# EFFECTS OF EXTENDED PITCH COUNT ON SHOULDER KINEMATICS IN INTERCOLLEGIATE BASEBALL PITCHERS

by

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Effects of Extended Pitch Count on Shoulder Kinematics in Intercollegiate Baseball Pitchers

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Abstract

Several studies have been conducted investigating the biomechanics of pitching [1-9]. These previous studies all report high compressive and distractive forces for shoulder external rotation, elbow flexion with a maximum varus torque, shoulder adduction torque, and elbow extension. These characteristics may be exacerbated with increased pitch counts.

The purpose of this study was to quantify changes in shoulder and elbow mechanics as a result of increased pitch count, by evaluating joint angles, accelerations, and velocities. Subjects each completed one testing session. Intercollegiate baseball pitchers pitched a simulated game, with 17 pitches per inning over the course of 9-innings. Shoulder and elbow kinematic data were evaluated for a fastball every tenth pitch of the simulated pitch count for each subject. Our overall hypothesis was that as the pitch count increased, abnormal throwing mechanics would result.

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# PREFACE

I would like to recognize the following members of my thesis committee, Dr. Scott M. Lephart, Dr. Joseph B. Myers, and Dr. Jean L. McCrory. I would first like to thank Dr. Lephart for his encouragement of this study and for serving as a role model to me in the research process. I would also like to thank Dr. Myers whose guidance and support enabled this study to flourish. I would like to thank Dr. McCrory for her encouragement throughout these past 3 years. Finally, I would like to give a special thanks to John Jolly and Steven Shade for all of their help throughout the collection process.

# 1 Chapter One

## 1.1 Introduction

### 1.1.1 Background

Even using the most conservative estimates, baseball accounts for more than 50,000 injuries per year in participants ranging in skill level from little league to professional [10]. Pitchers sustain a large portion of these injuries, with nearly 50% experiencing sufficient shoulder and/or elbow pain, preventing participation in throwing at some point in their career [10, 11]. Given that most pitching injuries stem from overuse mechanisms [12-14], it is important to understand how the pitching motion changes as the pitch count (and subsequent fatigue) increases over the course of a game.

The overhead throwing motion can be divided into six phases. These phases include 1) windup, 2) stride, 3) arm cocking, 4) acceleration, 5) deceleration, and 6) follow-through, which all have extreme amounts of motion and forces [1, 5, 7-9, 15-17]. Several studies have been conducted investigating the biomechanics of pitching [1-9]. These previous studies all report similar findings when looking at kinematics and kinetics of throwing among pitchers. These findings include high compressive and distraction forces for shoulder external and internal rotation, elbow flexion with a maximum varus torque, shoulder adduction torque, and elbow extension.

Changes in pitching mechanics may predispose these pitchers to shoulder and elbow injuries due to micro-trauma occurring repeatedly throughout skill development and skeletal maturity [9, 15]. The most serious injuries occur at the collegiate and professional levels, requiring surgical intervention and or rehabilitation [13]. Due to excessive ranges of motion, high movement speeds, and the magnitude of loads that the shoulder and elbow joint experience, it is only natural that attention must be drawn to these joints and the injuries sustained [2, 5, 18-21].

At the shoulder, kinematic analyses have been performed, showing values for external rotation and internal rotation angular velocities in excess of 180 and 7000 degrees per second, respectively [1, 5]. Kinetic variables were also studied, with compression forces occurring at the time of ball release equal to body weight [2, 5]. In regard to the elbow, distraction forces are as high as 780 N [2, 21]. Over a long period of time, these repetitive motions and improper mechanics can contribute to the injury of any number of anatomical [22].

Many reasons have been suggested to explain why these shoulder and elbow injuries are occurring. They include skeletal immaturity, overuse associated with improper mechanics, and fatigue [9, 23, 24]. Skeletal maturity plays a more substantial role in youth pitchers mainly because of strength deficits when compared to mature adult pitchers [9]. These strength deficits may be a reflection of improper development of bone and soft tissues. While kinematic parameters have been found to be similar in youth and adult pitchers, force production has varied significantly [9]. The study of little league players tended to support the observations that injury occurs secondary to poor pitching mechanics [23]. This study supported ideas of a previous study, emphasizing the importance of developing skills and control first, and then focusing on velocity later as physical development progresses [24]. Therefore it was found that symptoms of the pitchers correlated to pitching mechanics rather than age.

Fatigue is suggested to play a major role with respect to injury potential by increasing the individual's risk due to biomechanical changes. Fatigue is thought to negatively influence a pitcher's performance and to possibly increase vulnerability to injury [25, 26]. Furthermore, fatigue may be a strong contributor to increased injury potential among pitchers over the course of multiple innings and increasing pitch counts.

One study was conducted using a simulated game in a laboratory setting [27]. This study was one of the first to quantify kinematic changes of the shoulder and elbow over the course of an entire game (simulated). The investigators had 10 collegiate pitchers throw for multiple innings. Several significant changes in kinematics were noted with extended play including increased shoulder abduction, horizontal adduction, and external rotation at the instant of stride foot contact. At ball release, less shoulder abduction and a more extended lead leg were observed. These two criteria are often observed by pitching coaches and used to indicate fatigue. While significant changes were found, only an indirect measurement of fatigue could be reported, but the authors did not seek to correlate kinematic changes observed with kinetics or injury potential.

Based on the Barrentine study, a similar study was designed to analyze the changes in kinematic and kinetic parameters of the baseball pitcher that occur over the course of actual major league baseball game conditions [28]. Significant kinematic variables included maximum external rotation angle of the shoulder, knee angle at ball release, and ball velocity. Significant kinetic variables included maximum compression forces at the shoulder and elbow joints and horizontal abduction torque. Analysis revealed that 7 of the 13 parameters analyzed during the pitch changed significantly between the early and late innings. These changes probably resulted from fatigue and suggested an increased injury potential as the pitch count increased. Unfortunately, this study only analyzed a total of two fastballs per pitcher, one pitch from the first inning of play, and one pitch from the last inning of play. Therefore, these authors were able to significantly show that fatigue does occur over the course of a game, but were not able to show where in the pitch count fatigue is actually occurring.

The occurrence of fatigue has a tendency to be overlooked in our youth population. Generally, the role of fatigue and its responsibility for overuse injuries is thought to apply to collegiate and professional pitchers [14]. The risk of injury is known to increase with age and level of competition [13]. However, it is believed that many pitching injuries that receive medical treatment at higher competition levels result from cumulative micro-trauma that began at the youth level [12].

The effect of pitch counts, pitch types, pitching mechanics, and shoulder and elbow pain in youth pitches were evaluated over the course of a season [14]. Each team kept a pitch count log of the game pitches thrown by each pitcher. They also used videotape to analyze pitching mechanics. Interviews after every game including types of pitches thrown, fatigue, and pain levels were conducted. The total number of pitches thrown in each appearance varied from 1-161. This study also discussed that limiting pitch count rather than innings might improve the safety of pitchers, reducing injury potential.

Through quantification and subsequently limitation of the pitch count, pitchers will be able to reduce the amount of fatigue that occurs, decreasing the amount of micro-trauma occurring to the upper extremity as a result of repeated overuse and changes in segment positioning during the throwing process. The importance of this research and the contributions it will generate to the field of sports medicine will be useful in aiding the athletic trainers, coaches, and players to modify pitching procedures. Knowledge of a pitcher's pitch count, along with visual recognition of fatigue and its occurrence within the pitch count (represented by changes in pitching kinematics and kinetics), will allow for proper participation time to be considered by the coach and athletic trainer. By referring to pitch count as the basis for the amount of participation in competition, the alleviation of potential injury along with the time frame for rehabilitation and return to activity may be decreased.

Investigations looking at pitching kinematics and kinetics have been conducted [1-8]. However, these studies did not investigate the effect of true extended play exerted during an entire game as pitch count increased. Instead, they focused on the number of innings the pitcher threw and a limited amount of actual pitches. In no way did any of the investigators quantify a pitch count for any of the pitchers, nor did they capture where in the pitch count these pitchers were experiencing changes in their pitching.

The purpose of this research was to quantify kinematic arm motions as a result of increased pitch count, of collegiate baseball pitchers, and to investigate where in the pitch count kinematic changes occurred. More specifically, changes in shoulder and elbow kinematics were investigated as the pitch count increased. It is imperative to show the importance of the pitch count and using its quantification as a guide for better assessment of fatigue and kinematic and kinetic changes resulting in improper throwing mechanics. These improper throwing mechanics may result in micro-trauma injuries from repeated overuse. If pitch count is used to gauge individual pitching time, injury potential, need for surgical interventions, and time spent for rehabilitation may all decrease. This will result in a healthier, longer career for not just the elite baseball player, but maybe for players of all ages.

## 1.2 Specific Aims and Hypotheses

**Specific Aim 1**: To determine if as pitch count increases, kinematic changes of the shoulder occur. Shoulder kinematics will be assessed as pitch count increases in 12 intercollegiate baseball pitchers using motion analysis.

**Hypothesis 1**: Pitchers will demonstrate alterations in kinematics of the shoulder, including changes in joint angles during the early cocking, late cocking, acceleration, and deceleration phases as a function of pitch count. Specific changes will include:

Hypothesis 1.1: Decreased shoulder external rotation during the early cocking, late cocking, and acceleration phases.

Hypothesis 1.2: Increased shoulder horizontal abduction during the acceleration phase.

Hypothesis 1.3: Increased shoulder internal rotation during the deceleration phase.

Hypothesis 1.4: Decreased shoulder abduction during deceleration at instant of ball release.

**Specific Aim 2**: To determine if as pitch count increases, kinematic changes of the elbow occur. Elbow kinematics will be assessed as pitch count increases in 12 intercollegiate baseball pitchers using motion analysis.

**Hypothesis 2**: Pitchers will demonstrate alterations in kinematics of the elbow, including changes in joint angles during the early cocking, late cocking, acceleration, and deceleration phases as a function of pitch count.

# 2 Chapter 2

## 2.1 Review of Literature

### 2.1.1 Introduction

The shoulder is a very unique joint that acts as the primary center of motion for overhead propulsive activities [29]. Shoulder motion is determined by glenohumeral configuration, soft tissue flexibility, and freely gliding surfaces. The socket for the humeral head is formed by the glenoid cavity. Three-dimensional mobility occurs from the ball and socket configuration of this joint [29]. The acromion is large enough to cover the humeral head. The acromion also provides a mechanical leverage advantage with aid of the fibrous extension of the coracoid tip[29]. The acromion and the coracoacromial ligament form what is known as the acromial arch which prevents upward migration of the humeral head. Concurrent shift in muscle structure helps to maintain the humeral heads instantaneous center of rotation within the glenoid. This mechanism prepares the shoulder for overhead activity [30].

### 2.1.2 Anatomy

The bony anatomy of the shoulder joint complex consists of three bones: the scapula, clavicle, and humerus; four joints: the glenohumeral, scapulothoracic, acromioclavicular, and sternoclavicular joints; and numerous bony landmarks including the acromion process, head of the humerus, and the greater and lesser tuberosities and the bicipital groove of the humerus [30-32]. The four joints coordinate to produce precise and forceful motion through interaction of the articulations and the muscles that control the shoulder's delicate mobility, balance, and stability [31-33].

The humeral head is kept within the glenoid fossa through a vacuum effect. This effect is assisted by the glenoid labrum, proper balance of muscular forces, and the joint fluid, which acts as a hydraulic fit, to maintain joint congruency [30-32]. The glenohumeral joint has a ball and socket configuration component, where the relatively large humeral head articulates with the small glenoid fossa with minimal restraints [29]. This joint relies on the surrounding joint capsule and ligaments to provide static stability, as well as surrounding muscles, such as the rotator cuff group, to provide dynamic stability. The glenoid only articulates with approximately 30% of the humeral head, whereas this contact surface is increased to approximately 75% by the glenoid labrum [29, 34]. Next, the sternoclavicular joint consists of the proximal clavicle, which attaches to the sternomanubrial fossa. Stability is almost entirely by ligamentous structures. These ligamentous structures consist of the manubrial ligament, anterior and posterior sternoclavicular ligaments, and the inferior, anterior, and posterior costoclavicular ligaments. Only the inferior portion of the clavicle articulates with the manubrium and first rib. The presence of a fibrocartilaginous disk between these two surfaces helps to improve articular congruency. The acromioclavicular joint is formed by the lateral end of the clavicle and acromion. This joint articulation is relatively incongruent with the exception of an intraarticular fibrocartilagenous disk. The acromioclavicular joint is stabilized by the anterior and posterior capsular ligaments, and superiorly and inferiorly by the conoid and trapezoid corococlavicular ligaments. Lastly, the scapulothoracic joint functions primarily to stabilize the shoulder through muscular and ligamentous attachments. Unlike the three diarthroidal joints previously discussed, the scapulothoracic joint is a false joint, meaning it has no fibrous, cartilaginous, or synovial tissue connections. This joint enables scapular motion as it moves about the shoulder. The scapula is a thin concave sheet of bone, which has muscles underneath that allow the bone to move in a gliding fashion slowly on the convex rib cage. The overall pattern of scapular motions include an integration of scapulothoracic and glenohumeral motions [30-32].

Many muscles are responsible for the different movements of the shoulder. Their actions may be found to be an elevator, depressor, external rotator, internal rotator, adductor, abductor, flexor, or extensor of the shoulder, and flexor or extensor of the elbow [30-32].

Elevators of the humerus include the deltoid and supraspinatus [30-32, 35]. The elevators of the scapula consist of the trapezius, rhomboids, and the levator scapulae [30-32, 35]. The supraspinatus originates in the scapular supraspinatus fossa and inserts at the top of the humeral greater tuberosity. The deltoid is made up of three sections of muscle, the anterior, middle, and posterior deltoid. The deltoid originates in its anterior head along the lateral third of the clavicle, its medial head along the acromion, and its posterior head along the posterior scapular spine. The trapezius is necessary for scapular upward rotation and retraction, with the upper fibers pulling on the lateral scapular angle for elevation. It originates from the occiput, ligamentum nuchae, and the spinous processes of vertebrae C7 and T1. The rhomboid minor originates from T2 through T5 and inserts on the superomedial angle of the scapulae. The rhomboid major originates from T2 through T5 and inserts into the entire posteromedial edge of the scapula. Finally, the levator scapulae originates in the transverse processes and posterior tubercules of vertebrae C1 through C4 to insert on the superior angle of the scapula.

The infraspinatus is a depressor of the humerus. Depressors of the scapula join include the upper fibers of the serratus anterior and the pectoralis minor [30-32, 35]. The infraspinatus originates in the scapular infraspinatus fossa and inserts below the supraspinatus on the greater tuberosity. The serratus anterior is made up of three sections which originate from the anterolateral ribs. The first inserts on the superior angle of the scapula, the second inserts on the anteromedial border of the scapula, and the third inserts on the inferior angle of the scapula. Their primary function is to hold the scapula down during upward rotation. Lastly, the pectoralis minor originates from the second through the fifth ribs and inserts on the medial coracoid. It functions to depress the scapula with upward motions.

Major external rotators of the humerus include teres minor and infraspinatus [30, 31]. The teres minor originates from the central one third of the lateral border of the scapula below the scapular neck to pass behind the long head of the triceps and inserts onto the lower posterior aspect of the greater tuberosity under the infraspinatus. The infraspinatus originates from the infraspinosus fossa and travels laterally to insert on the posterior aspect of the greater tuberosity.

The internal rotators and adductor muscles of the humerus consist of the teres major and the latissimus dorsi [30, 31]. The teres major originates on the posterior scapula on the lateral border and inserts at the medial edge of the bicipital groove. The latissimus dorsi originates from the inferior angle of the scapula, the dorsal spine, and the lower four ribs, and inserts into the medial bicipital groove. Another adductor and a flexor of the humerus is the coracobrachialis muscle. It originates from the coracoid process and inserts on the anteromedial midhumerus [30, 31].

The biceps brachii performs elbow flexion and supination along with shoulder stabilization. It is made up of two heads. The long head originates from the superoposterior glenoid labrum while the short head originates from the coracoid tip. Finally, the triceps function as an extensor of the elbow. The long head originates from the infraglenoid tubercule of the scapula, the lateral head from the posterior surface of the lateral border of the humerus and lateral intermuscular septum, and the medial head from the posterior surface of the humerus and the medial intermuscular septum. Insertion of the triceps occurs on the posterior part of the olecranon process of the ulna, and the surface of the fascia of the dorsal forearm [30, 31].

### 2.1.3 Pitching Mechanics

The throwing process is a very dynamic skill among overhand throwing athletes. Tullos and King [11] divided the phases of throwing into three distinct groups. These phases were identified as cocking, acceleration, and follow-through. Based on these initial identifications, Pappas et al. [36] conducted an analysis of baseball pitching mechanics. They studied the three phases previously mentioned, examining body parameters (anthropometrics), phase characteristics, and various speeds of the body segments and phases of the throwing athlete.

Based on these previous pitching biomechanical investigations, the pitching sequence has been further divided into more distinct phases. It can be divided into six phases: 1) windup, 2) stride, 3) arm cocking, 4) acceleration, 5) deceleration, and 6) follow-through [1]. The biomechanical description of the six phases is based on a right handed thrower.

#### 2.1.3.1 Windup

Pitching is a downward throwing skill from a mound with a vertical height of ten inches [1]. To start the pitching motion, the pitcher positions themselves facing the batter [1]. The windup is described as the time between the initiation of motion and the moment at which the ball is removed from the glove [36]. The windup begins with the leg contralateral to the pitching arm pushing off from behind the pitching rubber. The throw is initiated by stepping backward with what will become the stride foot/leg. The body weight is momentarily supported by the stride foot, while the supporting foot is placed laterally in front of the rubber. The windup is initiated when the body weight is shifted back from the stride foot to the supporting foot [1]. As the contralateral leg pushes off and leaves the ground, three events occur simultaneously. Both arms flex forward with the ball in the glove, the ipsilateral leg and the trunk rotate approximately 90º, and the contralateral hip and knee flex so that the left side of the body is now facing the batter. The initiation of the throw begins at the stretch position. The weight is shifted from the striding leg to the ipsilateral or pivot leg. Following the weight shift, the striding leg is swung across the front of the body [36]. This shift of weight sets the rhythm for delivery of the pitch. Good balance is important when the knee of the stride leg has reached its maximum height. Concurrently the ball is removed from the glove, and the delivery of the ball to the catcher is initiated [1].

#### 2.1.3.2 Stride

Upon completion of the windup, the knee of the pivot leg is slightly flexed, the throwing shoulder is brought into a pattern of abduction, extension, and external rotation, the elbow may be completely extended or flexed to approximately 90° (depending on the pitcher), and the wrist is flexed [36]. The stride is normally directed toward the catcher. The key objective is to keep the trunk back as much as possible to retain its potential for contributing to the velocity of the pitch. As the striding leg moves downward and toward the catcher, the dominant hand breaks with the ball from the glove and moves in a upward/downward motion in rhythm with the body [1]. The striding leg continues across the body, the pivot leg vigorously extends with ankle plantar flexion, and knee and hip extension, to drive the body forward in the stride. Simultaneously, the hips and pelvis begin to rotate forward, followed by the segmental rotation of the trunk progressing from the pelvis to the shoulders [36]. If the throwing arm and striding leg are coordinated properly, the arm will be up in a semi-cocked position when the stride foot contacts the ground. The stride should be long enough to stretch out the body, but not so long that the pitcher cannot rotate his legs and hips properly. The stride length from the rubber should be slightly less than the pitcher's height. The stride foot should land almost directly in front of the back foot, with the toes pointed slightly inward [1]. The striding terminates with foot plant as trunk rotation continues to rotate forward [36].

#### 2.1.3.3 Arm Cocking

The cocking phase was described as the period of time between the cessation of the windup and the moment at which the shoulder is in maximal external rotation. This phase occurred in approximately 1500 ms (1.5 seconds), ending with the shoulder being brought into an extreme position of external rotation [36].

At the completion of the stride, the trunk moves laterally toward the catcher and hip rotation is initiated. Trunk rotation follows the hip, but in highly skilled pitchers, hyperextension of the upper trunk occurs as it is rotated around to face the plate. As the trunk is rotating and extending, the upper arm is flexed at the elbow, and the shoulder externally rotates (arm cocking). As the trunk faces the batter, maximum external rotation of the shoulder is achieved and the arm cocking phase is completed [1].

The arm cocking phase can be further broken down into the early cocking phase and the late cocking phase.

#### 2.1.3.3.1 Early Cocking

The early cocking phase starts with the individual separating their dominate hand from the glove and ends when the front foot makes contact with the mound. During this time, the scapula is retracted [37]. Also, the humerus is positioned in 90º of abduction and horizontal abduction, with very little external rotation of about 50º. These motions are accomplished by the activation of the anterior, middles, and posterior deltoid. Toward the end of the early cocking phase, the external rotators of the cuff are responsible for the placement of the humeral head in the glenoid fossa. As for the forearm, the biceps brachii and brachialis are activated to develop the necessary angle of the elbow [1]. At this time, it was found that the shoulder had reached a position of approximately 90º abduction, 90° of horizontal extension, and 30º to 120º of external rotation (**Table 1**). The elbow is flexed to 90º and the wrist is moved into a neutral position.

The humerus is supported by the anterior and middle deltoid as the posterior deltoid pulls the arm into approximately 30º of horizontal abduction. The static stability of the humeral head becomes dependent on the anterior aspect of the glenoid, specifically the glenohumeral ligament and the glenoid labrum [38]. The early cocking phase ends with foot plant.

| Shoulder Motion | Pappas et al. 1985 | Current Study |
|---|---|---|
| | | |
| **Abduction** | 90° | 90° |
| **Horizontal Abduction** | 30° | 90° |
| **External Rotation** | 120° | 120° |

**Table 1: Shoulder motion of previous study defined compared to definition of motion of current study**

*2.1.3.3.2 Late Cocking*

The late cocking phase begins when the front foot hits the mound, and ends when the humerus begins internal rotation. Immediately following foot plant, the upper trunk appears to reach its fastest angular velocity of forward rotation. This phase is the primary cause of chronic shoulder and elbow injuries that are reported each year [39]. At this time, the humerus is moved forward in relation to the trunk and begins to come into alignment with the upper body [38]. As forward trunk rotation decelerates, the shoulder and elbow are brought to a position of neutral horizontal extension, as the shoulder is externally rotated to approximately 160º or greater [36]. Deceleration of the external rotation of the humeus is achieved by the contraction of the subscapularis, until the completion of the late cocking phase. Also the serratus anterior and the pectoralis major have their greatest activity during deceleration. By producing a compressive axial load, the biceps brachii help to aid in maintaining the humerus head in the glenoid fossa. Once external rotation is achieved, the supraspinatus, infraspinatus, and teres minor become inactive. The triceps provide a compressive axial loading at the end of this phase to replace the force of the biceps [38]. The time from 90º of shoulder external rotation at foot plant to maximum external rotation at the end of the cocking phase averages 60ms in major league pitchers with a range of 28 to 88 ms. Forward movement of the ball does not occur during the cocking phase [36]. In preparation for the acceleration phase, external rotation must be increased to approximately 125º to ensure positioning for the power of the acceleration [38].

