Plummer H, Brambeck A. Hip and Glenohumeral Passive Range of Motion in Collegiate Softball Players. *International journal of sports physical therapy.* 2016;11(5):738-745.
66. Oliver GD, Plummer HA, Keeley DW. Muscle activation patterns of the upper and lower extremity during the windmill softball pitch. *Journal of strength and conditioning research.* 2011;25(6):1653-1658.
67. Oliver GD, Plummer HA, Washington JK, et al. Pitching Mechanics in Female Youth Fastpitch Softball. *International journal of sports physical therapy.* 2018;13(3):493-500.
68. Oliver GD, Saper MG, Drogosz M, et al. Epidemiology of Shoulder and Elbow Injuries Among US High School Softball Players, 2005-2006 Through 2016-2017. *Orthop J Sports Med.* 2019;7(9):2325967119867428.
69. Oliver GD, Wasserberger K, de Swart A, et al. Hip Range of Motion and Strength and Energy Flow During Windmill Softball Pitching. *Journal of Athletic Training.* 2021.
70. Prasartwuth O, Taylor JL, Gandevia SC. Maximal force, voluntary activation and muscle soreness after eccentric damage to human elbow flexor muscles. *J Physiol.* 2005;567(Pt 1):337-348.
71. Pytiak AV, 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;10(2):119-124.
72. Reagan KM, Meister K, Horodyski MB, et al. Humeral retroversion and its relationship to glenohumeral rotation in the shoulder of college baseball players. *The American journal of sports medicine.* 2002;30(3):354-360.
73. Reinold MM, Wilk KE, Macrina LC, et al. Changes in shoulder and elbow passive range of motion after pitching in professional baseball players. *The American journal of sports medicine.* 2008;36(3):523-527.
74. Robb AJ, Fleisig G, Wilk K, et al. Passive ranges of motion of the hips and their relationship with pitching biomechanics and ball velocity in professional baseball pitchers. *The American journal of sports medicine.* 2010;38(12):2487-2493.

75. Rojas IL, Provencher MT, Bhatia S, et al. Biceps activity during windmill softball pitching: injury implications and comparison with overhand throwing. *The American journal of sports medicine.* 2009;37(3):558-565.
76. Saito M, Kenmoku T, Kameyama K, et al. Relationship Between Tightness of the Hip Joint and Elbow Pain in Adolescent Baseball Players. *Orthop J Sports Med.* 2014;2(5):2325967114532424.
77. Sakurai S, Ikegami Y, Okamoto A, Yabe K, Toyoshima S. A Three-Dimensional Cinematographic Analysis of Upper Limb Movement During Fastball and Curveball Baseball Pitches. *Journal of Applied Biomechanics.* 1993;9(1).
78. Sauers EL, Dykstra DL, Bay RC, Bliven KH, Snyder AR. Upper extremity injury history, current pain rating, and health-related quality of life in female softball pitchers. *J Sport Rehabil.* 2011;20(1):100-114.
79. Sauers EL, Huxel Bliven KC, Johnson MP, Falsone S, Walters S. Hip and Glenohumeral Rotational Range of Motion in Healthy Professional Baseball Pitchers and Position Players. *The American journal of sports medicine.* 2013;42(2):430-436.
80. Sekiguchi T, Hagiwara Y, Yabe Y, et al. Restriction in the hip internal rotation of the stride leg is associated with elbow and shoulder pain in elite young baseball players. *Journal of shoulder and elbow surgery.* 2020;29(1):139-145.
81. Shanley E, Michener LA, Ellenbecker TS, Rauh MJ. Shoulder range of motion, pitch count, and injuries among interscholastic female softball pitchers: a descriptive study. *International journal of sports physical therapy.* 2012;7(5):548-557.
82. Shanley E, Rauh MJ, Michener LA, Ellenbecker TS. Incidence of injuries in high school softball and baseball players. *Journal of Athletic Training.* 2011;46(6):648-654.
83. Skillington SA, Brophy RH, Wright RW, Smith MV. Effect of Pitching Consecutive Days in Youth Fast-Pitch Softball Tournaments on Objective Shoulder Strength and Subjective Shoulder Symptoms. *The American journal of sports medicine.* 2017;45(6):1413-1419.
84. Smith MV, Davis R, Brophy RH, et al. Prospective Player-Reported Injuries in Female Youth Fast-Pitch Softball Players. *Sports health.* 2015;7(6):497-503.
85. Snyder Valier AR, Bliven KCH, Gibson A, et al. Non–Time-Loss and Time-Loss Softball Injuries in Secondary School Athletes: A Report From the National Athletic Treatment, Injury and Outcomes Network (NATION). *Journal of Athletic Training.* 2020;55(2):188-194.
86. Stodden DF, Fleisig GS, McLean SP, Lyman SL, Andrews JR. Relationship of pelvis and upper torso kinematics to pitched baseball velocity. *Journal of applied biomechanics.* 2001;17(2):164-172.
87. Trakis JE, McHugh MP, Caracciolo PA, et al. Muscle strength and range of motion in adolescent pitchers with throwing-related pain: implications for injury prevention. *The American journal of sports medicine.* 2008;36(11):2173-2178.
88. Warner JJ, Micheli LJ, Arslanian LE, Kennedy J, Kennedy R. Patterns of flexibility, laxity, and strength in normal shoulders and shoulders with instability and impingement. *The American journal of sports medicine.* 1990;18(4):366-375.
89. Wasserberger KW, Barfield JW, Downs JL, Oliver GD. Glenohumeral external rotation weakness partially accounts for increased humeral rotation torque in youth baseball pitchers. *J Sci Med Sport.* 2020;23(4):361-365.