#### 2.1.3.4 <u>Acceleration</u>

Acceleration refers to the increased speed in reference to angular velocities and the body. It is a ballistic action which lasts only one-tenth of a second [38]. The acceleration phase is described to begin with the throwing shoulder in the position of maximal external rotation and terminates with release of the ball. This phase is very explosive, accelerating the ball from an essentially stationary position to speeds up to 95 miles per hour in about 50 ms (1/20) of a second.

Acceleration starts when the humerus begins to internally rotate about the shoulder. To ensure a proper pitch, a short delay must occur between the onset of elbow extension and shoulder internal rotation. By extending the arm at the elbow, the pitcher can reduce the inertia that must be rotated at the shoulder. With less inertia, internal rotational torque generated at the shoulder can accelerate the arm to a greater angular velocity [1].

During acceleration, the scapula is protracted, rotated downward, and held to the chest wall by the serratus anterior. The arm continues into flexion and maximum internal rotation of the humerus is reached. The humerus travels forward in 100º of abduction, but adducts approximately 5º just before release. The latissimus dorsi and pectoralis major powerfully move the humerus forward. The subscapularis activity is at its maximum as the humerus travels into internal rotation. The triceps develop a strong action in accelerating the extension of the elbow. In this instant, the forces developed reflect the body's ability to build an amazing amount of power and at the same time protect itself from biomechanical forces. Midway through the acceleration phase, control of the ball is lost as the humerus is positioned slightly behind the forward flexing trunk and at an angle of about 110º of external rotation [38].

Four actions occur sequentially leading to ball release. The shoulder is forcefully de-rotated from external rotation to internal rotation with ball release occurring at about 48º of shoulder external rotation. Peak angular velocities of shoulder internal rotation as high as 9,198 deg/second, and an average of 6,180 deg/second have been measured (ref). Peak accelerations approaching 600,000 deg/sec/sec have also been found. The position of the arm relative to the head and trunk at ball release is determined more by lateral trunk flexion than shoulder joint action. The shoulder is in a position of 90º ± 10º of abduction at ball release. Pitchers who throw "over the top" do so through a greater degree of lateral trunk flexion toward the contralateral side. Pitchers who throw sidearm do so without lateral trunk flexion [36].

After ball release, the hand follows the ball but is unable to apply further force. When the ball is released, the trunk is flexed, the arm is almost in a fully extended position at the elbow, the shoulder is undergoing internal rotation, and the lead knee should be extending. The acceleration phase ends with the release of the ball [38].

#### 2.1.3.5 Deceleration

After ball release, the arm continues to extend at the elbow and internally rotate at the shoulder. Excessive forearm pronation observed may be the combined effect of these two actions [1]. The humerus travels across the midline of the body and develops a slight external rotation before finishing in internal rotation. This occurs within the first tenth of a second. This phase is very active for all glenohumeral muscles as the arm is decelerated. The deltoid, upper trapezius and the latissimus dorsi have strong activity. Also, as eccentric loads are produced, the infraspinatus, teres minor, supraspinatus, and subscapularis are all active. Peak activity is developed by the biceps when decelerating the forearm, imposing a traction force within the glenohumeral joint [38]. In the arm deceleration phase, shoulder internal rotation angular velocity decreases from its maximum value observed to zero near the time of ball release [1].

As the shoulder is de-rotated, the elbow first flexes from 90º to almost 120º of flexion. The elbow rapidly extends 30 to 40 milliseconds before ball release to an average position of 25º of flexion at ball release. Angular velocities averaging 4,595 deg/sec have been observed. Peak accelerations for the elbow were found to be approximately 500,000deg/sec/sec [36, 40]. Approximately 20 ms before ball release, wrist flexion begins from a position of extension and ends in a neutral position at release. The wrist does not flex beyond neutral. Radioulnar pronation begins approximately 10ms before ball release, with the forearm pronated to 90º at release [36]. Arm deceleration ends when the arm has reached an internal rotation position of approximately 0º [1].

#### 2.1.3.6 Follow-through

The follow-through phase of pitching begins at ball release and continues until the motion of throwing has ceased. The purpose of this phase is to comfortably decelerate the throwing limb. There are essentially two parts to the follow-through phase. Deceleration values of 500,000 deg/sec/sec are prominent at the shoulder and elbow [36, 40]. During this time, an active deceleration force is generated by the posterior shoulder girdle musculature and the biceps. The shoulder continues to move into horizontal flexion and internal rotation. The elbow undergoes a rebound effect and flexes to approximately 45º. Radioulnar pronation is evident. The final phase of deceleration can be described as a passive phase, with the body simply catching up with the arm, through a forward progression of the ipsilateral leg to a contact point which allows the pitcher to be in a proper fielding position [36]. The importance of a good follow-through is critical in minimizing risk of injury. Follow-through is completed with knee extension of the stride leg, continued hip extension, shoulder adduction, horizontal adduction, elbow flexion, and forearm supination [1].

### 2.1.4 Pitching Research

#### 2.1.4.1 Motions and Forces

Pitching mechanics consist of extreme motions and forces, especially in the collegiate and professional levels [1, 5, 7-9, 16, 17, 41]. These motions and forces, small to extreme, can be assessed as kinematics and kinetics. Kinematics is defined as a description of motion in terms of position, velocity, and acceleration [42]. Kinematic variables are involved in description of movement, independent of the forces that cause the specified movement [43]. These variables include linear and angular displacements, velocities, and accelerations. Kinetics is defined as a description of motion that includes consideration of force as the cause of motion [42]. Kinetics is a general term given to the forces that cause movement, including internal and external forces [43].

The pitching movement is a very quick, dynamic action which takes place in less than two seconds [1, 5, 36]. The entire pitching sequence has been broken down into percentages. The cocking phase accounts for nearly 80% of the time required to complete the entire pitching sequence, which is approximately 1500 milliseconds (msec). The acceleration phase accounts for 2% of the pitching sequence, approximately 50 msec. Finally, the follow-through phase accounts for approximately 18% of the pitching sequence in approximately 350 msec [36].

Feltner and Dapena [2] have investigated dynamics of the shoulder of the throwing arm during a baseball pitch. Pitches observed during the study consisted of all fastballs. Various kinematic parameters of the shoulder were calculated to help describe the motions of the shoulder joint throughout the pitch. Also, the resultant joint forces and torques were calculated. All values reported are based on the mean values throughout the study. At the instant of 0.075

seconds prior to stride foot contact, the upper arm (shoulder) was in a position of 28° adduction, of 24º horizontal abduction, and of 8º internal rotation. At stride foot contact, the shoulder was still in a position of 14º adduction, 18º horizontal abduction, and 44º of internal rotation. From this instant the upper arm continued to abduct, horizontally abduct, and externally rotate until the instant of maximum external rotation. At the instant of maximum external rotation, the upper arm was positioned in 12º of abduction, 11º of horizontal adduction, and 80º of external rotation. The upper arm was subsequently internally rotated and slightly adducted and horizontally abducted until the instant of ball release. Peak angular velocity of internal rotation (6100º/s ± 1700º/s) coincided approximately with the instant of ball release. At the instant of ball release, the angle of abduction and horizontal adduction of the upper arm were both positive, but very small (2º). The upper arm was still in an externally rotated position (23º of external rotation) at the instant of ball release while rapid internal rotation occurred. After ball release, the upper arm continued to undergo internal rotation, and again began to abduct and horizontally adduct. Neutral position of internal/external rotation (0º) was reached just after the instant of ball release.

The magnitude of anterior-posterior shoulder joint forces between the instants of stride foot contact and ball release increased rapidly between the instants of maximum external rotation and ball release in all subjects, reaching its peak value (860N ± 120N) near instant of ball release [2]. Medial-lateral forces were near 0 just prior to maximum external rotation when they became positive. Forces remained positive until an instant between the time of maximum external rotation and ball release, when the direction was reversed and became negative.

Feltner and Dapena [2] reported joint forces and torques of small magnitudes during the early stages of the pitch to bring the upper arm into a position of approximately 15º of abduction, 10º of horizontal abduction, and 0º of internal/external rotation. Just after the instant of stride foot contact, horizontal adduction torque occurred at the shoulder, moving the elbow forward. Jobe et al. [44] reported electromyographic activity of the pectoralis major that coincided with this torque for the period of time between the stride foot contact and ball release. Later an abduction torque at the shoulder lifts the elbow. Along with the motions of horizontal adduction and abduction that the upper arm is subjected to, it also experiences external rotation that eventually takes it to an extreme externally rotated position (80º) [2].

Fleisig et al. [6], reported kinematic parameter values throughout the baseball pitching motion. At the instant of foot contact, mean values of 93º ± 12º of shoulder abduction, 17º ± 12º of shoulder horizontal adduction, and 67º ± 24º of shoulder external rotation were reported. During the arm cocking phase, mean values of maximum shoulder horizontal adduction of 18º ± 8º and maximum upper torso angular velocity of 1700º/s ± 10º were reported. They reported mean values of maximum shoulder external rotation of 173º ± 10º at the instant of maximum shoulder external rotation. Arm acceleration revealed average shoulder abduction mean values of 93º ± 9º. At the instant of ball release, mean values were reported for shoulder horizontal adduction of 7º ± 7º.

Werner et al. [17] quantified joint loads and kinematic parameters of pitching mechanics at the major league level, and studied their relationships. The average ball velocity at release for the 40 fastballs was 89 ± 3 miles per hour. Mean time from stride foot contact to maximum shoulder external rotation was 124 ± 22 msec. The time interval from maximum external rotation to ball release averaged 30 ± 12 msec. From stride foot contact to maximum external rotation, the shoulder joint continued to abduct, horizontally adduct, and externally rotate. Mean maximum shoulder external rotation was 184º ± 14º for the pitchers. Maximum horizontal adduction of the shoulder averaged 14º ± 9º near ball release. Peak magnitudes of angular velocities were higher for the 40 pitchers when compares to those of less elite populations described in previous literature [1, 2, 5].

At the instant of maximum external rotation, Werner et al. [17] reported shoulder distraction to reach a mean value of 63% $\pm$ 22% of body weight. Just before ball release, the force began to increase steadily reaching a mean value of 96% $\pm$ 19% of body weight at the instant of ball release. Peak values were recorded ranging from 677 to 1396 newtons (N). A peak internal rotation torque, acting to resist external rotation of the shoulder occurred at maximum external rotation and averaged 111 $\pm$ 17 N*m. Werner et al. [17] also, reported the position of the shoulder at maximum external rotation and the peak external rotation and abduction torques to strongly affect shoulder distraction. Results of this study supported shoulder distraction forces reported by Feltner and Dapena [2] and Fleisig et al. [5].

Based on the results of Werner et al. [17], throwers with more limited ranges of shoulder external rotation, 184º $\pm$ 14º, at the end of the cocking phase were described to have less distraction at the shoulder joint. Lower magnitudes of external rotation torque, 111 $\pm$ 17N*m, and abduction torque, 117 $\pm$ 34 N*m, were also associated with a reduction in shoulder distraction.

Dillman et al. [1] collected kinematic data of the 3 fastest pitches that hit within a strike zone on 29 elite pitchers, using a 3-Dimensional modeling technique. The time from foot contact to release averaged 0.145 seconds(s) ($\pm$ 0.015 seconds). Atwater [22] illustrated that in most throwing and striking skills, the shoulder abduction angle remains fairly constant. Dillman's group [1] described shoulder kinematics of shoulder abduction, horizontal adduction, and external/internal rotation. Shoulder abduction positions relative to the trunk remained fairly constant, between 90º and 110º during the foot contact release period. Immediately after release, the arm rapidly abducts about the shoulder. This supports Atwater's report. During the initial 80% of foot contact during the release phase, the arm rotates relative to the trunk from an abducted position of 30º to 14º of adduction. During the final period of this phase, as internal rotation about the shoulder occurs, the arm seems to horizontally rotate backward (horizontally abduct) to the 0º position. During follow through, the arm continues into horizontal adduction. The shoulder externally rotates to about 175º during the initial 80 % of the foot contact release period and subsequently underwent rapid internal rotation, continuing through release and arm deceleration. At release, the arm reaches an externally rotated position of 100º to 110º [1].

#### 2.1.4.2 Extended Play

Murray et al. [28] investigated the effects of extended play on professional baseball pitchers. Kinematic and kinetic changes of pitching mechanics were investigated. Kinematic variables that were found to have significant changes were maximum external rotation angle of the shoulder and ball velocity. Ball velocity in the first inning pitched was 90mph and dropped to 85mph in the last inning pitched. Maximum external rotation angle at the shoulder was 181º and dropped to 172º in the last inning pitched. Kinetic variables that were found to have significant changes include maximum distraction force at the shoulder and horizontal abduction torque. The maximum shoulder distraction force found was 97% body weight in the first inning pitched and dropped to 88% body weight in the last inning pitched. The horizontal abduction torque at ball release was 5 % body weight*height in the first inning pitched and dropped to 4 % body weight*height in the last inning pitched. Also, the maximum horizontal abduction torque reported was 11% body weight*height in the first inning pitched and only 8% body weight*height in the last inning pitched.  Although these authors found significant kinematic and kinetic alterations, they failed to show where and when these changes were occurring within the pitch count.

Barrentine et al. [27] investigated kinematic and electromyographic changes in baseball pitching during a simulated game. Kinematic changes observed over the course of the game (inning 1-9) were greater shoulder abduction (+5º), shoulder horizontal adduction (+5º), and shoulder external rotation (+8º) at the instant of foot contact with the mound. During the arm cocking and acceleration phases, shoulder external rotation decreased (-4º) and upper torso angular velocity decreased (-90 º/sec). At the instant of ball release, decreased shoulder abduction (-4º) and decreased ball velocity (-1 meter/sec) occurred.

### 2.1.5 Injuries and Baseball

Fleisig et al. [5] discussed the results of their study and evaluated the relevance of their results to commonly described mechanisms of overuse throwing injuries. McLeod and Andrews [45] stated that any force that shifts the humeral head to the rim of the glenoid fossa during distraction will cause the humeral head to be reseated off center, placing the labrum in jeopardy for injury. Labral tears result from translation and subluxation of the humeral head in the anterior or posterior direction and can cause forceful entrapment of labrum between humeral head and the glenoid rim [46]. Andrews and Angelo [47] found that most rotator cuff tears in throwers were located from the posterior midsupraspinatus to the midinfraspinatus area. They believed that these tears were a consequence of tensile failure, as the rotator cuff muscles tried to resist distraction, horizontal adduction, and internal rotation at the shoulder during arm deceleration. In support of Andrews and Angelo, DiGiovine et al. [48] showed that the posterior shoulder muscles (teres minor, infraspinatus, and posterior deltoid) were very active during this phase through EMG analysis. Fleisig's group [5] reported compression force and horizontal adduction torque during arm deceleration which coincides with Andrews and Angelo as well.

#### 2.1.5.1 Epidemiology

Baseball accounts for more than 50,000 injuries per year, in participants ranging from the little league to professional level [10]. Pitchers account for nearly 50% of those who experience shoulder and or elbow pain, preventing them from throwing at some point in their career [10, 11]. Although overuse of the shoulder can contribute significantly to injury, many symptoms begin with improper mechanics and the repetitive nature of the throw. By understanding the pathophysiology of an injury, we can better understand why an isolated injury to the capsule, rotator cuff, or labrum, is usually secondary to the breakdown of another structure [49]. Based on this idea, Kvite and Jobe [49] established a classification system to determine types of shoulder instability at the glenohumeral and acromioclavicular joints. It has been broken down into four categories: 1) Primary disease (overuse syndrome), 2) Primary instability, 3) Acute traumatic instability, and 4) Chronic instability.

#### 2.1.5.2 Types of Injuries and Pathomechanics

Primary disease refers to any injury in the throwing shoulder that can be attributed to the normal, but excessive forces and extreme motions observed in all throwers [50, 51]. The stresses across the joint during the throwing motion in the stable shoulder are great enough to result in damage to the static and dynamic restraints even without underlying glenohumeral instability. In some athletes with articular or periarticular injury, assessment of the glenohumeral laxity may reveal only minimal to no asymmetric laxity [50-52]. In such instances, the disease may be considered primary and not secondarily related to a breakdown of the static capsular restraints. To further clarify overuse syndromes commonly observed in the overhead thrower, it is important to understand the rotator cuff/ biceps superolabral complex. Significant firing of the supraspinatus, infraspinatus, and teres minor allow the shoulder to be moved to the point of maximum external rotation in the late cocking phase. Those same muscles fire violently during the deceleration phase as significant posterior shear and compressive loads are recorded across the joint [37].

Tendons are maintained by the tenocyte production of collagen. The tenocyte must be able to increase collagen and matrix production in response to increased loading. Also, adequate blood supply must exist in order to maintain viability of the tenocytes. The insertion area of the supraspinatus muscle has been shown to be a watershed area of diminished blood flow that is particularly susceptible to repetitive overload stresses [53]. The repetitive stresses of throwing may speed up the normal process of degeneration [54, 55]. Therefore, repetitive stressful loading of the rotator cuff as well as the cuff muscles attempt to resist distraction, horizontal adduction, and internal rotation of the shoulder during arm deceleration can result secondary to fatigue in acute inflammatory response in the early stages and in tendon failure in the late stages [52].

During the late cocking phase, the biceps muscle fires only moderately. However, during deceleration, the biceps muscle contraction is particularly strong as it contracts to both decelerate the elbow extension and act with the rotator cuff to resist glenohumeral distraction [5, 48, 56]. Rodosky et al. [57] evaluated the role of the biceps muscle and superior labrum in anterior instability of the shoulder and suggested that the biceps muscle is essential to limiting torsional forces to the shoulder in the abducted, externally rotated position. In the position of extreme external rotation, the biceps may have two functions. It is primarily an internal rotator to the humerus. The secondary function is to resist distraction and compress the humeral head against the glenoid [57].

Biceps muscle load may increase as a result of excessive throwing and poor mechanics. When proper pitching mechanics are applied, maximum elbow flexion torque occurs before maximum shoulder compressive force [1, 5]. However, improper mechanics may cause these two loads to occur closer together in time, requiring greater maximum force by the biceps muscle [56]. Loss of the biceps muscle anchor and complete avulsion of the superolabral complex with the arm in the cocked position, may reduce the torsional rigidity as much as 38%. As a result, strain in the inferior glenohumeral complex may increase as much as 100%. Therefore, initial failure of the biceps-superolabral complex may contribute to late failure of the anterior glenohumeral ligaments. In a series of 73 baseball pitchers undergoing arthroscopic examination, Andrews et al. [58] noted significant tearing of the superolabral complex in all 73 players, with most occurring in the anterosuperior portion of the complex. The force of pull of the biceps muscle was observed in the area of abnormalities by enervation of the biceps and observation of during arthroscopic examination. Injury may therefore manifest as acute or chronic tendonitis [47, 58-60].

Andrews et al. [58] also introduced the concept of the “grinding factor” as a potential cause of labral damage in the stable throwing shoulder. The grinding factor results from the translation of the humeral head during arm acceleration and deceleration. Humeral head displacement combined with compression and internal rotation during deceleration can cause the humeral head to grind on the labrum [45]. Tears at the base of the biceps as well as at the anterosuperior portion of the labrum are commonly seen [58, 61, 62].

Neer [63] has described the stages of progression of the impingment syndrome, identifying edema and hemorrhage in stage 1, fibrosis and tendonitis in stage 2, and tendon degeneration, bony changes, and tendon ruptures in stage 3. Subacromial impingment may also be a contributing factor to primary disease of the rotator cuff and biceps tendon. The shoulder is repeatedly positioned at 100º of abduction and, with every throw, moves from horizontal abduction and external rotation to a position of horizontal adduction and internal rotation. During arm deceleration, a large inferior force and adduction torque are produced [1, 5]. With weakness in the rotator cuff muscles, fatigue, or improper mechanics, an inability to generate needed forces can lead to superior migration of the humeral head into the subacromial space, resulting in subacromial impingement. In addition, loss of internal rotation can occur over the career of the athlete, partly from contracture of the posterior capsule, resulting in anterior and superior migration of the humeral head [64]. Superior migration of the humerus causes impingement of the greater tuberosity, rotator cuff muscles, or biceps muscle against the inferior surface of the acromion or coracoacromial ligament [56].

Primary instability was broken into two groups by Jobe et al.: 1) Secondary to microtrauma and 2) Secondary to generalized ligamentous laxity [50, 51]. Persons, who exhibit instability signs secondary to microtrauma, demonstrate with asymmetric shoulder laxity. The late cocking and early acceleration phases of the throwing cycle place significant shear across the anterior aspect of the shoulder during normal throwing. Rotation of the torso after foot plant has been previously noted to generate an anterior shear estimated at 400 N[1]. Over time, secondary to poor mechanics ("opening up" in late cocking), overthrowing, or weakness, the anterior capsule sees increasing loads unshielded by equal contributions of the surrounding musculature. The anterior capsule then fatigues and fails, resulting in increased laxity of the glenohumeral joint. Failure of the anterior capsule leads to increased anterior translation in the most stressful phases of the throwing motion. Manifestations that can result include secondary rotator cuff tendonitis or subacromial impingement, anterior labral fraying from increased translation in the deceleration phase, SLAP lesions, and posterior glenohumeral impingement [59, 62, 65]. Athletes who exhibit instability signs of generalized ligamentous laxity demonstrate symmetric shoulder laxity. Arthroscopic examination of the glenohumeral joint of athletes with this type of instability reveals a hypoplastic glenoid labrum and an increased joint volume. Abnormalities of the labral complex and rotator cuff are often observed [51, 66].

The third category of injury is acute traumatic instability. Although common in athletics, this cause of instability is seen least in overhead athletes. However, an athlete who attempts to throw after this event and does not develop overt primary instability may often manifest difficulties with secondary damage to the rotator cuff and the superior and posterior labral complexes [37].

Posterosuperior glenohumeral impingement is the fourth category of injury. The concept of impingement occurring in the shoulder at a spot other than in subacromial space is relatively new. Previous literature suggests that such a mechanism of injury to the rotator cuff and glenoid exists [67-72]. Limits of capsular restraint and contact of the greater tuberosity on the glenoid impose constraints on glenohumeral joint motion. Contact of the greater tuberosity on the glenoid is most critical in varying positions of elevation and external rotation [73, 74]. Forceful contact of the tuberosity against the superior glenoid has been believed to be a mechanism of fracture of the greater tuberosity. In overhand throwing sports, repeated extreme movements of glenohumeral abduction and external rotation result in contact of the superior and posterior glenoid rim with the supraspinatus and infraspinatus muscles and posterior humeral head [73, 74]. Increased impingement may result from increased anterior capsular laxity [75]. A loss of normal posterior translation in the late cocking and acceleration phases of throwing may result in impingement of the undersurface of the rotator cuff rather than the posterior glenoid. Repetition of this contact may be responsible for tearing of the undersurface of the rotator cuff and posterosuperior glenoid labrum. As the arm horizontally adducts and internally rotates during acceleration and deceleration, further grinding and contact of the greater tuberosity may be responsible for more significant tears of the superior labral complex.

The thrower with posterosuperior glenohumeral impingement will most often complain of pain in the posterior aspect of the shoulder in the late cocking and early acceleration phases of throwing. An inability to fully rotate the shoulder secondary to posterior pain will cause a loss of velocity. An early ball release results in loss of control [37].

In addition, the scapula is responsible in maintaining a foundation for normal physiology and biomechanics of the thrower [37]. It has five essential roles in the shoulder function of the athlete [76]. These roles include providing a stable base in the glenohumeral articulation, retraction and protraction, base for muscle attachment, elevation of the acromion provided by muscles, and a link to the transfers of the forces from the trunk to the arm in the normal throwing function. Scapula dysfunction occurs from abnormal function and an imbalance in the workings of the periscapular musculature. The most common causes of dysfunction are direct trauma to the scapular musculature and indirect injury from repetitive microtraumas. Such microtraumas can be observed in the throwing shoulder or muscle inhibition from painful conditions of the shoulder. The serratus anterior and lower trapezious muscles are the most sensitive to this inhibitory effect [60]. Their dysfunction becomes evident early in abnormalities of the glenohumeral joint [60, 77]. Loss of glenohumeral motion can also result in scapular dysfunction. In throwing athletes, tightness in the posterior capsule and musculature leads to increased protraction of the scapula in the cocking and follow through phases [76]. Lack of full scapular retraction causes loss of a stable cocking point, dissipating the flow of energy from the torso and trunk to the arm. Loss of coordinated retraction-protraction also results in relative glenoid anteversion, which leads to the loss of the normal bony buttress to resist anterior translation of the humeral head. With relative loss of this, increased shear is felt across the anterior soft tissue structures and leads to injury [76, 78]. Lack of appropriate acromial elevation in the coking and follow through phases can result in impingement problems. Inhibition of the lower trapezius and serratus anterior muscles can lead to relative closure of the coracoacromial arch. Loss of this arch space can result in primary impingement or contribute to the problems of secondary impingement in cases of concomitant instability [50, 76].

#### 2.1.5.3 **Critical Instances**

Kinematic comparisons of baseball pitchers among various levels have also been investigated. Fleisig et al. [9] compared these variables among youth (Y), high school (HS), collegiate (C), and professional (P) levels. Maximum external rotation values during the arm cocking phase were reported as follows: (Y) $177^{o} \pm 12^{o}$, (HS) $174^{o} \pm 9^{o}$, (C) $173^{o} \pm 10^{o}$, and (P) $175^{o} \pm 11^{o}$. Maximum internal rotation velocity values during the arm acceleration phase were also reported as follows: (Y) $6900^{o}/sec^2 \pm 1050^{o}/sec^2$, (HS) $6820^{o}/sec^2 \pm 1380^{o}/sec^2$, (C) $7430^{o}/sec^2 \pm 1270^{o}/sec^2$, and (P) $7240^{o}/sec^2 \pm 1090^{o}/sec^2$. These differences observed are most likely due to the differences in skeletal maturity and strength based on age differences. Whether or not these differences observed are due to differences in age, it is important to determine the when changes are occurring so that a pitch count may be used as a guide for participation in all levels.

Although this study is focusing on shoulder kinematics, it is important to realize the emphasis that shoulder kinetics have on injury mechanism. Fleisig et al. [5] described two critical instants. The first critical instant occurred shortly before the arm reached maximum external rotation when 67 N*m of shoulder internal rotational torque was generated. The second occurred shortly after ball release when 1090N of shoulder compressive force was produced. Results from this study were similar to others reported by Dillman [1], Feltner and Dapena [2], and Pappas [36]. During the first critical instant, near the end of the arm cocking phase, at 64% of time from foot contact until ball release had been completed, the following was observed. The arm was externally rotated 165° ± 11°, abducted 94° ± 21°, and horizontally abducted 11° ± 11°. Large loads produced at the shoulder consisted of a 67 ± 11 N*m internal rotational torque, and a 310 ± 100 N anterior force. A 250 ± 80N superior shear force, 480 ± 130N compressive force, 87 ± 23 N*m horizontal adduction torque, and a 44 ± 17 N*m abduction torque were generated. The second critical instant occurred during arm deceleration when 108% of the foot contact to ball release time interval had been completed. At this critical instant, a maximum compression force of 1090 ± 110N were generated at the shoulder. When this maximum compressive force was produced, minimal shear forces in the anterior direction of 80 ± 188N, and in an inferior direction of 100 ± 130N were recorded. A 26 ± 44N*m adduction torque, 44 ± 51N*m horizontal abduction torque, and negligible (7 ± 5N*m) external rotational torques were produced at the shoulder at this time. These incredibly large forces combined with changes in shoulder kinematics, such as scapular and humeral motion changes, can be detrimental to the competitive athlete over a long period of time.

#### 2.1.5.4 Pitch Count

Due to the repetitive nature of overhand throwing, it is important to monitor the number of pitches thrown by the individual during game situations. Lyman et al. [14] evaluated the effect of pitch counts, pitch types, pitching mechanics, and shoulder and elbow pain in youth baseball pitchers. Over the course of a season, each team kept a pitch count log of game pitches thrown by each pitcher. They also videotaped them to analyze proper pitching mechanics. Interviews after every game to determine the types of pitches thrown, fatigue, and pain levels were conducted. The total number of pitches thrown in each appearance varied from 1 to 161. There was a significant association between the number of pitches thrown in a game, during the season, and the rate of shoulder pain. Lyman et al [14] also discussed that limiting pitch count rather than limiting innings might improve the safety of pitchers, reducing injury potential. Therefore, it is imperative to establish the role of pitch count as a guide for participation, and to ensure a longer, healthier career.

Starting pitchers in college pitch between 14.93 and 16.45 pitches per inning and 5 to 6 innings per game resulting in 76 to 94 pitches per game [79]. While Murray et al. [28] and Barrentine et al. [27] have investigated kinematic changes over the course of a game (real or simulated), they have failed to establish where in the pitch count these changes are actually occurring. Quantification of pitch count to set guidelines for participation is important, especially in the elite athlete. Recognition of kinematic changes about the shoulder early on during the pitch count may decrease common injuries due to unnecessary repetitive stress placed on the shoulder joint complex. Therefore, this study is necessary to build a better foundation of knowledge, quantification, and regulation of the pitch count.

### 2.1.6 Methodological Considerations

Dillman et al. [1] used an automated high-speed video digitizing system to record three-dimensional throwing patterns of motion. Each subject was marked with retroreflective markers, 1-inch diameter balls on all of the body's major joints since clinical evaluation of throwing mechanics required total body analysis. Reflections of markers were tracked individually by four electronic cameras at 200 Hz. Data was merged mathematically from each camera to accurately reconstruct a three-dimensional motion of pitching. The three fastest pitches thrown that hit within the strike-zone ribbon were digitized and averaged for each pitch. The examination of a three-dimensional pitching motion is similar to what will be used in the present study.

Escamilla et al. [8] and Fleisig et al. [6] also used the three-dimensional automated digitizing system to quantify each athlete's motion. Subjects threw toward a strike-zone ribbon located over a home plate at a distance of 18.4 meters (60.5ft) from the pitching rubber. Reflective markers were attached bilaterally at the lateral malleoli, lateral femoral epicondyles, greater femoral trochanters, lateral superior tip of acromions, and lateral humeral epicondyles. Also, a marker was attached to the ulnar styloid process of the non-pitching wrist and a reflection band was placed around the wrist. Subjects were instructed to prepare just as if they were going to pitch in a game. Four electronically synchronized, charged couple device cameras transmitted pixel images of the reflection markers directly into a video processor without being recorded onto video. Each camera was set at 200 Hz. Three-dimensional marker locations were calculated with Motion Analysis Expertvision 3-D software utilizing the direct linear transformation method [80, 81]. Camera coefficients were calibrated by recording the position of markers attached to four vertically suspended wires. Three reflective markers spaced at 61cm intervals were attached to each wire. The wires were positioned so that the markers made a matrix approximately 1.5m x 1.2m x 1.2m in size, were suspended approximately 0.3m above the ground. This matrix was designed to encompass as much testing area as possible while having each marker visible in the field of view of all four cameras. Subject setup, preparation and data collection in this study are relevant to the present study. The marker setup and warm-up preparation will be mimicked with slight alterations in this study.

Feltner and Dapena [2] filmed subjects using Direct Linear Transformation method of 3D cinematography [80, 81]. Direct Linear Transformation is defined as the relationship between 3D world coordinates (x,y,z) and 2D image coordinates (x,y) using simple equations expressed on linear form [43]. Two battery powered LOCAM cameras were used to record the trials on 16mm Fujicolor 500 ASA film. The cameras viewed the subjects from the rear and from the throwing arm side, and they were set at nominal frame rates of 200fps. Quintic spline functions were used to smooth the time-dependent coordinates of each landmark. All subsequent calculations were performed with smoothed landmark data. The reference frames and calculations from Feltner and Dapena's previous study will be used with slight modifications in this present study to determine changes in shoulder kinematics [2].

Murray et al. [28] used three high-speed (120Hz) cameras for data collection. Two of the cameras were positioned along the first and third base lines (typically in the dugouts) to provide side views for left and right-handed pitchers. The third camera was located in the press box above and behind home plate, provided a frontal view and was used for analysis of all pitches. Twenty-four point calibration object (Peak Performance Tech, Inc, Englewood, CO) was videotaped simultaneously by all 3 cameras both before and after the game to calibrate the pitching area. Horizontal and vertical reference markers were placed on the pitching mound to create a mound-relevant reference frame. Data were collected from the frontal and appropriate side-view cameras for each pitcher throughout his time on the mound. For data reduction, Peak Performance Motus System was used to manually digitize 20 body landmarks and the ball for one fastball from each pitcher's first and last inning of play. Unlike Murray's study, this study will examine fastball pitches throughout the simulated game and will attempt to determine when in the pitch count kinematic changes are occurring, in hopes of a more accurate assessment of potential altered mechanics, which may lead to pathology.

### 2.1.7 Summary

Shoulder injuries due to repetitive forces and motions over a long period of time place elite athletes as well as developing pitchers under an increased risk for injury. It is important to understand what forces and motions are being placed about the shoulder joint. Furthermore, it is necessary to understand where in the pitch count these changes are occurring. Although the studies previously described show throwing mechanics and changes in the throwing mechanics, they are unclear as to when during a game the changes are occurring [1-3, 5-8].

Quantification of pitch count to set guidelines for participation is important, especially in the elite athlete. Recognition of kinematic changes about the shoulder early on during the pitch count may decrease common injuries due to unnecessary repetitive stress placed on the shoulder joint complex. Therefore, this study is necessary to continue to build a better foundation of knowledge, quantification, and regulation of the pitch count. This knowledge will be beneficial to the athletic trainer, coach, and most importantly the athlete, making for a longer, healthier career for athletes of all ages.

# 3 Chapter 3

## 3.1 Experimental Design

### 3.1.1 Introduction

This study consisted of one testing session. A descriptive design was utilized to assess kinematic changes in pitching mechanics of intercollegiate baseball pitchers as pitch count increased, using a high speed three-dimensional motion analysis system. The independent variable was pitch count, specifically fastball pitches 1, 2, 3, 9, 10, 11, 19, 20, 21, 29, 30, 31, 39, 40, 41, 49, 50, 51, 59, 60, 61, 69, 70, 71, 79, 80, 81, 89, 90, 91, 99,100, 101, 109,110, 111, 119, 120, 121, 129, 130, 131, 139, 140, 141, 149, 150, and 151. The dependent variables of interest included kinematic changes in shoulder and elbow joint angles. More specifically, shoulder abduction/adduction, horizontal abduction/horizontal adduction, internal/external rotation, and elbow flexion joint angles were investigated.

### 3.1.2 Subjects

#### 3.1.2.1 Power Analysis

The use of previous studies [6, 28] (pitch one maximum external rotation angle = 181°, pitch 150 maximum external rotation = 172°, common SD 20°) indicated that an effect size of $f$ = 0.90 and an alpha level of $\alpha$ = 0.05 (two-sided hypothesis test) required 12 subjects for a statistical power of P = .80.

The participants of the experiment consisted of intercollegiate starting baseball pitchers, who were currently participating on a collegiate baseball team. Each subject reported for testing on one of his regularly scheduled pitching days by adding an extra game to their season.

Potential subjects were screened to ensure they met the following criteria for inclusion and exclusion of the study.

#### 3.1.2.2 Inclusion Criteria

- Male between the ages of 18 – 24 years
- Currently a starting pitcher competing on an intercollegiate baseball team
- No shoulder or elbow pathologies that prevent the subject from current participation in competition

#### 3.1.2.3 Exclusion Criteria

- Significant limitation of shoulder or elbow rotation
- History of neurological disorders

### 3.1.3 Recruitment Procedures

Subjects were recruited via paper flyers distributed to coaches, certified athletic trainers, and posted throughout local universities. Interested individuals contacted the Neuromuscular Research Laboratory to schedule an appointment. No identifiable information was collected during phone contact.

### 3.1.4 Instrumentation

#### 3.1.4.1 <u>Three-Dimensional Motion Analysis</u>

The Peak Motus 3D Optical Capture System (Peak Performance Technologies, Englewood, CO) was utilized to assess throwing kinematics of the shoulder. The Peak Motus system is a high-speed three-dimensional optical capture motion analysis system with eight cameras used to capture kinematics of the shoulder during the throwing motion for each subject **(Figure 1)**. Infrared lamps from the camera system output light, which is reflected off the markers back into the camera lens apparatus. Anthropometrics were used to determine segment length and joint centers, which created a 3-D image of the subject throwing. Kinematic data was collected with the Peak system to assess changes in joint angles, angular velocities, and angular accelerations of the shoulder as pitch count increased.

**Figure 1: Digital Camera System**

Anthropometric measurements of the subject body height (m), body mass (kg), humerus length (cm), humeral epicondyle diameter (cm), and forearm length (cm) were recorded bilaterally. Linear circumferential measurements of the upper extremity were recorded along with the retroreflective markers attached to the designated anatomical landmarks. Passive reflection markers were secured with 3M adhesive double-sided discs tape to the designated landmarks.

#### 3.1.4.2 Kistler Force Plate

The force plate was secured in a wooden walkway to allow for a level, flat surface and integrated with one Kistler force plate (Kistler Coorporation, Worthington, OH) (Surface 0.6 x 0.4m) **(Figure2)**. A built in amplifier to enhance analog force signals collected at 1200 Hz was used.

**Figure 2: Foot Contact on Force Plate**

#### 3.1.4.3 Finger Switch

A prefabricated finger switch was worn by each subject **(Figure 3)**. The finger switch consisted of two wires, one secured to the middle finger and the other to the index finger via medical tape. The finger switch signaled ball release by creating a circuit between the index and middle finger of the throwing arm and ball. The finger switch was powered by a 9-Volt battery. Each baseball had a strip of aluminum tape adhered to it. A signal was produced when the finger switch made contact with the adhesive aluminum strip on the ball. The signal from the finger switch was recorded in the Peak Motus Analog acquisition module **(Figure 4)**. Each variable of interest was measured during each of the designated pitches.

**Figure 3: Finger Switch**

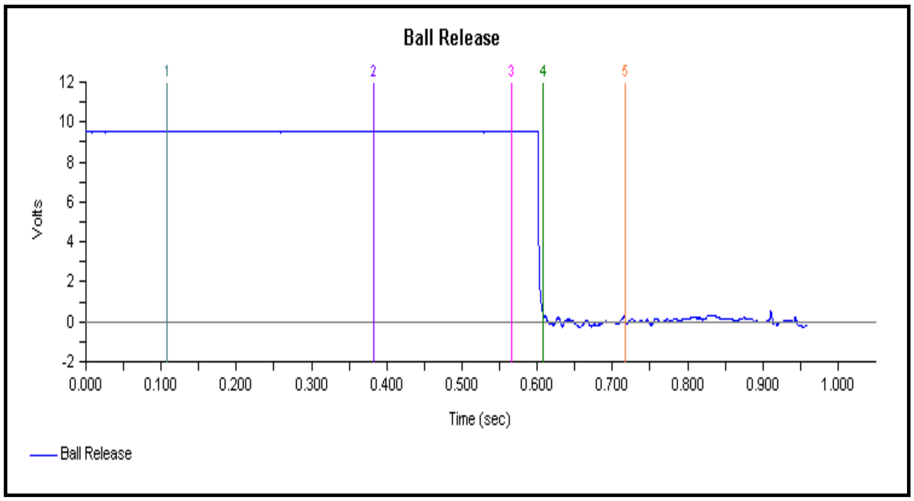


**Figure 4: Typical Ball Release Signal**

### 3.1.5 Testing Procedures

#### 3.1.5.1 <u>Procedure</u>

All subjects provided informed consent as required by the University of Pittsburgh Institutional Review Board. The testing procedure followed previously reported protocols [1, 6, 8, 28, 82]. Each subject reported for testing on one of his regularly scheduled pitching days by adding an extra game to his season. Following an explanation of the equipment and experiment, provision of history information and informed consent approved by the University of Pittsburgh Institutional Review Board, the subject changed into athletic shorts. Next, anthropometric measurements were taken. The retroreflective markers were then secured using 3M adhesive double-sided discs tape to the designated anatomical landmarks. The designated landmarks consisted of the acromion, lateral epicondyle, mid wrist, and anterior superior iliac spine (ASIS) bilaterally, as well as to T4 and the sacrum **(Figure 5 and Figure 6)**. The anthropometrics were entered into Peak to correspond segment length to the retroreflective markers to help create a 3-D image of the subject throwing. The prefabricated finger switch was attached to the dominant hand by securing a wire to each the index and middle finger via medical tape. Also, the subject's stride length was adjusted by placing a mark on the ground to ensure proper landing.

**Figure 5: Anterior View of Retroreflective Marker Setup**

**Figure 6: Posterior View of Retroreflective Marker Setup**

### 3.1.5.2 <u>Throwing Preparation</u>

Prior to assessment, each subject was given a warm-up period determined by their typical warm-up length which consisted of throwing and stretching. Testing involved each subject throwing a rotation of the three most common types of pitches (16). The fastball, curveball, and change up were thrown in a designated order for a total of 17 pitches per inning. Each pitch was thrown during each inning of the 9 inning simulated baseball game into a retractable net, which was distanced approximately 40 feet from the subject. The order the pitches to be thrown were pre-selected so that a continuous order was followed and that three fastball pitches were collected every ten pitches of the pitch count (1-150). Prior to each inning, the subject threw 7 warm-up pitches. There were 15 seconds of rest between each throw and 12 minutes of rest between each inning. Each subject was assessed for kinematic changes of the shoulder over the course of the simulated baseball game as pitch count increased.

### 3.1.6 Trial Procedures

Prior to the initiation of the simulated game, the subject threw 10 pitches to familiarize himself with the surface, surroundings, the retroreflective markers, and the finger switch. Kinematics were measured in pitches 1, 2, 3, 9, 10, 11, 19, 20, 21, 29, 30, and 31 to establish a baseline. Kinematics were measured in pitches 39, 40, 41, 49, 50, 51, 59, 60, 61, 69, 70, 71, 79, 80, 81, 89, 90, 91, 99, 100, 101, 109, 110, 111, 119, 120, 121, 129, 130, 131, 139, 140, 141, 149, 150, and 151 of the pitch count for changes. Each inning consisted of 17 pitches, thrown in a counter balanced order of the fastball, curveball, and change up. All analyzed data collected was for the fastball pitch.

### 3.1.7 Data Reduction

#### 3.1.7.1 <u>Kinematic Data</u>

Path identification was used to identify each of the four phases of throw. All kinematic variables were determined using Peak Motus. Peak uses a fourth order Butterworth filter, zero lag, with an optimized cutoff frequency [83]. Processed kinematic data from the pitching study underwent custom calculations in Peak Motus software’s KineCalc module according to previously published data. All angles were calculated similar to Feltner and Dapena [2], but with slight modifications. The abduction/adduction angle was calculated as the angle between the upper arm and the vector of the vertical line of the trunk in the frontal plane **(Figure 7)**. The internal/external rotational angle was defined as the angle between the forearm and the horizontal line running through the trunk in the sagittal plane **(Figure 8)**. The horizontal abduction/horizontal adduction angle was calculated as the angle between the upper arm and the horizontal line running through the trunk in the transverse plane **(Figure 9)**. Sample data from one subject can be viewed in **Figure 10**.