90. Wasserman EB, Register-Mihalik JK, Sauers EL, et al. The First Decade of Web-Based Sports Injury Surveillance: Descriptive Epidemiology of Injuries in US High School Girls' Softball (2005-2006 Through 2013-2014) and National Collegiate Athletic Association Women's Softball (2004-2005 Through 2013-2014). *Journal of Athletic Training.* 2019;54(2):212-225.
91. Wight J, Richards J, Hall S. Influence of pelvis rotation styles on baseball pitching mechanics. *Sports biomechanics.* 2004;3(1):67-83.
92. Wilk KE, Andrews JR, Arrigo CA, Keirns MA, Erber DJ. The strength characteristics of internal and external rotator muscles in professional baseball pitchers. *The American journal of sports medicine.* 1993;21(1):61-66.
93. Wilk KE, Macrina LC, Fleisig GS, et al. Correlation of glenohumeral internal rotation deficit and total rotational motion to shoulder injuries in professional baseball pitchers. *The American journal of sports medicine.* 2011;39(2):329-335.
94. Wilk KE, Meister K, Andrews JR. Current Concepts in the Rehabilitation of the Overhead Throwing Athlete. *The American journal of sports medicine.* 2002;30(1):136-151.
95. Wilk KE, Meister K, Fleisig G, Andrews JR. Biomechanics of the overhead throwing motion. *Sports Medicine and Arthroscopy Review.* 2000;8(2):124-134.
96. Wilk KE, Obma P, Simpson CD, et al. Shoulder injuries in the overhead athlete. *The Journal of orthopaedic and sports physical therapy.* 2009;39(2):38-54.
97. 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. International Society of Biomechanics. *J Biomech.* 2002;35(4):543-548.
98. Yanagisawa O, Taniguchi H. Changes in lower extremity function and pitching performance with increasing numbers of pitches in baseball pitchers. *Journal of exercise rehabilitation.* 2018;14(3):430.
99. Yang J, Mann BJ, Guettler JH, et al. Risk-Prone Pitching Activities and Injuries in Youth Baseball: Findings From a National Sample. *The American journal of sports medicine.* 2014;42(6):1456-1463.
100. Yang JS, Stepan JG, Dvoracek L, et al. Fast-Pitch Softball Pitchers Experience a Significant Increase in Pain and Fatigue During a Single High School Season. *HSS J.* 2016;12(2):111-118.
101. Zeppieri G, Jr., Lentz TA, Moser MW, Farmer KW. CHANGES IN HIP RANGE OF MOTION AND STRENGTH IN COLLEGIATE BASEBALL PITCHERS OVER THE COURSE OF A COMPETITIVE SEASON: A PILOT STUDY. *International journal of sports physical therapy.* 2015;10(4):505-513.

Appendix A

SCHOOL OF
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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.)