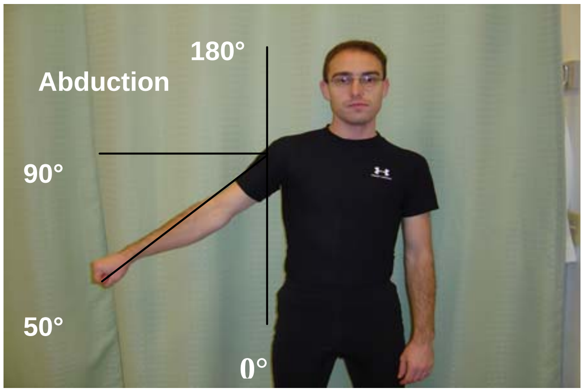


**Figure 7: Shoulder Abduction/Adduction Angle**

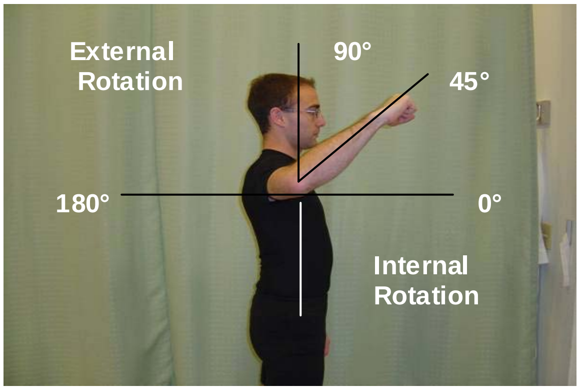


**Figure 8: Shoulder Internal/External Angle**

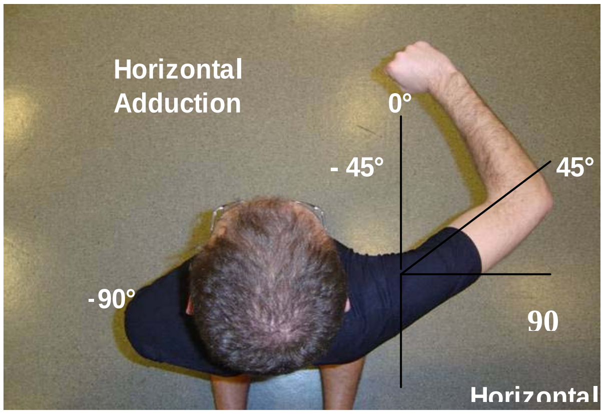


**Figure 9: Shoulder Horizontal Abduction/Adduction Angle**

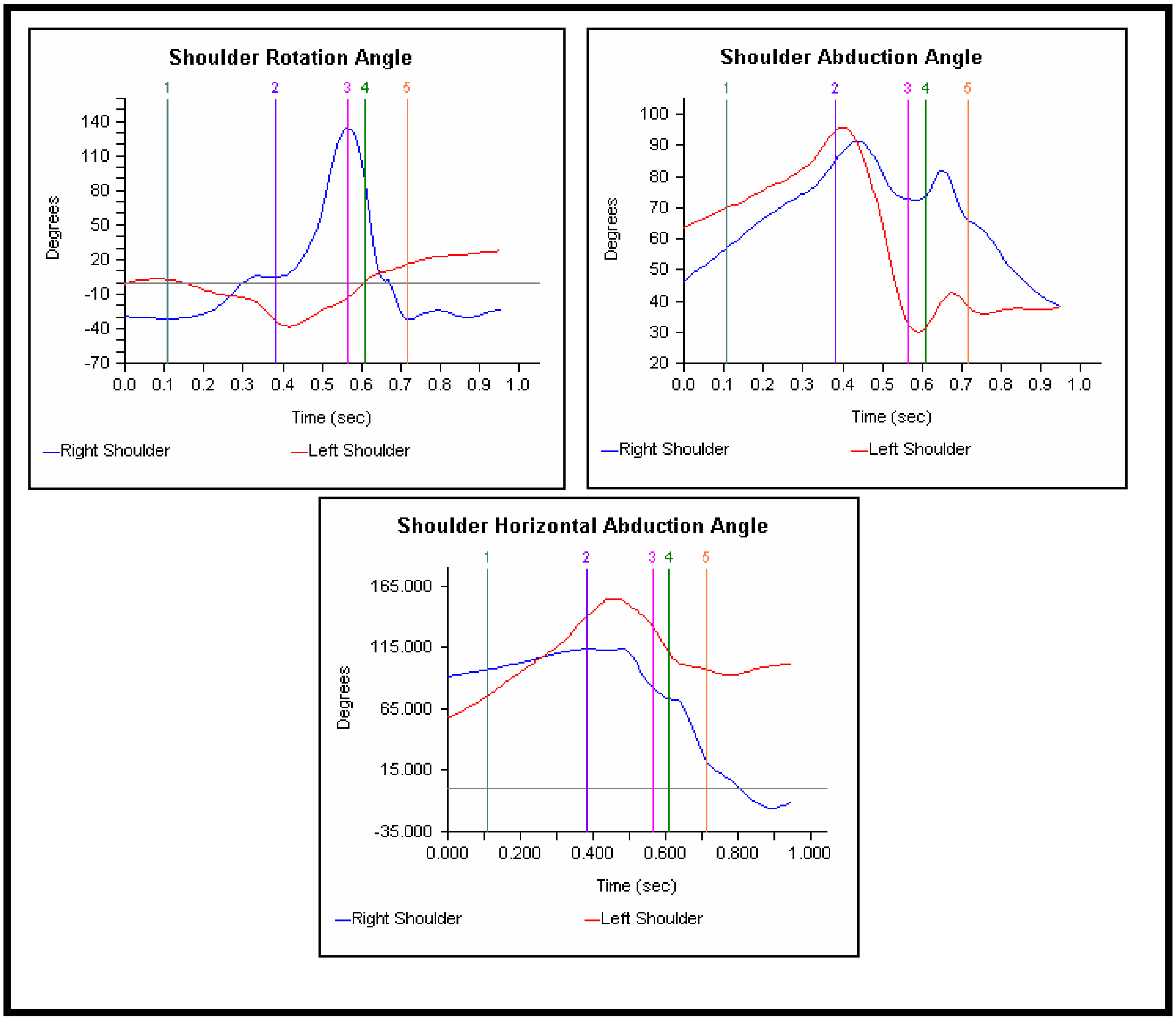


**Figure 10: Subject Data for Shoulder Angles**
**Events 1-5 (1) Begin External Rotation, (2) Maximum external rotation, (3) Foot Contact, (4) Ball Release, (5) Minimum Internal Rotation**

### 3.1.7.2 Events

To determine the kinematics of the throwing motion, the throw was divided into four phases including early cocking, late cocking, acceleration, and deceleration. Events of the four phases were defined by kinematics, the force plate, and the finger switch. Early cocking was defined from the beginning of external rotation until foot contact. Shoulder internal and external rotation calculations were used to identify the beginning of external rotation and foot contact, and calculated using 5% body weight foot contact with the force plate **(Figure 11)**. Late cocking was defined as the phase from foot contact to maximum external rotation. Maximum external rotation was determined with internal/external rotation calculations **(Figure 12)**. The acceleration phase began with maximum external rotation and ended at ball release. The ball release trigger (finger switch) identified ball release when loss of the 9-volt signal dropped to approximately a zero (0) voltage **(Figure 13)**. The deceleration phase began at ball release until the arm completed follow-through and went to minimum internal rotation and was determined using internal/external calculations.

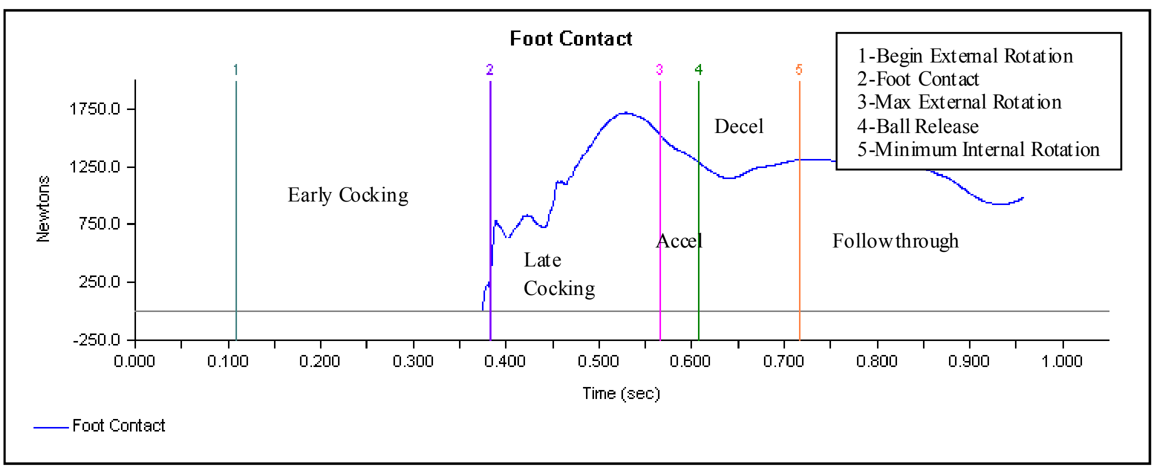


**Figure 11: Events in Relation to Foot Contact**

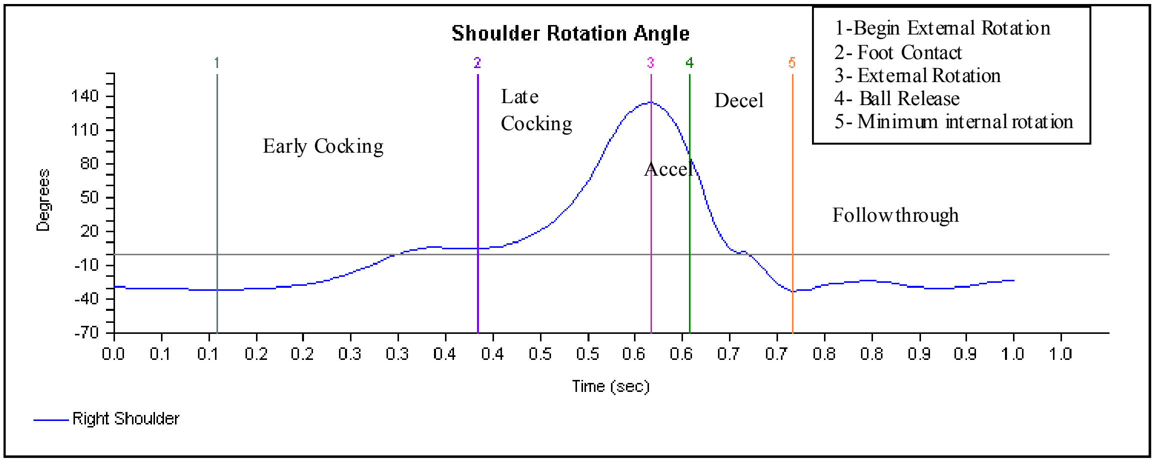


**Figure 12: Events in Relation to Shoulder Rotation Angle**

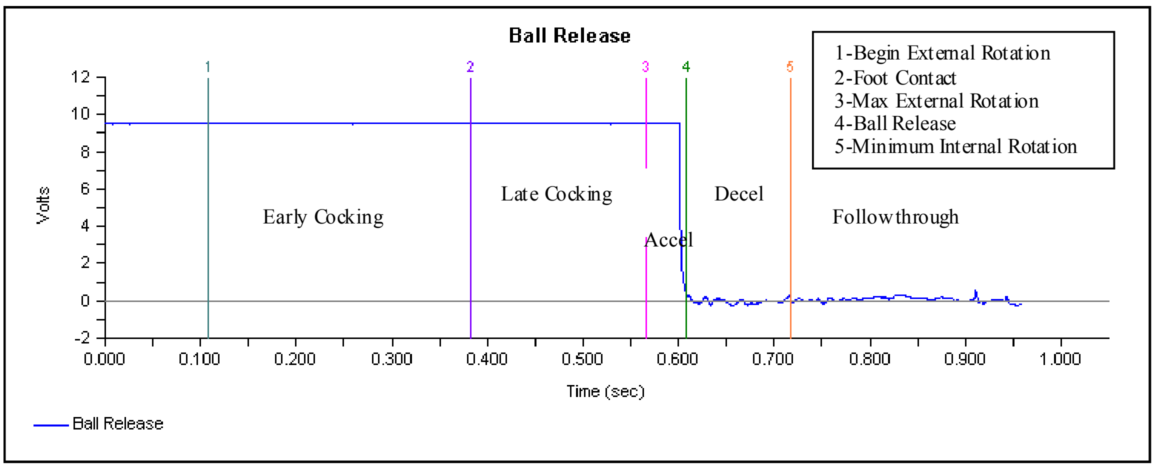


**Figure 13: Events in Relation to Ball Release**

Kinematic data and event times were exported and averaged for the three trials for each pitch analyzed via a custom written Matlab (Matlab Version 6.0 R12, The Mathworks, Inc., Natick, MA) program.

### 3.1.8 Statistical Analysis

Given the descriptive nature of this study, no interferential statistics were utilized. The only statistical analyses were descriptive in nature (i.e. mean and standard deviation). Initially, the mean and standard deviation for all dependent variables (during each phase of the pitch) were calculated for pitches 1, 2, 3, 9, 10, 11, 19, 20, 21, 29, 30, and 31. These pitches (and calculated data) represented the data collection from the first two innings when any fatigue effects would be minimal and provided a baseline for all comparisons as pitch count increased (i.e. pitches 39-151). Each dependent variable was then calculated at all pitch count intervals for pitches 39, 40, 41, ... , 149, 150, 151 and compared to the baseline data established during the first two innings. A change as a result of increased pitch count was indicated if the dependent variable differed from the baseline variable by more than two standard (2 SD) deviations and continued to differ by more than 2SD for the rest of the simulated game. Significant changes were discussed as potential recommendations for coaches and athletic trainers when determining a pitchers pitch count allowance during practice and competition.

# 4 Chapter 4

## 4.1 Results

This study consisted of one testing session. A descriptive design was utilized to assess kinematic changes in pitching mechanics of intercollegiate baseball pitchers as pitch count increased. The independent variable was pitch count, specifically fastball pitches 1, 2, 3, 9, 10, 11, 19, 20, 21, 29, 30, 31, 39, 40, 41, 49, 50, 51, 59, 60, 61, 69, 70, 71, 79, 80, 81, 89, 90, 91, 99,100, 101, 109,110, 111, 119, 120, 121, 129, 130, 131, 139, 140, 141, 149, 150, and 151. The dependent variables of interest included shoulder rotation, shoulder abduction, shoulder horizontal abduction, and elbow flexion.

### 4.1.1 Subject Characteristics

Participants of this study consisted of 8 healthy intercollegiate baseball pitchers that were currently competing as a starting pitcher on a collegiate baseball team. Subjects were recruited from the University of Pittsburg Main campus, University of Pittsburgh Greensburg Campus, Geneva College, and CCAC South Campus. No subjects had a history of any neurological disorders, shoulder or elbow pathologies, or significant limitation of shoulder or elbow rotation. Descriptive statistics for this study appear in **Table 2**. Seven subjects were right hand dominant, while one subject was left hand dominant.

**Table 2: Subject Demographics**

| | Pitching Group (8 subjects, 7 right hand dominant, 1 left hand dominant)) | |
|---|---|---|
| | **Mean** | **$\pm$ SD** |
| **Age (yrs)** | 19.50 | 1.41 |
| **Height (cm)** | 183.12 | 3.92 |
| **Weight (kg)** | 84.77 | 11.50 |

### 4.1.2 Shoulder Kinematics

#### 4.1.2.1 Shoulder Rotation at Early Cocking

Significant differences existed within subject 4 and subject 5. Shoulder external rotation at early cocking increased for subject 4 **(Table 3)**. Shoulder external rotation at early cocking decreased for subject 5 **(Table 4)**. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder rotation at early cocking for pitches 1-150 appear in **Figure 14**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder rotation at early cocking for pitches 1-150 appear in **Figure 15.**

**Table 3: Shoulder Rotation at early cocking for subject 4**

| Pitch Count | Shoulder Rotation |
|---|---|
| 130 | 64.99 |
| 140 | 71.17 |
| 150 | 65.51 |
| **Mean + 2SD** | 62.02 |
| **Mean – 2SD** | 6.03 |

**Table 4: Shoulder Rotation at Early Cocking for Subject 5**

| Pitch Count | Shoulder Rotation |
|---|---|
| 140 | 9.28 |
| 150 | 5.40 |
| **Mean + 2SD** | 30.45 |
| **Mean – 2SD** | 9.55 |

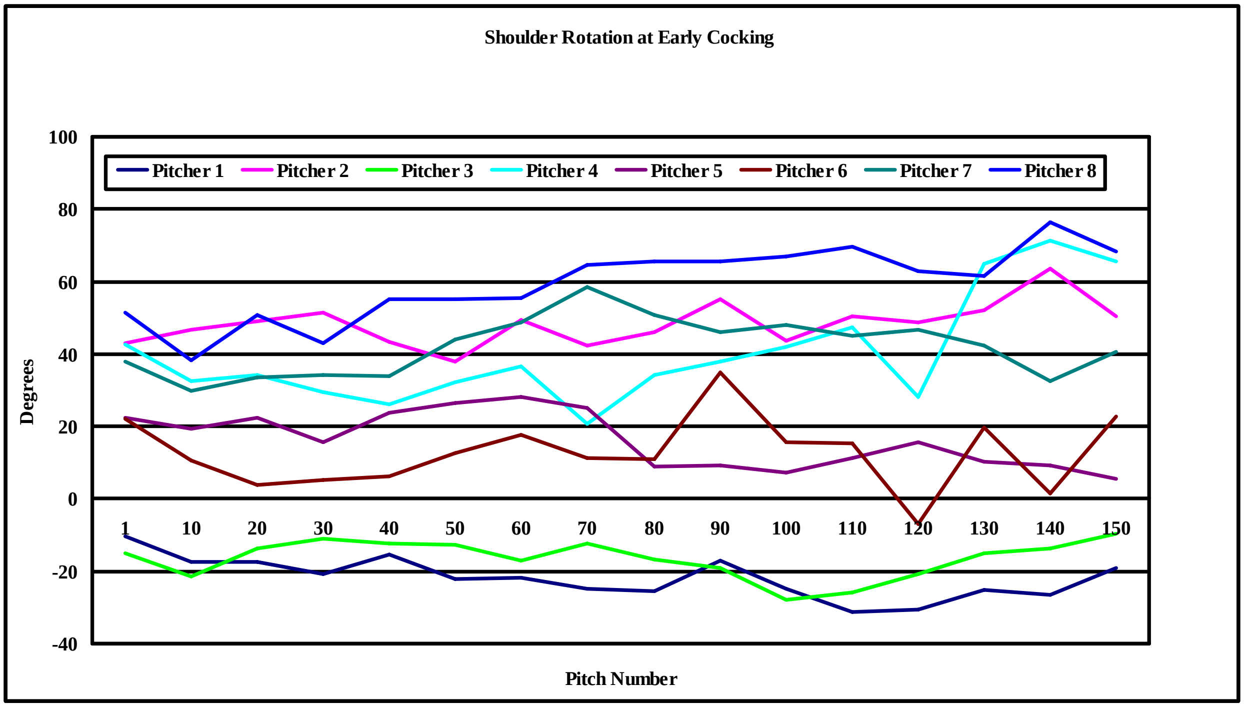


**Figure 14: Shoulder Rotation at Early Cocking for Each Pitcher**

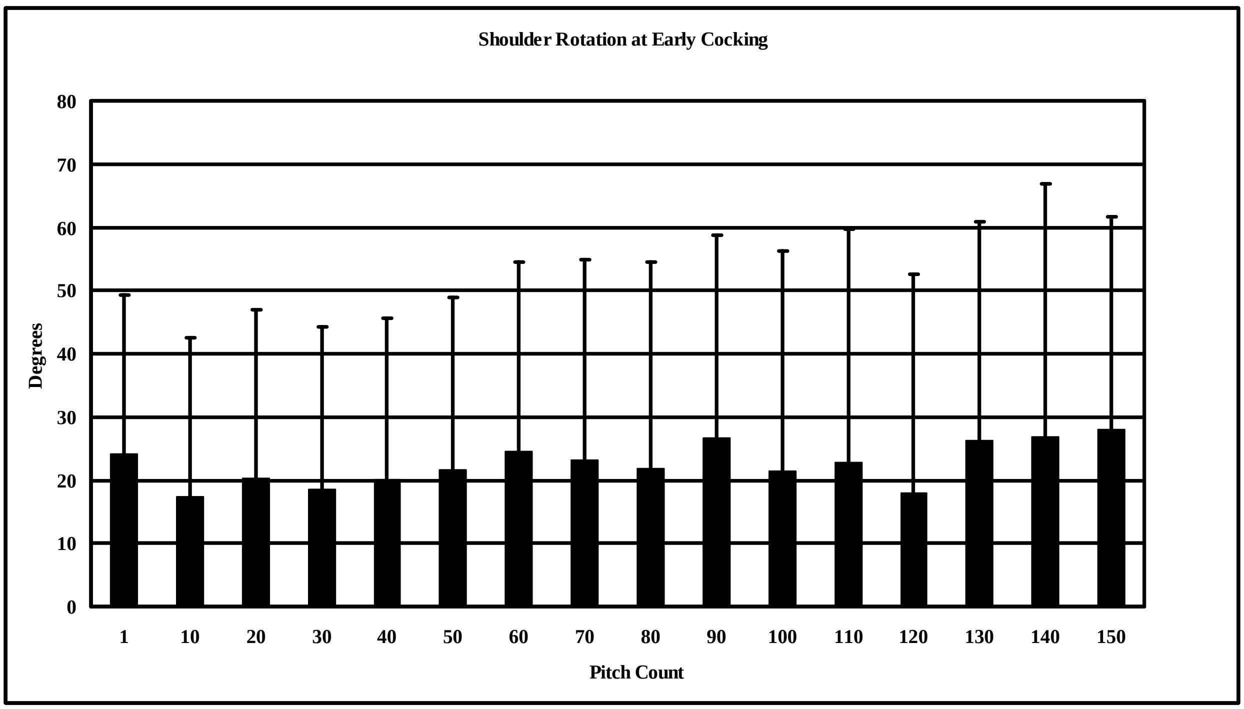


**Figure 15: Shoulder Rotation at Early Cocking (Group Means ± SD)**

#### 4.1.2.2 Shoulder Rotation at Maximum External Rotation (Late Cocking)

No significant differences existed within subjects. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder rotation at maximum external rotation for pitches 1-150 appear in **Figure 16**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder rotation at maximum external rotation for pitches 1-150 appear in **Figure 17**.

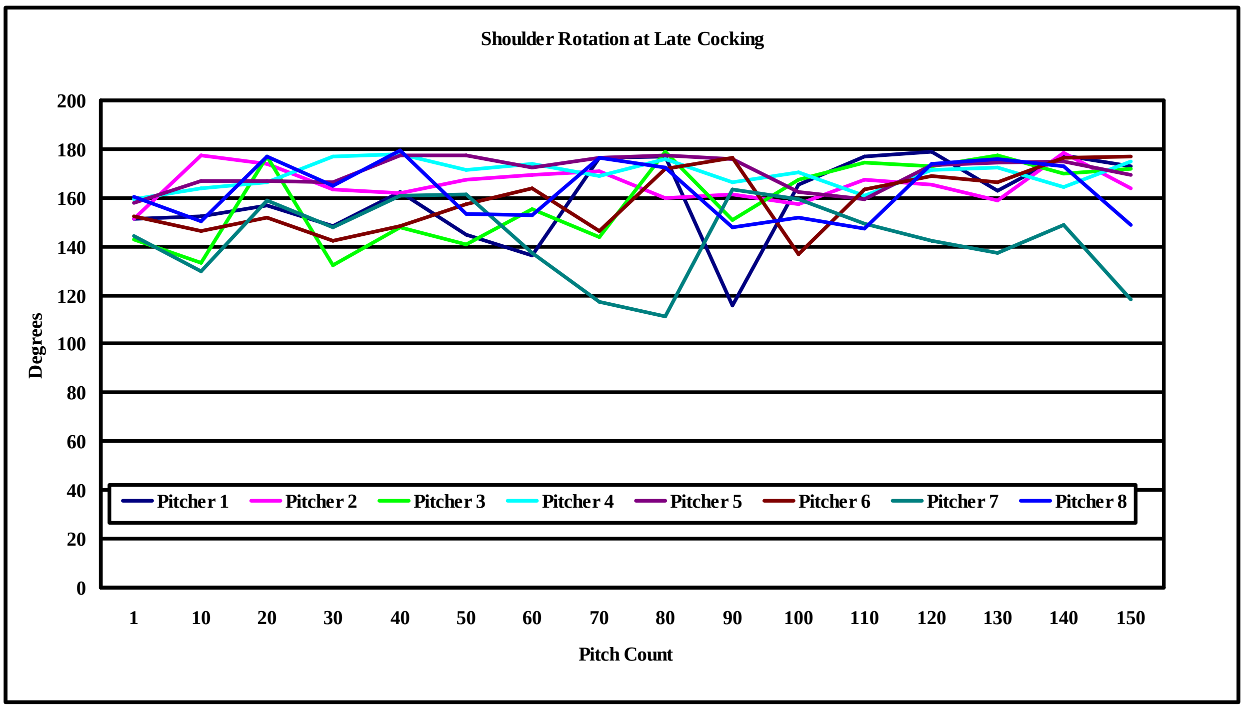


**Figure 16: Shoulder Rotation at Late Cocking for Each Pitcher**

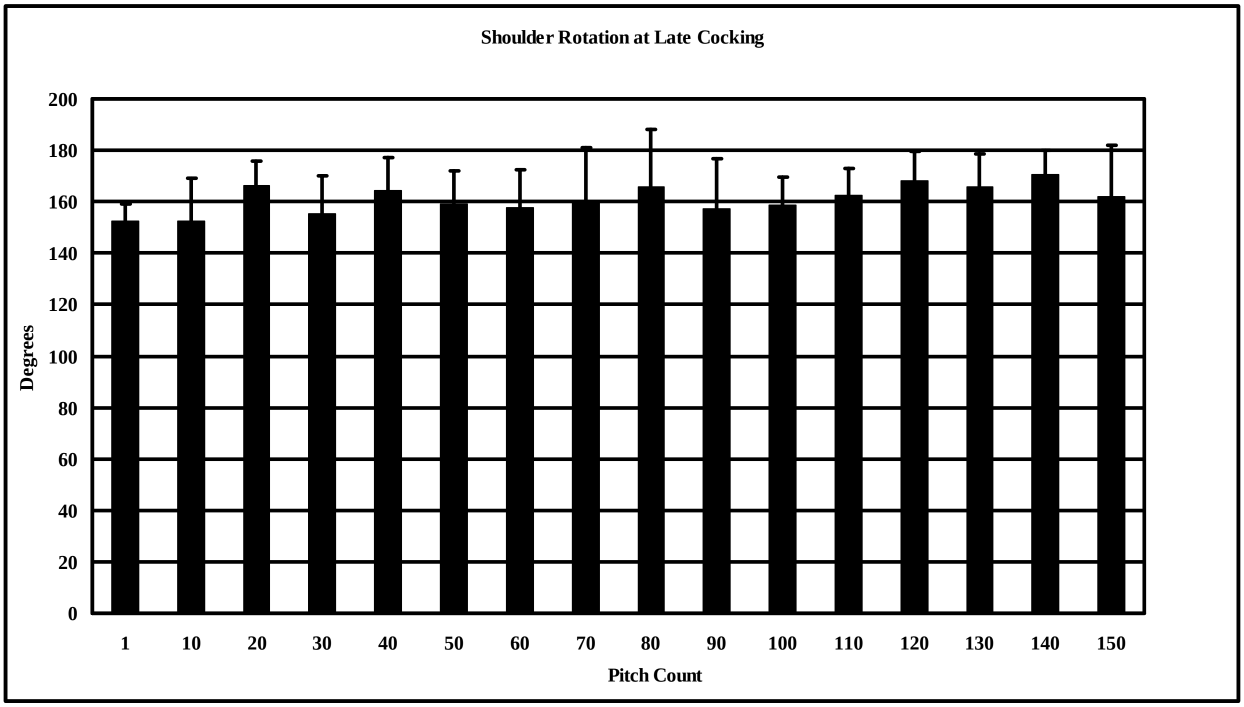


**Figure 17: Shoulder Rotation at Late Cocking (Group Means + SD)**

#### 4.1.2.3 <u>Shoulder Rotation at Ball Release</u>

No significant differences existed within subjects. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder rotation at ball release for pitches 1-150 appear in **Figure 18**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder rotation at ball release for pitches 1-150 appear in **Figure 19**.