Auburn University
CONSENT TO PARTICIPATE IN RESEARCH
Title: The Effects of Pitching a Simulated Game on Mechanics and Clinical Measures

<u>Explanation and Purpose of the Research</u>
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 confidentially 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 effects of pitching a simulated game on mechanics and its influence on shoulder range of motion and isometric strength in participants between the ages of 9-40. Participants must be without surgery or injury for the past 6 months and currently active as a softball pitcher on a team's roster. Must also feel comfortable and have experience pitching the fastball, curveball, dropball, and change-up pitch type in a game setting.

<u>Research Procedures</u>
To be considered for this study, you must be injury and surgery free for at least the past 6 months. Testing for 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 MotionMonitor Motion capture system 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. Range of motion will be measured with a digital inclinometer and strength will be measured with a handheld dynamometer.

Once these measurements have been collected, both shoulder and hips internal and external range of motion and strength will be assessed. You will then have eight sensors that measure muscle activity on your pitching arm bicep and both hamstrings and 14 electromagnetic sensors on your legs, arms, torso, and neck affixed to your skin with tape. Manual muscle testing will be performed to establish baseline muscle activity in which all data will be compared.

After you have warmed up you will pitch 25 pitches to a catcher, with a 40-60second break between pitches and a 4-7-minute break given between every 25 pitches. This will be repeated until a pitch count of 100 has been reached. Some pitches thrown will be digitally recorded for later analysis. Once the max pitch count has been achieved range of motion and strength will be measured again and then a 30min break will be given. Once the break is over range of motion and strength will be assessed, and you will pitch three trials of each pitch type. Both hip and shoulder range of motion and strength will be assessed again and then the collection will be deemed complete. This will take approximately three hours.

Participant Initials: _______

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A ball tracking device will also be used to collect ball performance variables.

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 may include muscle strain, muscle soreness, ligament, labral, and tendon damage to the throwing arm. Every effort will be made to minimize these risks and discomforts by selecting participants who are currently playing the position of pitcher competitively. It is your responsibility, as a participant, to inform the investigators if you notice any indications of injury or fatigue or feel symptoms of any other possible complications that might occur during testing.

Due to (the need for your physical presence at the research site, face to face interaction with the researcher or others, etc.) there is a risk that you may be exposed to COVID-19 and the possibility that you may contract the virus. Twenty-four hours before data collection participants will be asked if they have experienced any symptoms and/or been in contact with someone diagnosed with COVID-19 within the past two weeks. If they answer no to the previous question participants will be allowed to report to the Sports Medicine & Movement Lab for baseline testing.

For most people, COVID-19 causes only mild or moderate symptoms. For some, especially older adults and people with existing health problems, it can cause more severe illness. Current information suggests that about 1-3% of people who are infected with COVID-19 might die as a result. You will need to review the Information on COVID-19 for Research Participants that is attached to this consent document. To minimize your risk of exposure any investigator who needs to come less than 6 feet in contact with the participant. The investigator(s) will wear the appropriate personal protective equipment (PPE) of a face mask, eye protection, gloves (discarded after each participant), and lab coat (discarded after each participant). Additionally, all research equipment that will come in contact with the participant will be decontaminated BEFORE and AFTER each participant with EPA approved disinfectant. Participants will be required to wear a cloth mask while researchers are within 6 feet. These procedures will be enforced while the Human Research Protection Program requires additional safety measures due to COVID-19.

To reduce the risk of injury, certain precautions will be taken. During the throwing protocol, one board certified athletic trainers will be present to monitor participants as they 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.

Confidentiality

All information gathered in completing this study will remain confidential. Your 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 scientific research. Your name or identity shall not be revealed should such publication occur. 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 or she will help you. Should an emergency arises, we will call 911 and follow our Emergency Action Plan. You are responsible for any cost associated with medical assistance.

Participation and Benefits

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.

Participant Initials ________

By participating in this study, you will receive information regarding appropriate age related pitch counts that may help prevent injury. This will allow you the opportunity to alter your training programs in an effort to minimize injury resulting from fatigue. By receiving this information, you and your parent(s) /legal guardian(s) may be able to better determine the proper length of the pitching performance. Additionally, participants will receive a Rapsodo pitching report.