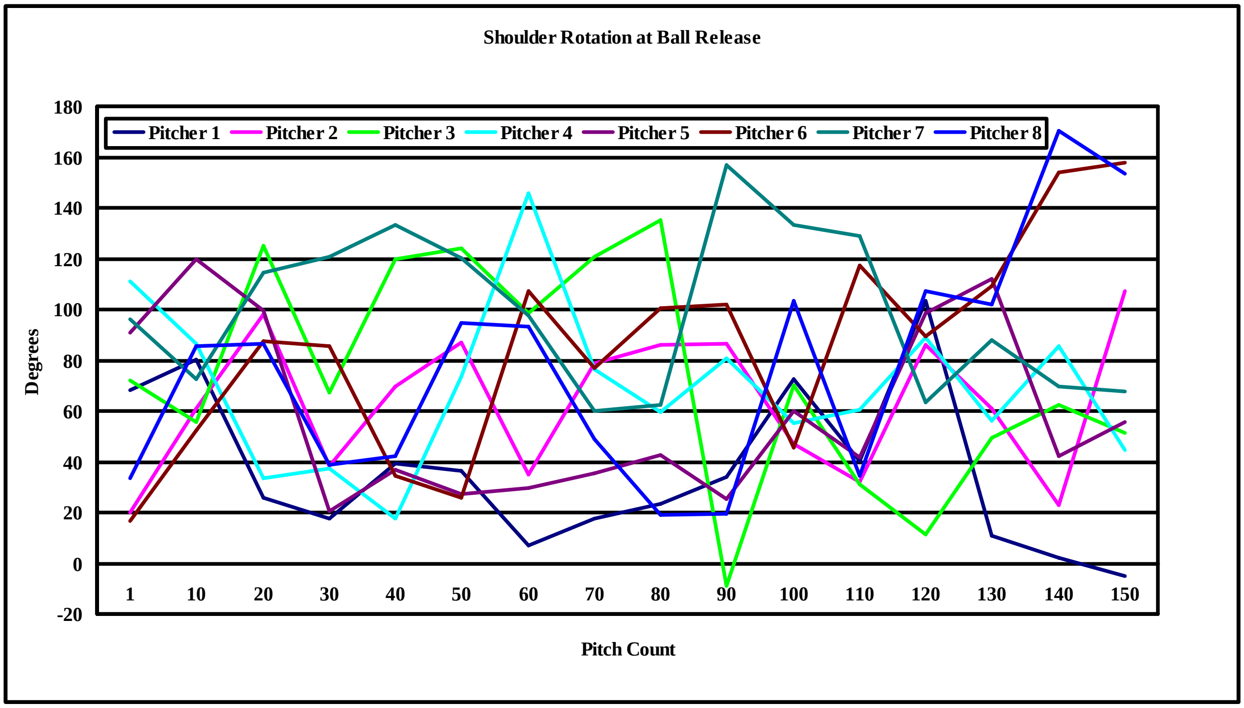


**Figure 18: Shoulder Rotation at Ball Release for Each Subject**

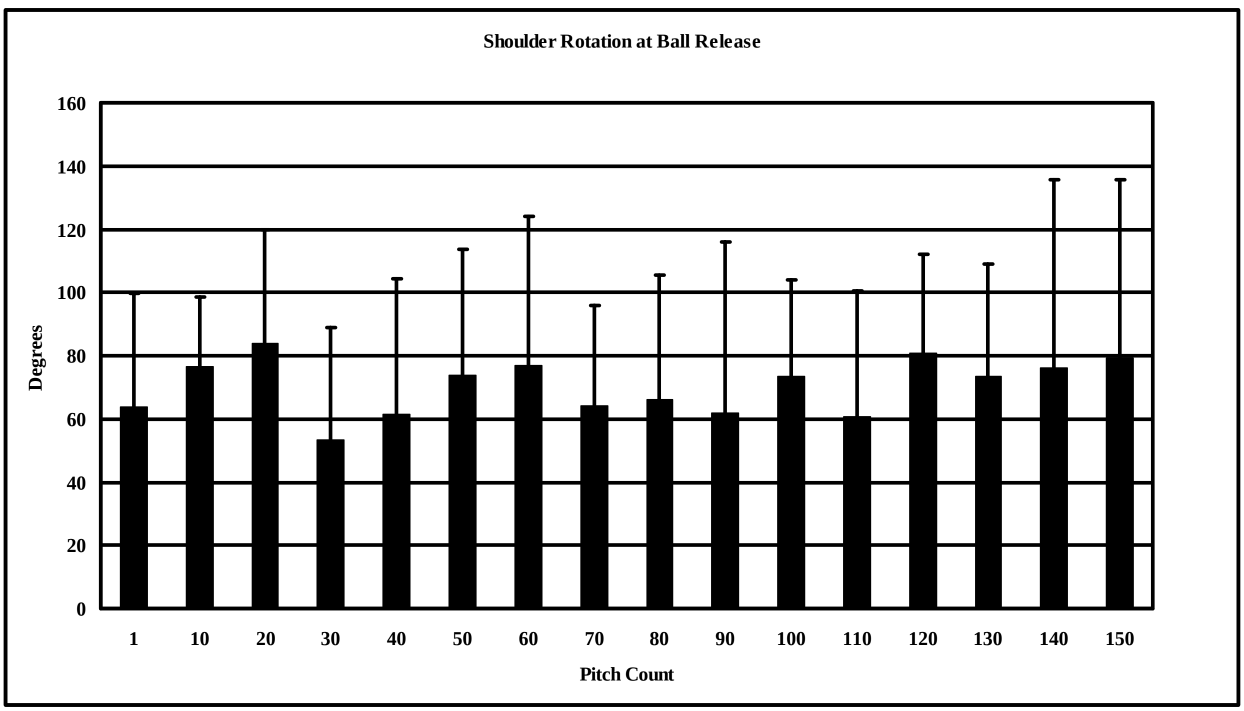


**Figure 19: Shoulder Rotation at Ball Release (Group Means ± SD)**

#### 4.1.2.4 <u>Shoulder Rotation at Deceleration</u>

Significant differences existed within subject 3 and subject 7. Shoulder external rotation at deceleration decreased for both subjects 3 **(Table 5)** and 7 **(Table 6)**. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder rotation at deceleration for pitches 1-150 appear in **Figure 20**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder rotation at deceleration for pitches 1-150 appear in **Figure 21**.

**Table 5: Shoulder Rotation at Deceleration for Subject 3**

| Pitch Count | Shoulder Rotation |
|---|---|
| 70 | -16.90 |
| 80 | -24.31 |
| 90 | -17.34 |
| 100 | -22.20 |
| 110 | -16.84 |
| 120 | -10.48 |
| 130 | -11.68 |
| 140 | -15.66 |
| 150 | -12.59 |
| **Mean + 2SD** | 22.32 |
| **Mean – 2SD** | -7.98 |

**Table 6: Shoulder Rotation at Deceleration for Subject 7**

| Pitch Count | Shoulder Rotation |
|---|---|
| 130 | 9.69 |
| 140 | 11.36 |
| 150 | 9.24 |
| **Mean + 2SD** | 20.64 |
| **Mean – 2SD** | 12.81 |

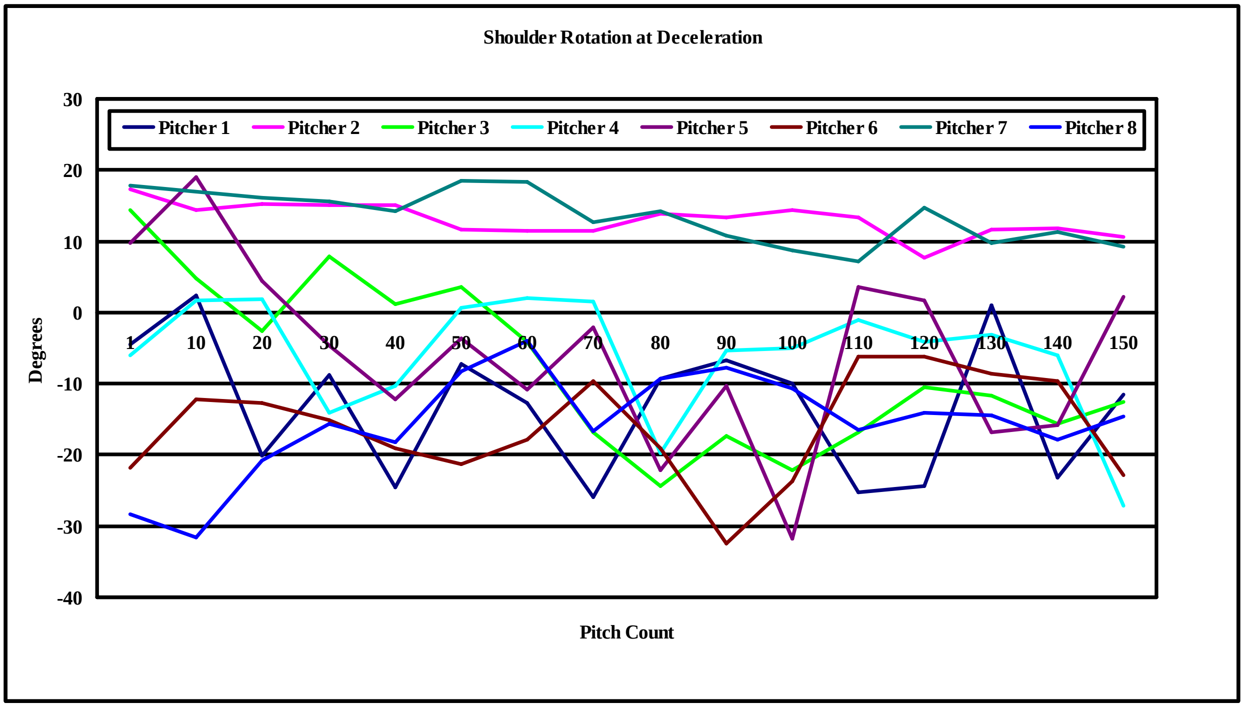


**Figure 20: Shoulder Rotation at Deceleration for Each Pitcher**

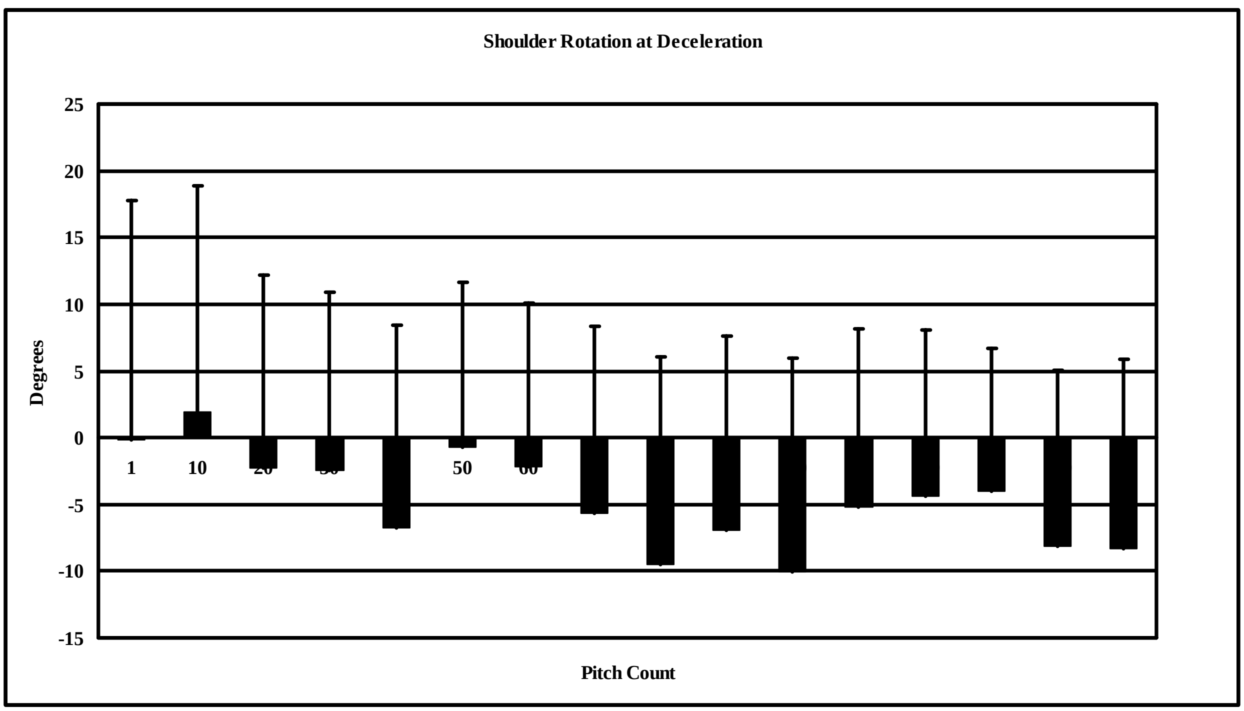


**Figure 21: Shoulder Rotation at Deceleration (Group Means ± SD)**

#### 4.1.2.5 Shoulder Abduction at Early Cocking

Significant differences existed within subject 6. Shoulder abduction at Early Cocking increased for subject 6 **(Table 7)**. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder abduction at early cocking for pitches 1-150 appear in **Figure 22**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder abduction at early cocking for pitches 1-150 appear in **Figure 23**.

**Table 7: Shoulder Abduction at Early Cocking for Subject 6**

| Pitch Count | Shoulder Abduction |
|---|---|
| 70 | 101.18 |
| 80 | 103.49 |
| 90 | 100.95 |
| 100 | 105.12 |
| 110 | 102.12 |
| 120 | 108.19 |
| 130 | 99.28 |
| 140 | 99.24 |
| 150 | 101.88 |
| **Mean + 2SD** | 98.78 |
| **Mean – 2SD** | 88.41 |

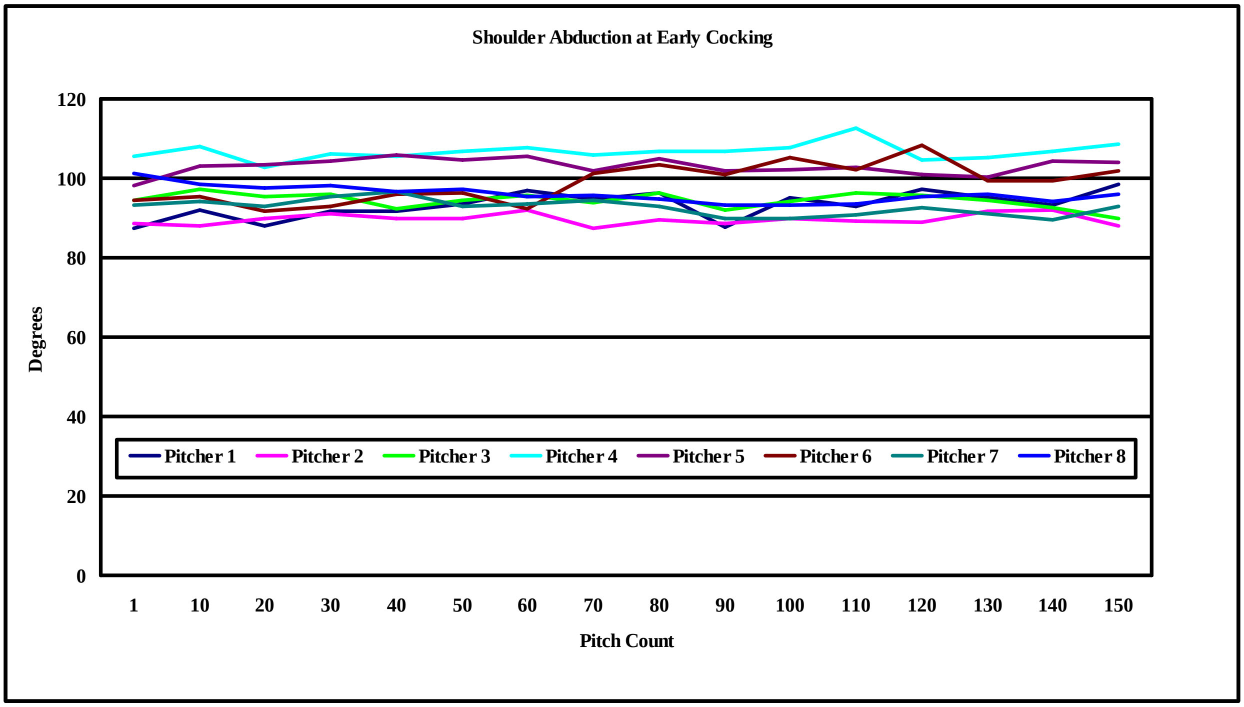


**Figure 22: Shoulder Abduction at Early Cocking for Each Subject**

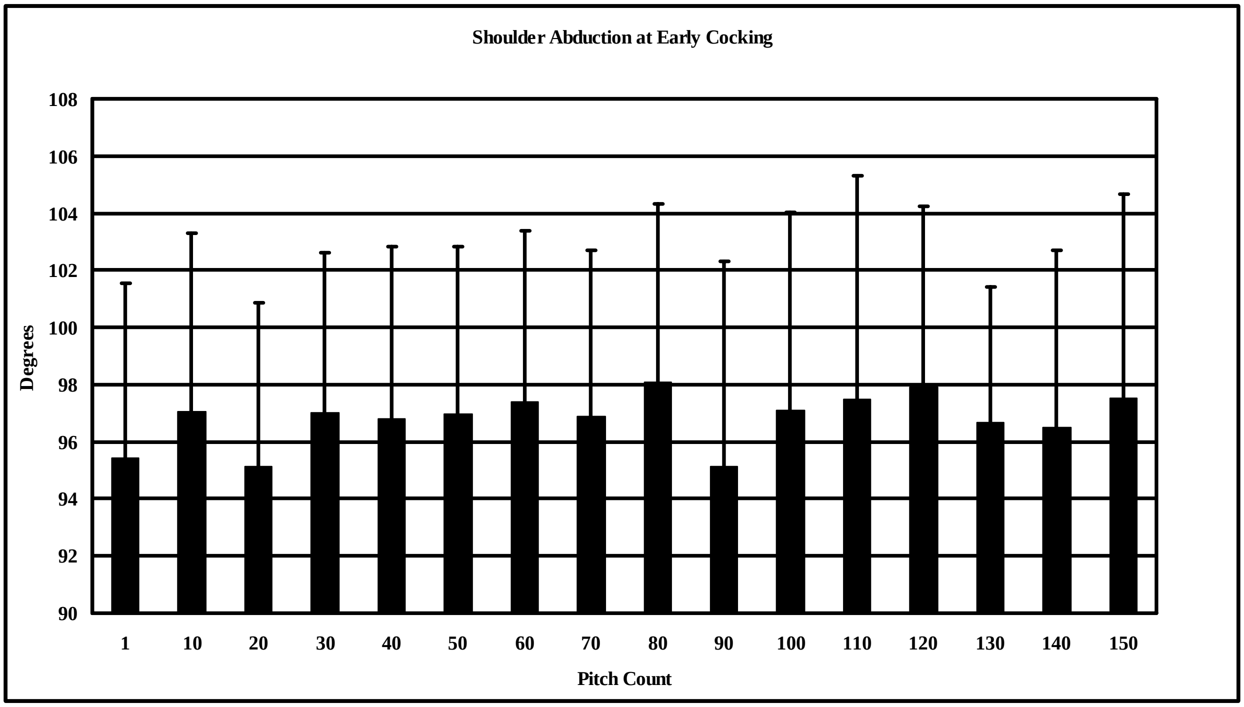


**Figure 23: Shoulder Abduction at Early Cocking (Group Means ± SD)**

#### 4.1.2.6 Shoulder Abduction at Maximum External Rotation (Late Cocking)

No significant differences existed within subjects. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder abduction at maximum external rotation for pitches 1-150 appear in **Figure 24**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder abduction at maximum external rotation for pitches 1-150 appear in **Figure 25**.

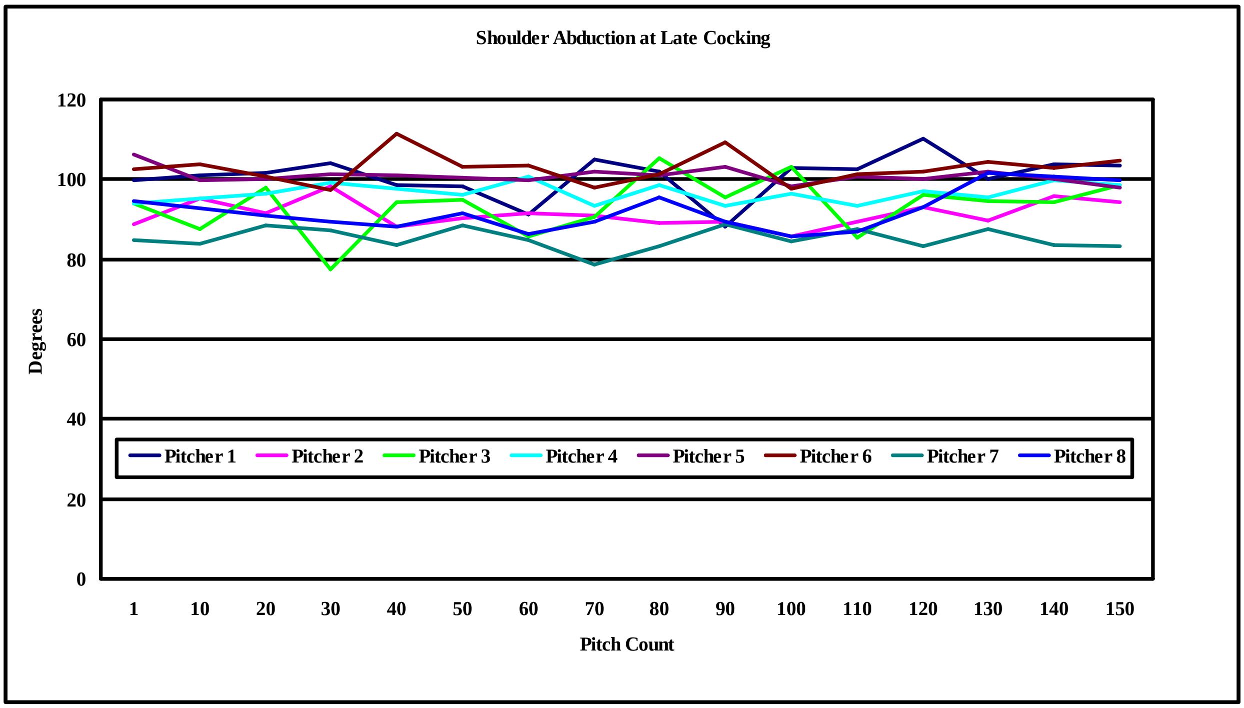


**Figure 24: Shoulder Abduction at Late Cocking for Each Subject**

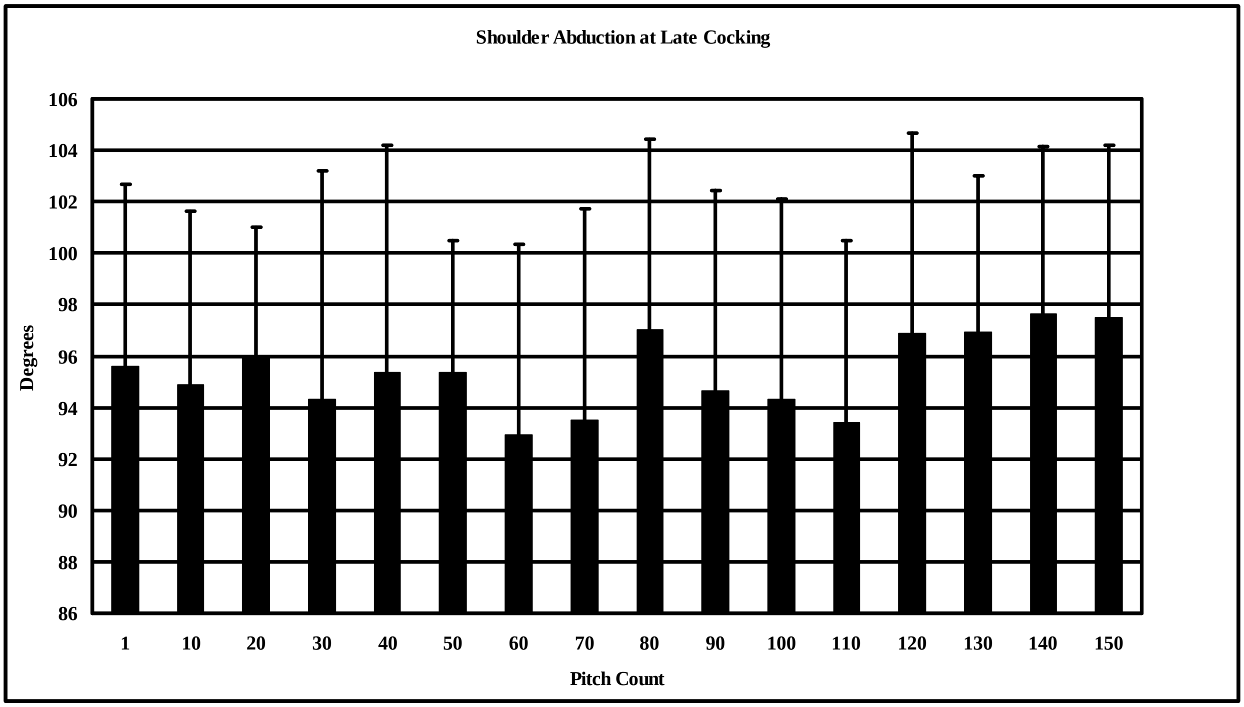


**Figure 25: Shoulder Abduction at Late Cocking (Group Means + SD)**

#### 4.1.2.7 Shoulder Abduction at Ball Release

Significant differences existed within subject 6. Shoulder abduction at ball release increased for subject 6 **(Table 8)**. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder abduction at ball release for pitches 1-150 appear in **Figure 26**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder abduction at ball release for pitches 1-150 appear in **Figure 27**.

**Table 8: Shoulder Abduction at Ball Release for Subject 6**

| Pitch Count | Shoulder Abduction |
|---|---|
| 140 | 108.32 |
| 150 | 116.38 |
| **Mean + 2SD** | 106.63 |
| **Mean – 2SD** | 85.25 |

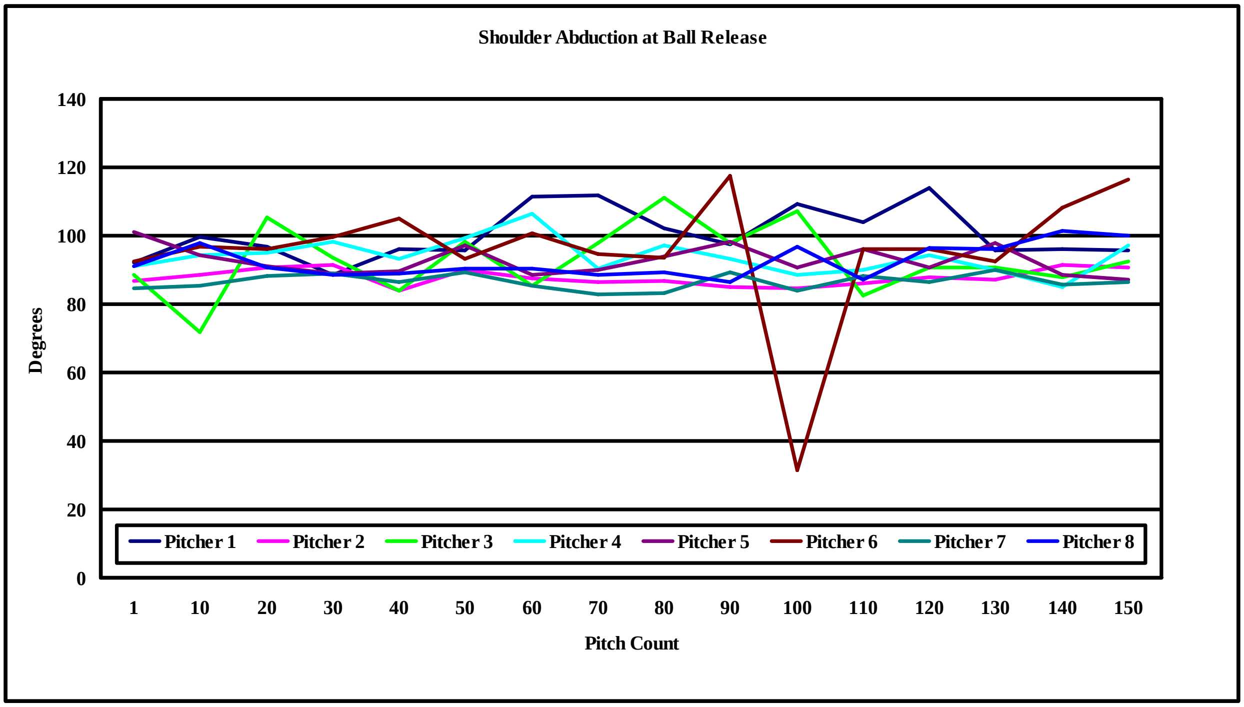


**Figure 26: Shoulder Abduction at Ball Release for Each Pitcher**

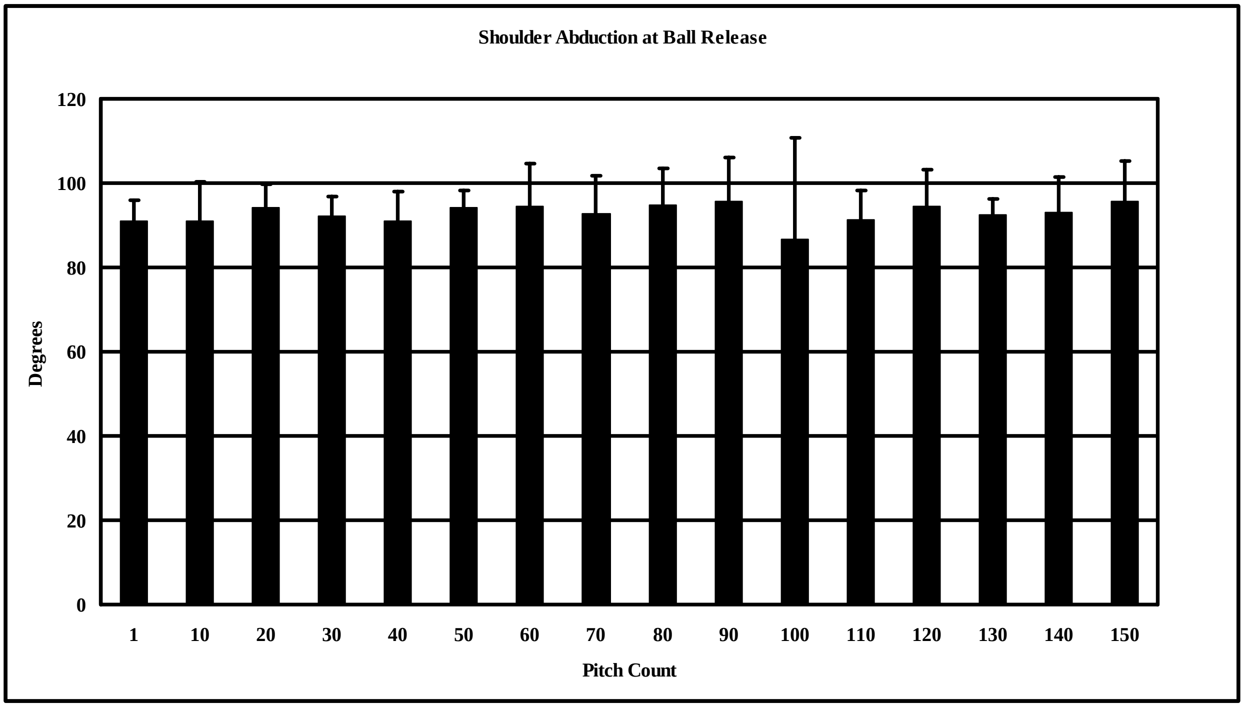


**Figure 27: Shoulder Abduction at Ball Release (Group Means ± SD)**

#### 4.1.2.8 Shoulder Abduction at Deceleration

No significant differences existed within subjects. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder abduction at deceleration for pitches 1-150 appear in **Figure28**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder abduction at deceleration for pitches 1-150 appear in **Figure 29**.

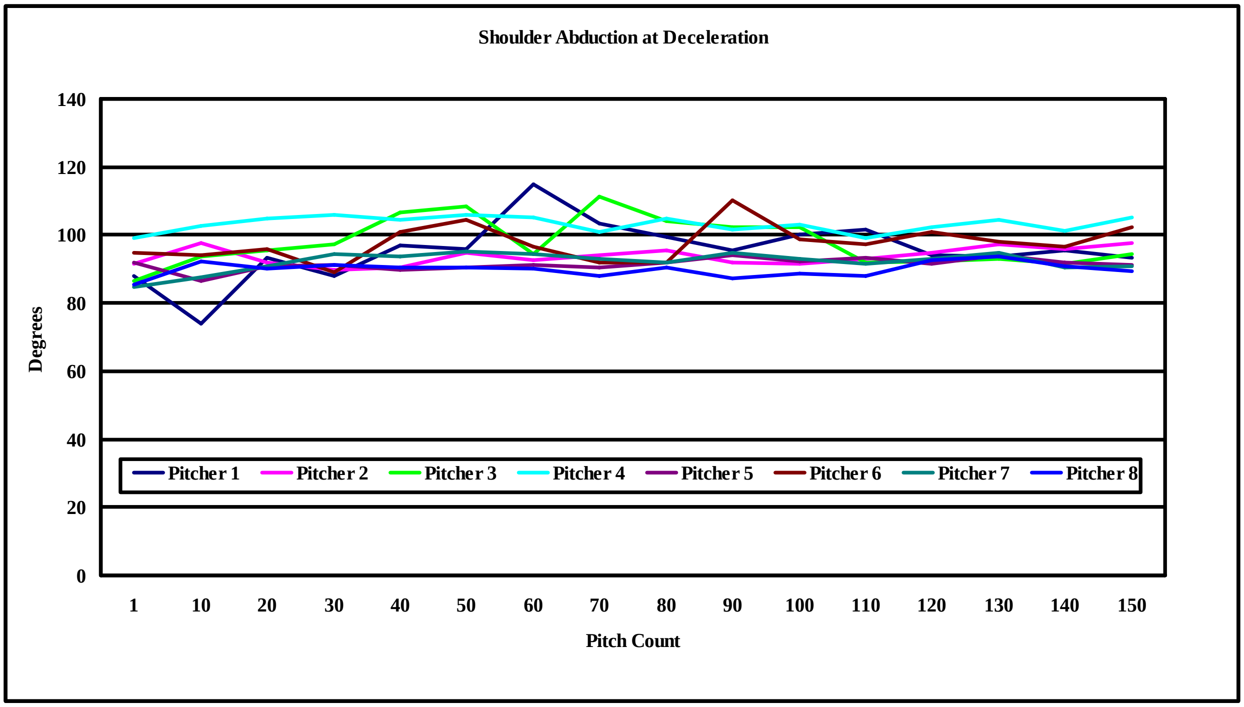


**Figure 28: Shoulder Abduction at Deceleration for Each Pitcher**

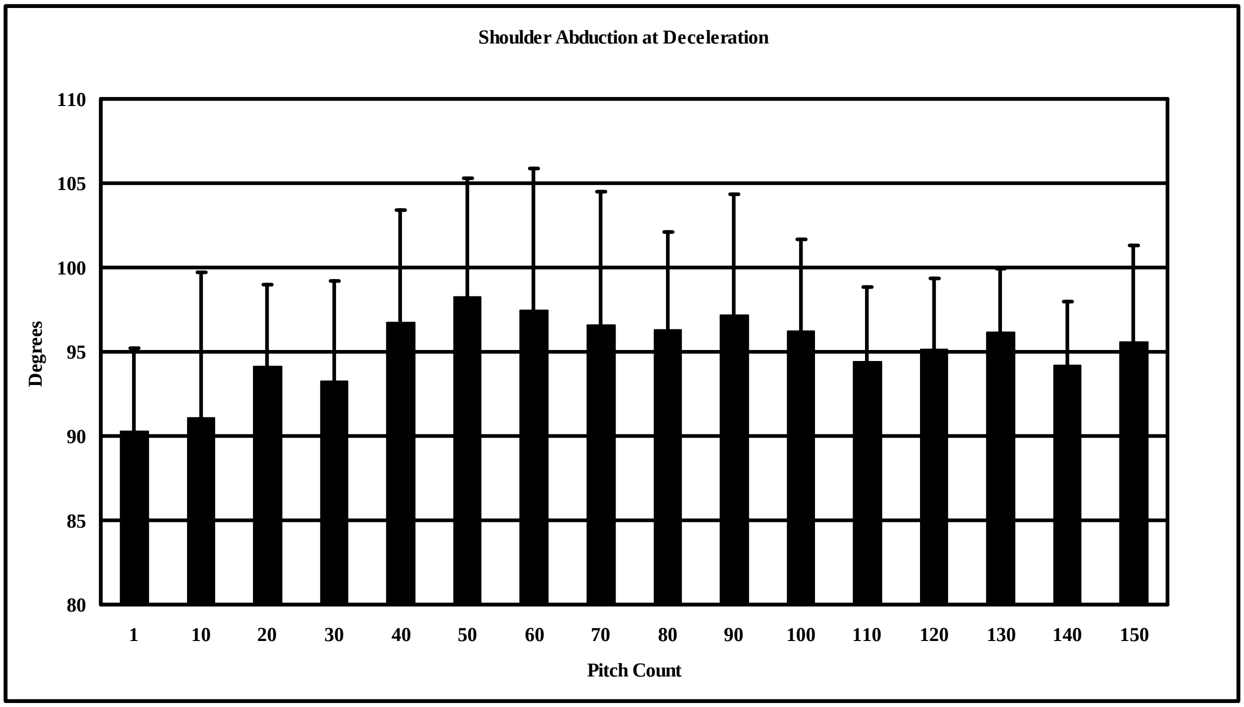


**Figure 29: Shoulder Rotation at Deceleration (Group Means ± SD)**

### 4.1.2.9 Shoulder Horizontal Abduction at Early Cocking

Significant differences existed within subjects 2 and 6. Shoulder horizontal abduction at early cocking decreased for both subjects 2 **(Table 9)** and 6 **(Table 10)**. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder horizontal abduction at early cocking for pitches 1-150 appear in **Figure 30**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder horizontal abduction at early cocking for pitches 1-150 appear in **Figure 31**.

**Table 9: Shoulder Horizontal Abduction at Early Cocking for Subject 2**

| Pitch Count | Shoulder Horizontal Abduction |
|---|---|
| 110 | 101.78 |
| 120 | 102.44 |
| 130 | 99.08 |
| 140 | 96.32 |
| 150 | 102.63 |
| **Mean + 2SD** | 119.26 |
| **Mean – 2SD** | 106.43 |

**Table 10: Shoulder Horizontal Abduction at Early Cocking for Subject 6**

| Pitch Count | Shoulder Horizontal Abduction |
|---|---|
| 90 | 102.96 |
| 100 | 103.01 |
| 110 | 103.11 |
| 120 | 103.99 |
| 130 | 103.92 |
| 140 | 102.83 |
| 150 | 103.55 |
| **Mean + 2SD** | 110.74 |
| **Mean – 2SD** | 104.83 |

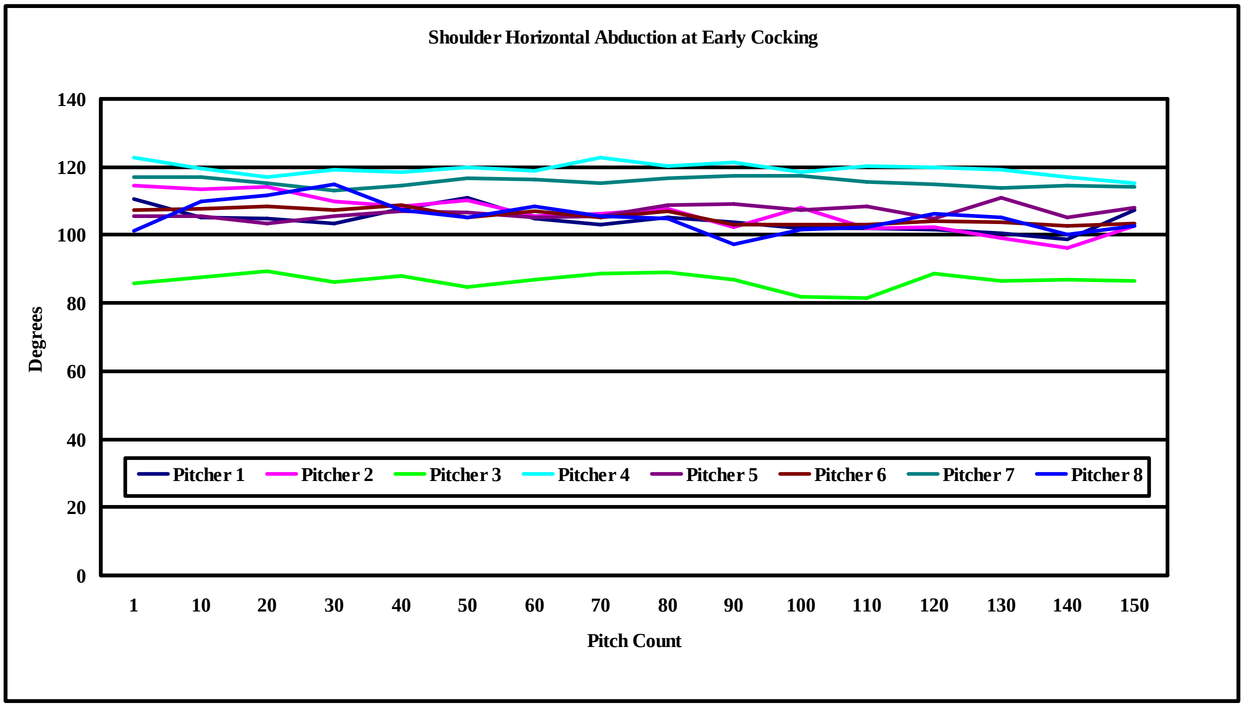


**Figure 30: Shoulder Horizontal Abduction at Early Cocking for Each Pitcher**

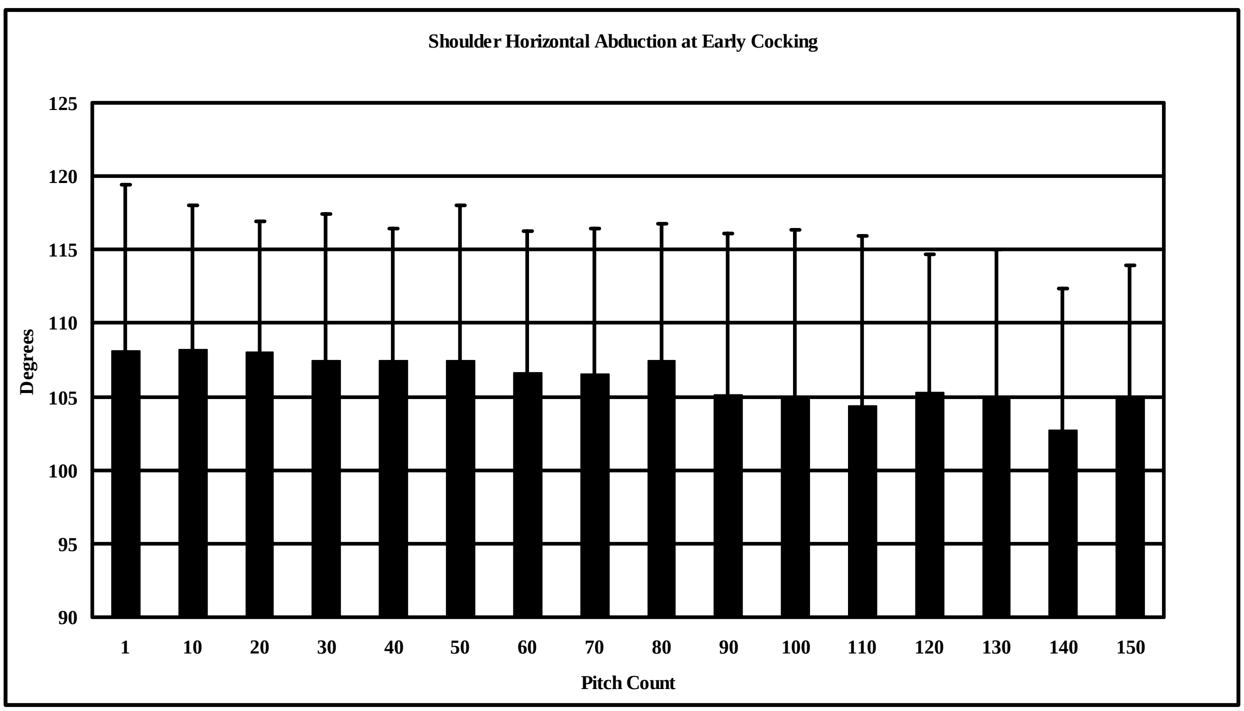


**Figure 31: Shoulder Horizontal Abduction at Early Cocking (Group Means ± SD)**

#### 4.1.2.10 Shoulder Horizontal Abduction at Maximum External Rotation (Late Cocking)

Significant differences existed within subject 8. Shoulder horizontal abduction at ball release decreased for subject 8 **(Table 11)**. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder horizontal abduction at maximum external rotation for pitches 1-150 appear in **Figure 32**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder horizontal abduction at maximum external rotation for pitches 1-150 appear in **Figure 33**.