Questions Regarding the Study

If you have questions about this study, please ask them now. If you have questions later you may contact Jessica Downs, 252-599-0259 or email at jzd0075@auburn.edu.

If you have any questions about your 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.

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.

_______________________________________ ______________
Printed Name of Participant Date of Birth

_______________________________________ ______________
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 Date

Information on COVID-19 For Research Participants

Auburn University recognizes the essential role of research participants in the advancement of science and innovation for our university, community, state, nation, and beyond. Therefore, protection of those who volunteer to participate in Auburn University research is of utmost importance to our institution.

As you are likely aware, COVID-19 references the Coronavirus that is being spread around the world including in our country, state, and community. It is important that we provide you with basic information about COVID-19 and the risks associated with the virus so that you can determine if you wish to participate or continue your participation in human research.

How is COVID-19 spread? COVID-19 is a respiratory virus that is spread by respiratory droplets, mainly from person-to person. This can happen between people who are in close contact with one another. It is also possible that a person can get COVID-19 by touching a surface or object (such as a doorknob or counter surface) that has the virus on it, then touching their mouth, nose, or eyes.

Can COVID-19 be prevented? Although there is no guarantee that infection from COVID-19 can be prevented and no vaccine is currently available, there are ways to minimize the risk of exposure to the virus. Examples include but are not limited to, "social distancing" where individuals physically distance themselves from others (a minimum of 6 feet is often used as a standard distance); using effective barriers between persons; wearing personal protective equipment like masks, gloves, etc.; washing hands with soap and water or sanitizing hands after touching objects; disinfecting objects touched by multiple individuals, etc.

What are the risks of COVID-19? For most people, COVID-19 causes only mild or moderate symptoms, such as fever and cough. For some, especially older adults and people with existing health problems, it can cause more severe illness. While everyone is still learning about this virus, current information suggests that about 1-3% of people who are infected with COVID-19 might die as a result.

Who is most at risk? Individuals over age 65 and those with chronic conditions such as cancer, diabetes, heart or lung or liver disease, severe obesity, and conditions that cause a person to be immunocompromised have the highest rates of severe disease and serious complications from infection.

What precautions should be taken? Based on the proposed research, precautions for the risk of COVID-19 will be addressed on a project by project basis. You will be provided with information about precautions for the project in which you may participate. Any site where research activities will occur that are not a part of Auburn University (offsite location) are expected to have standard procedures for addressing the risk of COVID-19. It is important for participants to follow any precautions or procedures outlined by Auburn University and, when applicable, offsite locations. Further, participants will need to determine how best to address the risk of COVID-19 when traveling to and from research locations. The US Center for Disease Control and Prevention has issued recommendations on types of prevention measures you can use to reduce your risk of exposure and the spread of COVID-19.

Auburn University is continuing to monitor the latest information on COVID-19 to protect our students, employees, visitors, and community. Our research study teams will update participants as appropriate. If you have specific questions or concerns about COVID-19 or your participation in research, please talk with your study team. The name and contact information for the study team leader, along with contact information for the Auburn University Institutional Review Board for Protection of Human Research Participants, can be found in the consent document provided to you by the study team.

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PARENTAL PERMISSION & MINOR ASSENT for a Research Study entitled
"Effects of Pitching a Simulated Game on Mechanics and Clinical Measures"

Explanation and Purpose of the Research

Your child is 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 (and your child) understands certain aspects of what might occur. This statement describes the purpose, methodology, benefits, risks, discomforts, and precautions of this research. This statement describes your child's right to confidentially and your child's right to discontinue your child's 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 effects of pitching a simulated game on mechanics and its influence on shoulder range of motion and isometric strength in participants between the ages of 9-40. Participants must be without surgery or injury for the past 6 months and currently active as a softball pitcher on a team's roster. Must also feel comfortable and have experience pitching the fastball, curveball, dropball, and change-up pitch type in a game setting.

Research Procedures

To be considered for this study, your child must be injury and surgery free for at least the past 6 months

Testing for this research will require your child to be dressed in shorts, t-shirt, and tennis shoes. Your child's height, body mass, and age will be documented. Height and mass will be measured with Motion Monitor Motion capture system 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. Range of motion will be measured with a digital inclinometer and strength will be measured with a handheld dynamometer.