**Table 11: Shoulder Horizontal Abduction at Late Cocking for Subject 8**

| Pitch Count | Shoulder Horizontal Abduction |
|---|---|
| 140 | 58.82 |
| 150 | 59.43 |
| **Mean + 2SD** | 110.13 |
| **Mean – 2SD** | 62.27 |

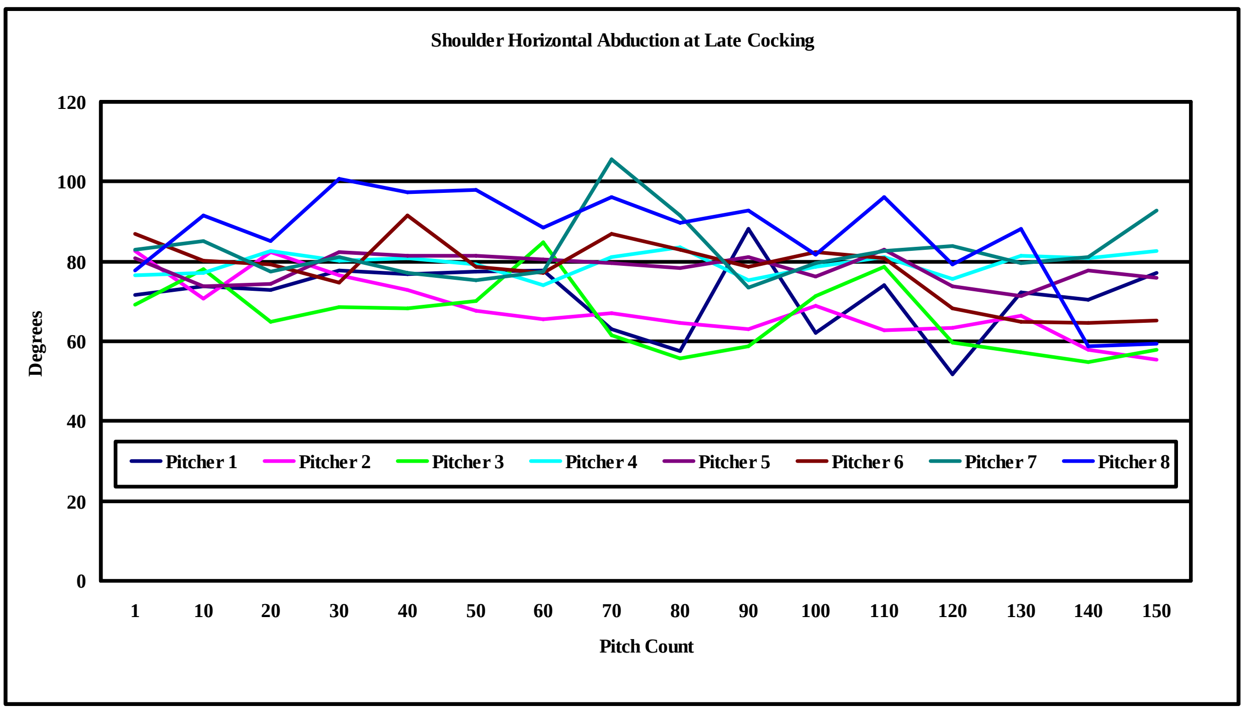


**Figure 32: Shoulder Horizontal Abduction at Late Cocking for Each Pitcher**

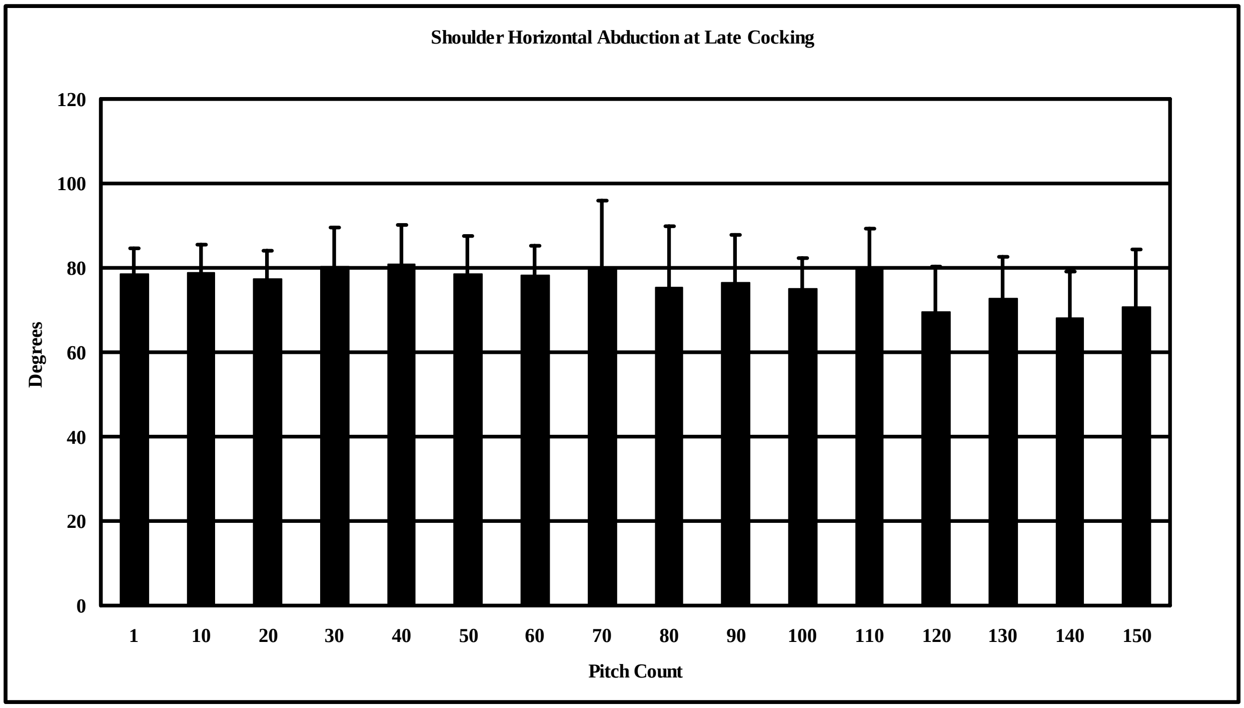


**Figure 33: Shoulder Horizontal Abduction at Late Cocking (Group Means ± SD)**

### 4.1.2.11 <u>Shoulder Horizontal Abduction at Ball Release</u>

No significant differences existed within subjects. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder horizontal abduction at ball release for pitches 1-150 appear in **Figure 34**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder horizontal abduction at ball release for pitches 1-150 appear in **Figure 35**.

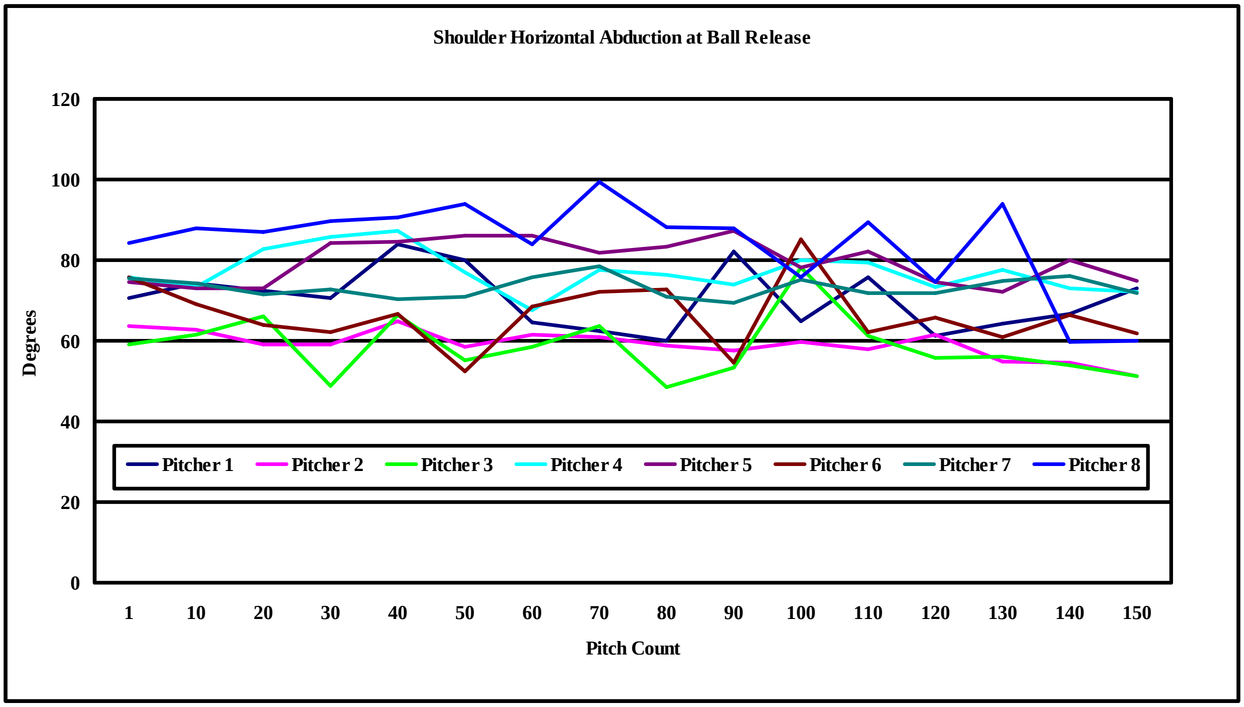


**Figure 34: Shoulder Horizontal Abduction at Ball Release for Each Pitcher**

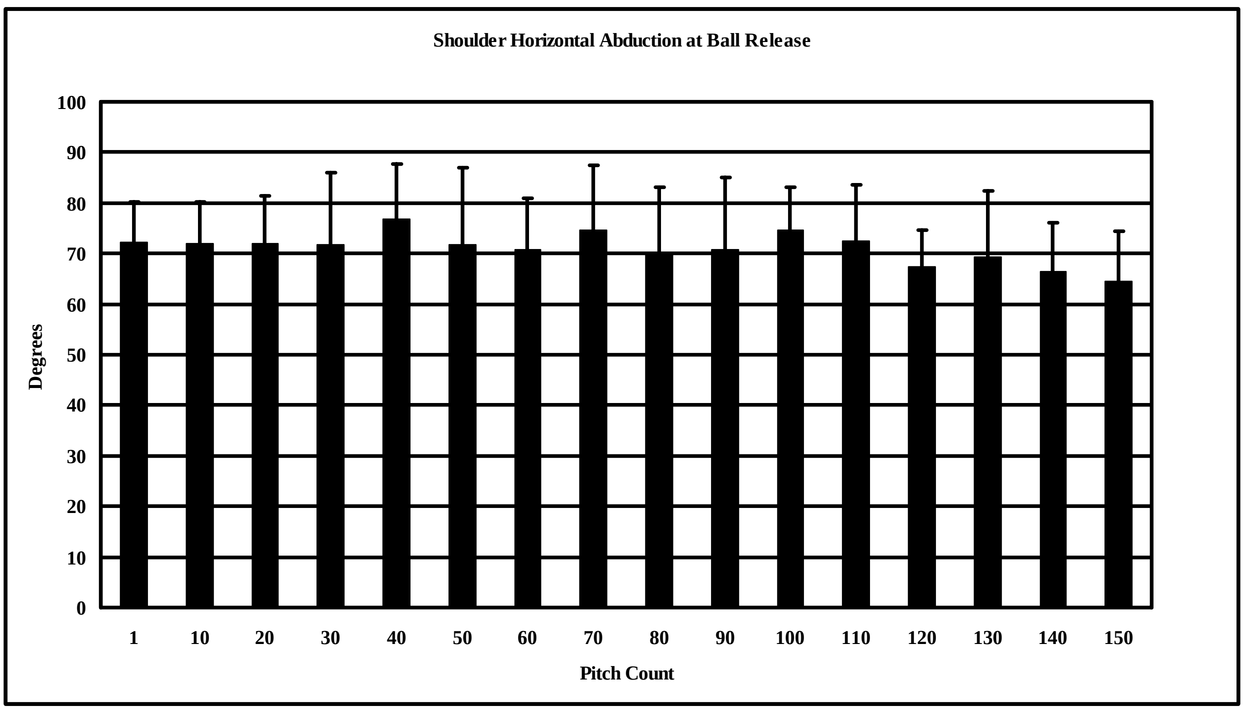


**Figure 35: Shoulder Horizontal Abduction at Ball Release (Group Means ± SD)**

#### 4.1.2.12 <u>Shoulder Horizontal Abduction at Deceleration</u>

No significant differences existed within subjects. Graphical representation of the descriptive statistics (mean) for each pitcher of shoulder horizontal abduction at deceleration for pitches 1-150 appear in **Figure 36**. Graphical representation of group descriptive statistics (mean and standard deviation) of shoulder horizontal abduction at deceleration for pitches 1-150 appear in **Figure 37**.

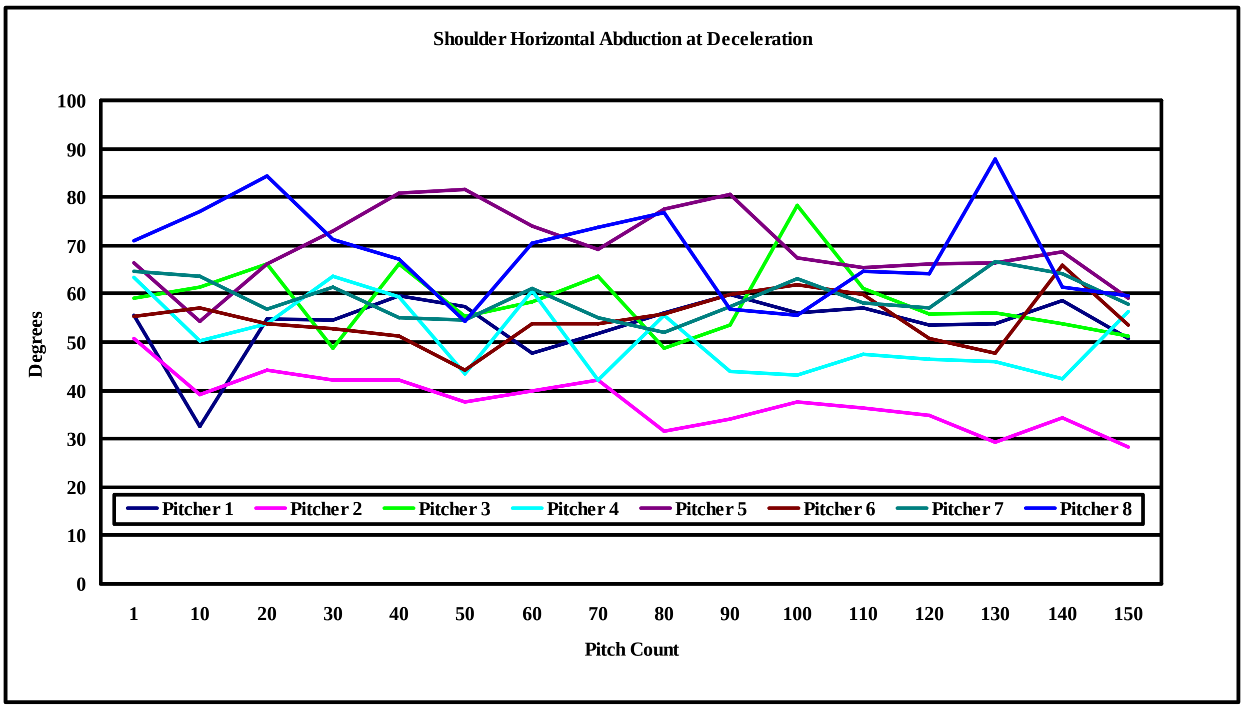


**Figure 36: Shoulder Horizontal Abduction at Deceleration for Each Pitcher**

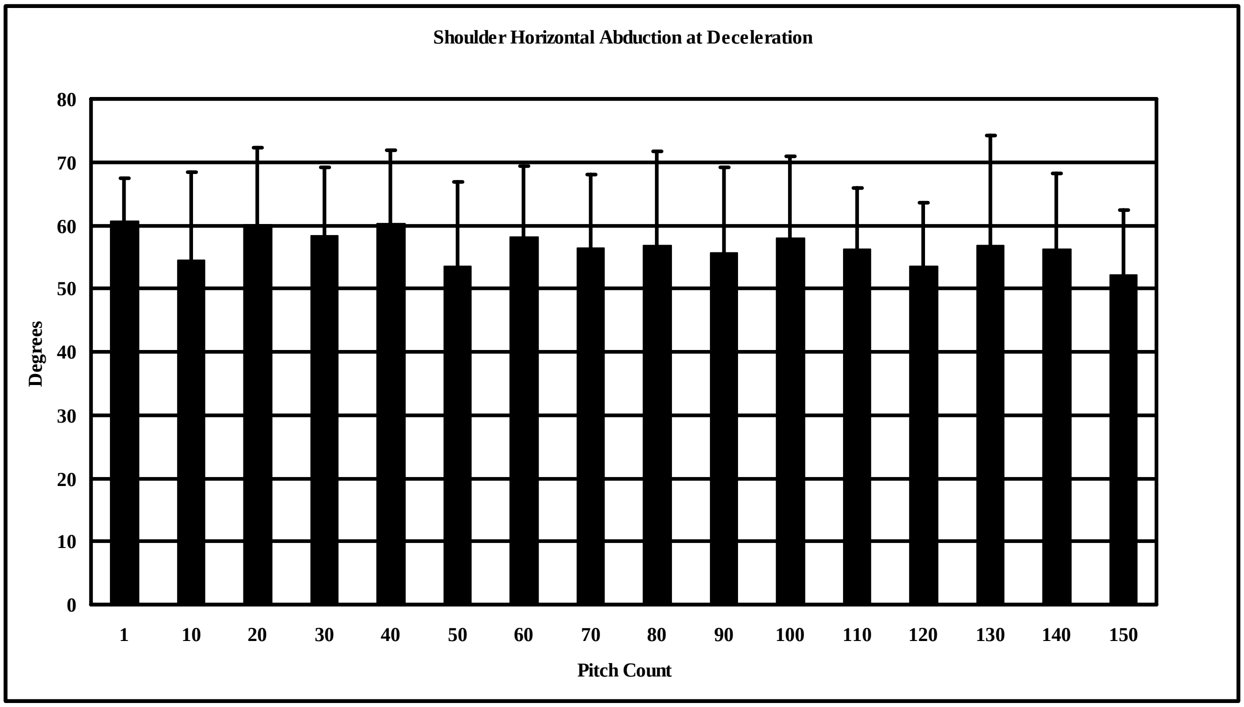


**Figure 37: Shoulder Horizontal Abduction at Deceleration (Group Means + SD)**

### 4.1.3 Elbow Kinematics

#### 4.1.3.1 Elbow Flexion at Early Cocking

No significant differences existed within subjects. Graphical representation of the descriptive statistics (mean) for each pitcher of elbow flexion at early cocking for pitches 1-150 appear in **Figure 38**. Graphical representation of group descriptive statistics (mean and standard deviation) of elbow flexion at early cocking for pitches 1-150 appear in **Figure 39**.