Once these measurements have been collected, both shoulder and hips internal and external range of motion and strength will be assessed. Your child will then have eight sensors that measure muscle activity on your child's pitching arm bicep and both hamstrings and 14 electromagnetic sensors on your child's legs, arms, torso, and neck affixed to your child's skin with tape. Manual muscle testing will be performed to establish baseline muscle activity in which all data will be compared.

Parent (Legal Guardian) Initials: ________
Participants Initials: _______

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After your child has warmed up your child will pitch 25 pitches to a catcher, with a 40-60second break between pitches and a 4-7-minute break given between every 25 pitches. This will be repeated until a pitch count of 100 has been reached. Some pitches thrown will be digitally recorded for later analysis. Once the max pitch count has been achieved range of motion and strength will be measured again and then a 30min to hour break will be given. Once the break is over range of motion and strength will be assessed, then your child will pitch three trials of each of their pitch type. Both hip and shoulder range of motion and strength will be assessed again and then the collection will be deemed complete. A ball tracking device will also be used to collect ball performance variables. This will take approximately three and half hours.

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 may include muscle strain, muscle soreness, ligament, labral, and tendon damage to the throwing arm. Every effort will be made to minimize these risks and discomforts by selecting participants who are currently playing the position of pitcher competitively. It is your child's responsibility, as a participant, to inform the investigators if your child notices any indications of injury or fatigue or feel symptoms of any other possible complications that might occur during testing.

Due to (the need for your child's physical presence at the research site, face to face interaction with the researcher or others, etc.) there is a risk that your child may be exposed to COVID-19 and the possibility that your child may contract the virus. Twenty-four hours before data collection participants will be asked if they have experienced any symptoms and/or been in contact with someone diagnosed with COVID-19 within the past two weeks. If they answer no to the previous question participants will be allowed to report to the Sports Medicine & Movement Lab for baseline testing.

For most people, COVID-19 causes only mild or moderate symptoms. For some, especially older adults and people with existing health problems, it can cause more severe illness. Current information suggests that about 1-3% of people who are infected with COVID-19 might die as a result. Your child will need to review the Information on COVID-19 for Research Participants that is attached to this consent document. To minimize your child's risk of exposure any investigator who needs to come less than 6 feet in contact with the participant. The investigator(s) will wear the appropriate personal protective equipment (PPE) of a face mask, eye protection, gloves (discarded after each participant), and lab coat (discarded after each participant). Additionally, all research equipment that will come in contact with the participant will be decontaminated BEFORE and AFTER each participant with EPA approved disinfectant. Participants will be required to wear a cloth mask while researchers are within 6 feet. These procedures will be enforced while the Human Research Protection Program requires additional safety measures due to COVID-19.

To reduce the risk of injury, certain precautions will be taken. During the throwing protocol, one board certified athletic trainers will be present to monitor participants as they throw. Ample warm-up and cool-down periods will be required of your child, water will be provided to Your child as needed, and ice will be made available after testing.

Parent (Legal Guardian) Initials: _________

Participants Initials: _______

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 scientific research. your child's name or identity shall not be revealed should such publication occur. The researcher will try to prevent any problem that could happen because of this research. If at any time there is a problem your child should let the researcher know and he or she will help Your child. Should an emergency arises, we will call 911 and follow our Emergency Action Plan. You are responsible for any cost associated with medical assistance.

Participation and Benefits
Participation in this research is strictly voluntary and refusal to participate will result in no penalty. Your child will be allowed to withdraw consent and discontinue their participation in this research at any time; without bias or prejudice from Auburn University Department of Kinesiology or the Sports Medicine and Movement group. 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.

By participating in this study, your child will receive information regarding appropriate age-related pitch counts that may help prevent injury. This will allow you the opportunity to alter their training programs in an effort to minimize injury resulting from fatigue. By receiving this information, you may be able to better determine the proper length of the pitching performance. Additionally, participants will receive a Rapsodo pitching report.

Questions Regarding the Study
If you have questions about this study, please ask them now. If you have questions later you may contact Jessica Downs, 252-599-0259 or email at jzd0075@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

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

____
Printed Name of Participant

______ yr. ______ mo.
Age of Participant

____
Printed Name of Parent of Participant

____
Date

____
Signature of Parent

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 Date