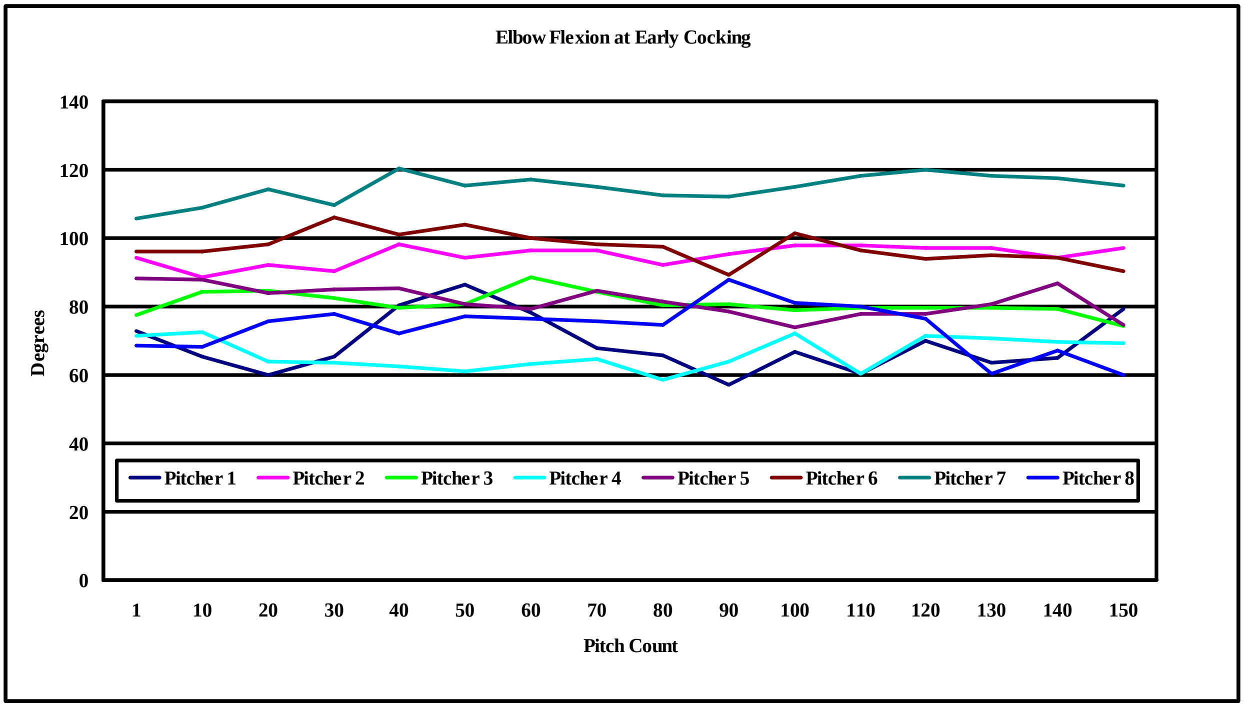


**Figure 38: Elbow Flexion at Early Cocking for Each Pitcher**

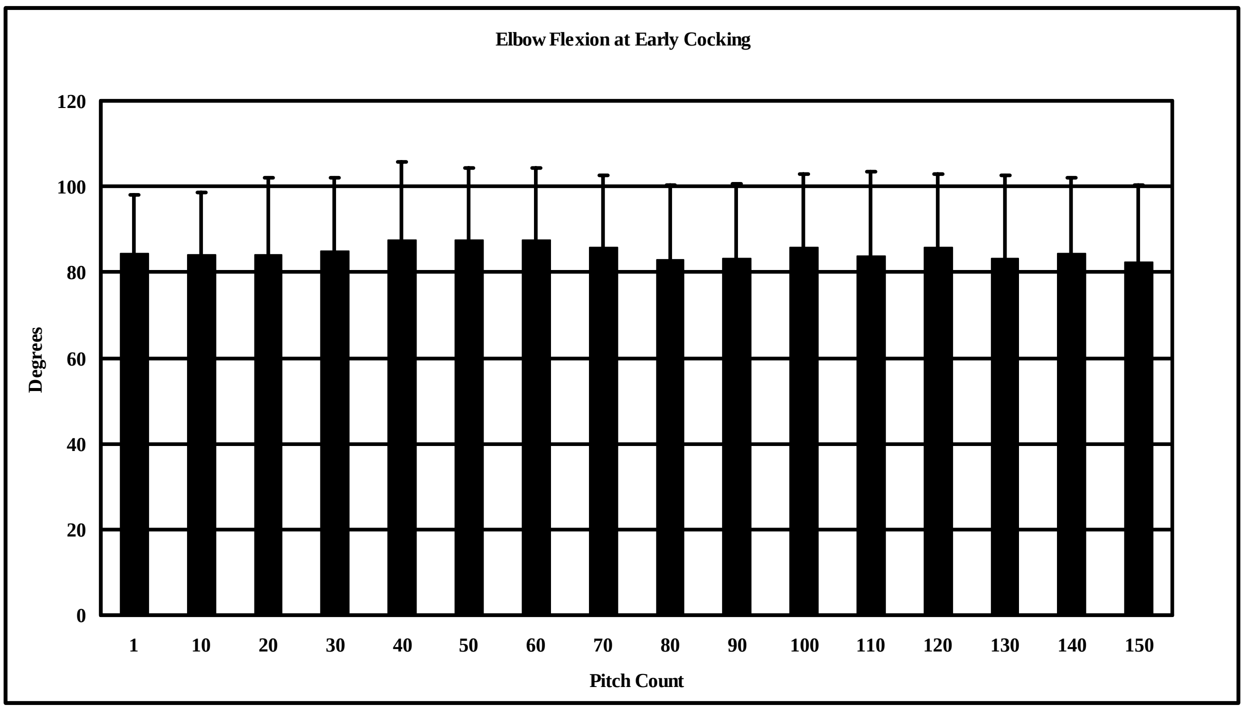


**Figure 39: Elbow Flexion at Early Cocking (Group Means ± SD)**

#### 4.1.3.2 Elbow Flexion at Maximum External Rotation (Late Cocking)

Significant differences existed within subject 8. Elbow flexion at maximum external rotation decreased for subject 8 **(Table 12)**. Graphical representation of the descriptive statistics (mean) for each pitcher of elbow flexion at maximum external rotation for pitches 1-150 appear in **Figure 40**. Graphical representation of group descriptive statistics (mean and standard deviation) of elbow flexion at maximum external rotation for pitches 1-150 appear in **Figure 41**.

**Table 12: Elbow Flexion at Late Cocking for Subject 8**

| Pitch Count | Elbow Flexion |
|---|---|
| 140 | 32.41 |
| 150 | 30.72 |
| **Mean + 2SD** | 207.75 |
| **Mean – 2SD** | 37.98 |

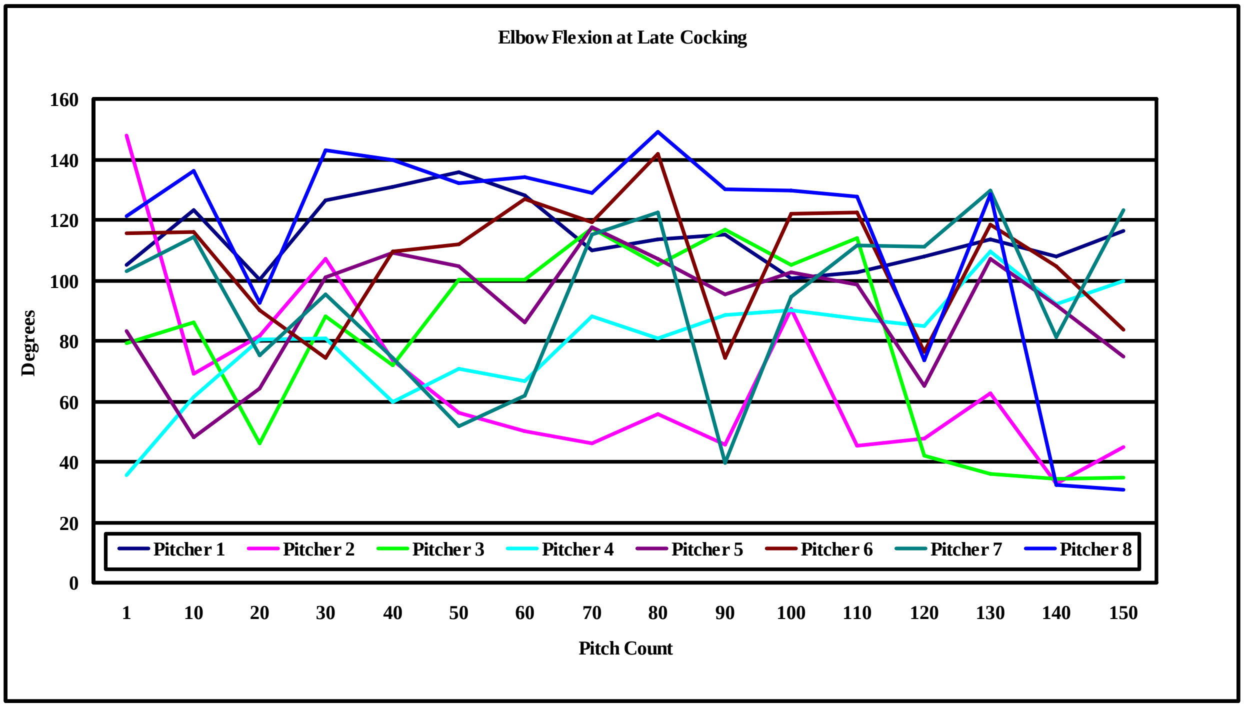


**Figure 40: Elbow Flexion at Late Cocking for Each Pitcher**

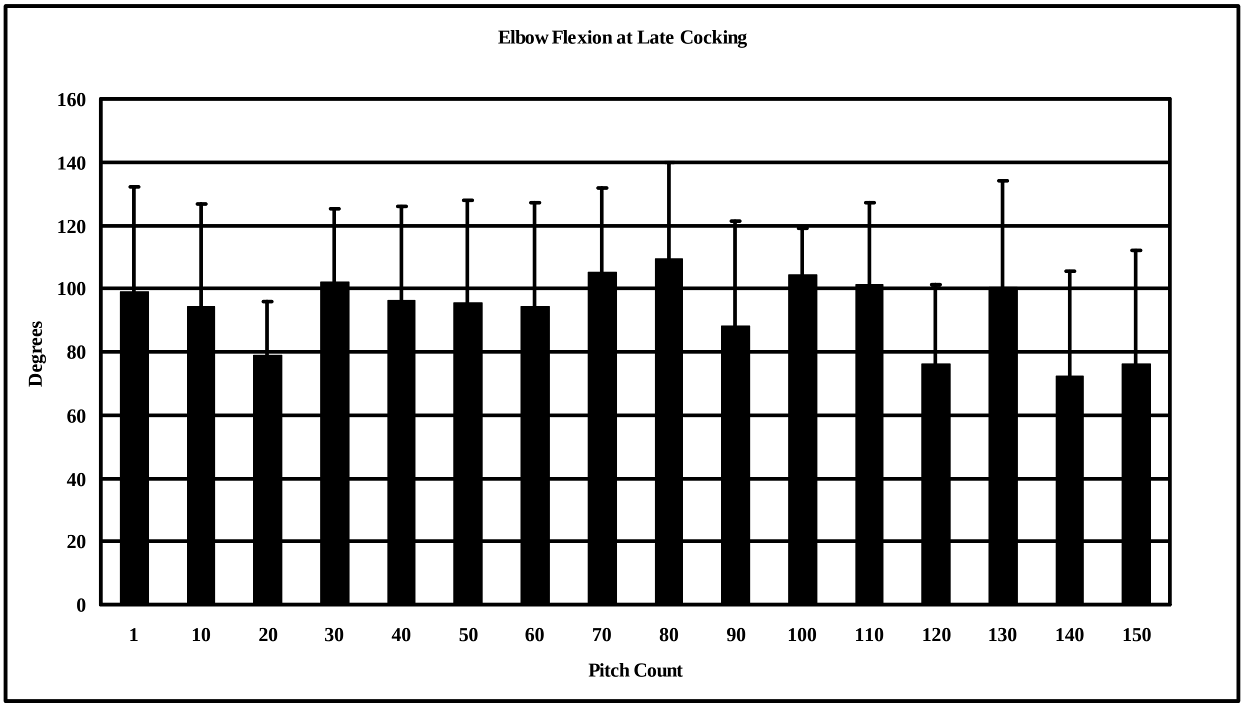


**Figure 41: Elbow Flexion at Late Cocking (Group Means $\pm$ SD)**

### 4.1.3.3 Elbow Flexion at Ball Release

No significant differences existed within subjects. Graphical representation of the descriptive statistics (mean) for each pitcher of elbow flexion at ball release for pitches 1-150 appear in **Figure 42**. Graphical representation of group descriptive statistics (mean and standard deviation) of elbow flexion at ball release for pitches 1-150 appear in **Figure 43**.

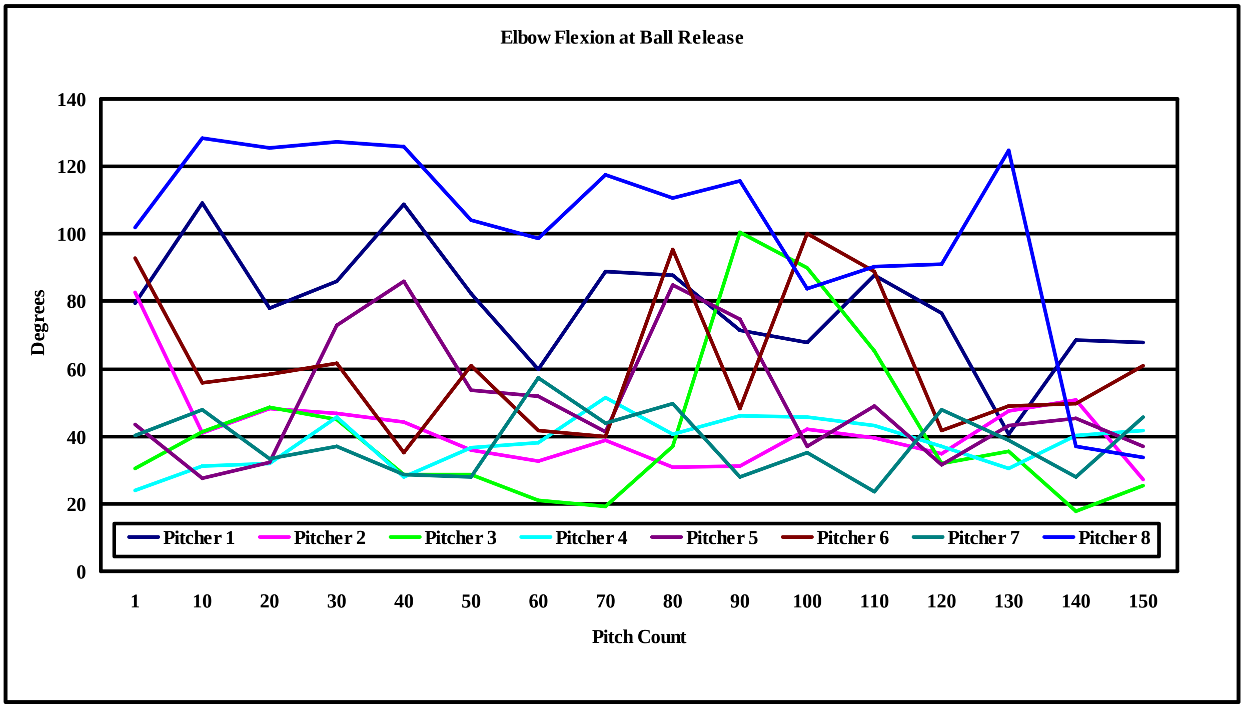


**Figure 42: Elbow Flexion at Ball Release for Each Pitcher**

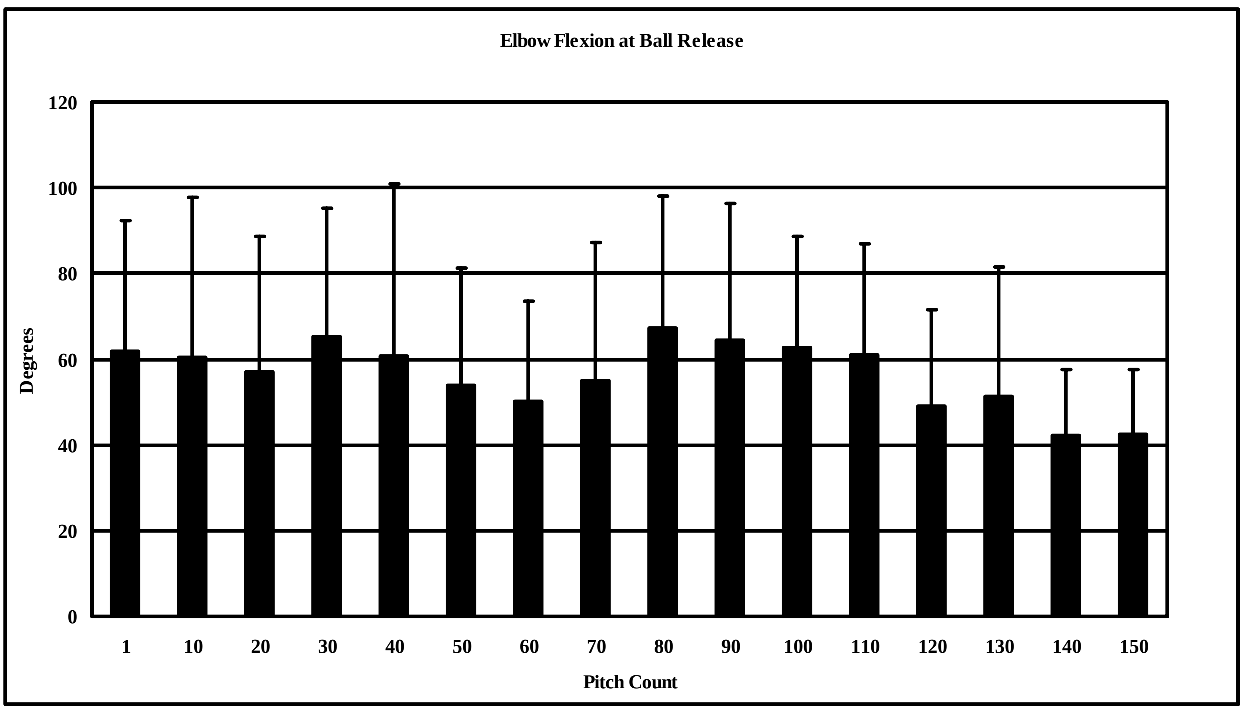


**Figure 43: Elbow Flexion at Ball Release (Group Means ± SD)**

#### 4.1.3.4 <u>Elbow Flexion at Deceleration</u>

No significant differences existed within subjects. Graphical representation of the descriptive statistics (mean) for each pitcher of elbow flexion at deceleration for pitches 1-150 appear in **Figure 44**. Graphical representation of group descriptive statistics (mean and standard deviation) of elbow flexion at deceleration for pitches 1-150 appear in **Figure 45**.

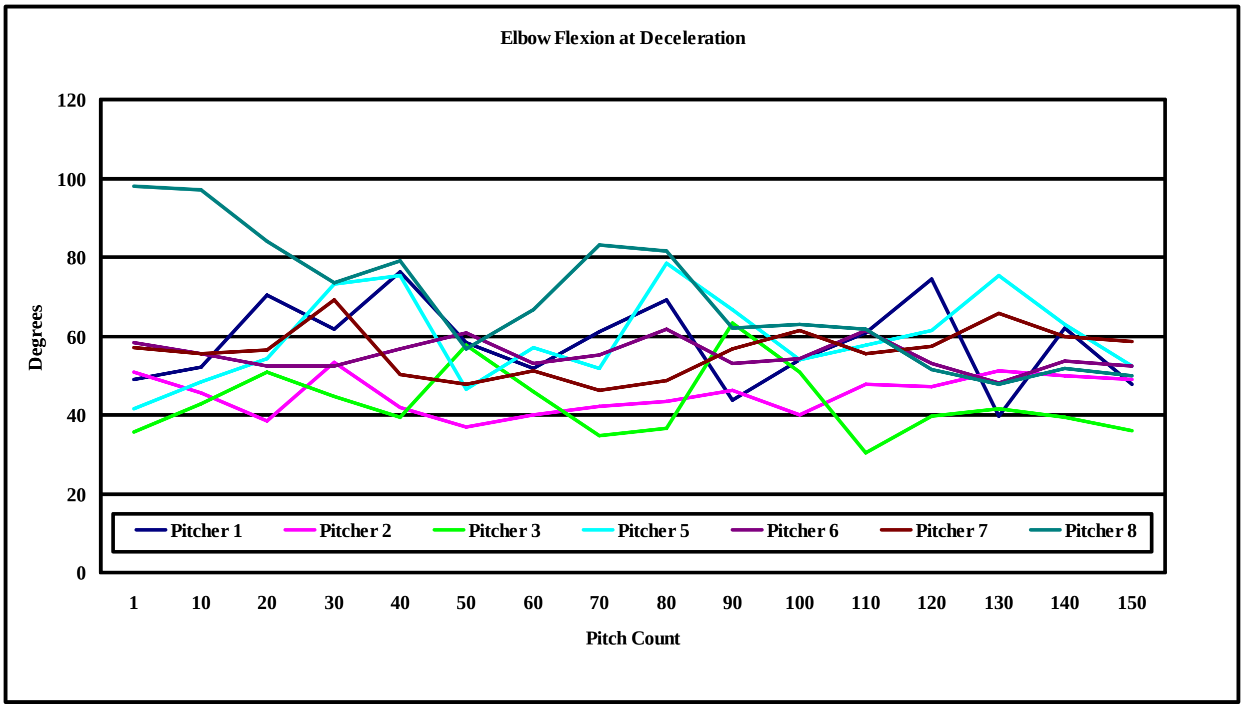


**Figure 44: Elbow Flexion at Deceleration for Each Pitcher**

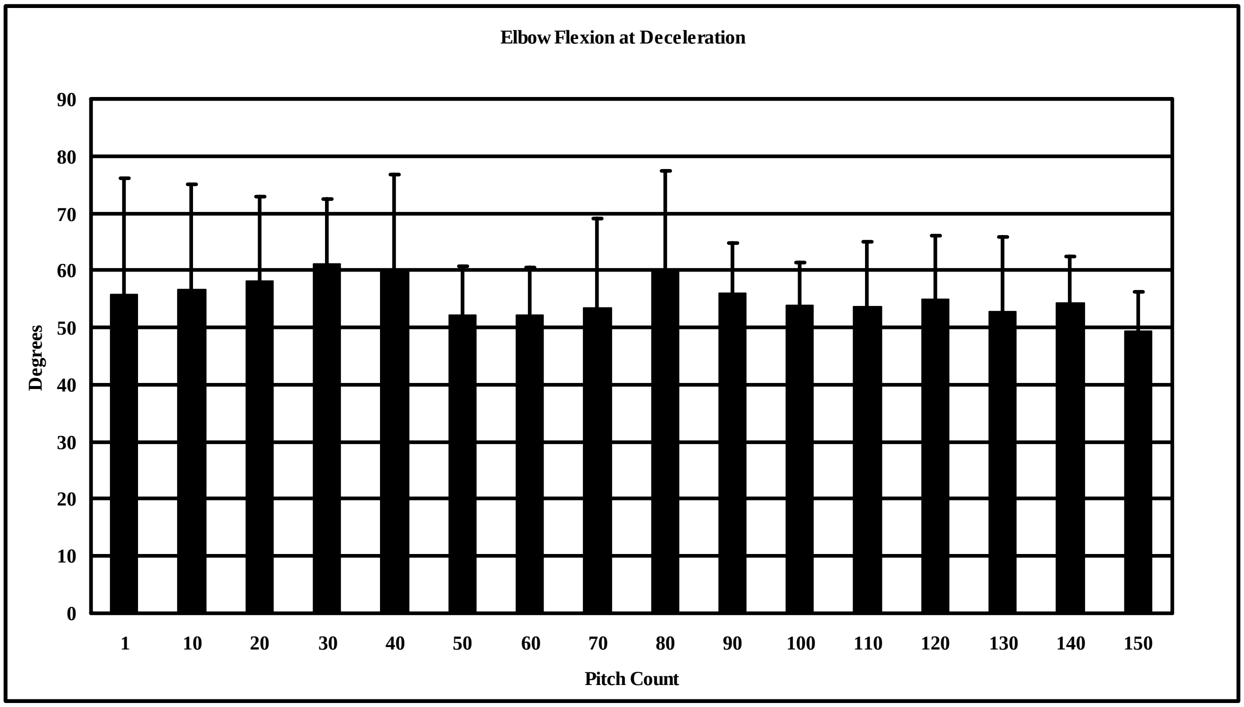


**Figure 45: Elbow Flexion at Deceleration (Group Means ± SD)**

### 4.1.4 Pitch Count Characteristics

As the pitch count increased, changes in shoulder and elbow motion were observed. Both significant and not significant changes appear in **Tables 13, 14, 15,** and **16**.

**Table 13: *Significant and Not Significant Changes within the Pitch Count at Early Cocking**

| | Shoulder Rotation | Shoulder Abduction | Shoulder Horizontal Abduction | Elbow Flexion |
|---|---|---|---|---|
| **Pitch Count** | | | | |
| **1** | | | | |
| **10** | | | | |
| **20** | | | | |
| **30** | | | | |
| **40** | | S3 | | S7 |
| **50** | S2 | | S2 | |
| **60** | | | S2 | |
| **70** | S7 | S6 | | |
| **80** | S5 / S7 | S6 | S2 / S5 | |
| **90** | S5 / S6 | S3 / *S6 / S7 / S8 | S5 / *S6 | S8 |
| **100** | S1 / S5 | *S6 / S8 | S2 / *S6 | |
| **110** | S1 | *S6 / S8 | S2 / S5 / *S6 | S7 |
| **120** | | *S6 | S2 / *S6 | S7 |
| **130** | *S4 | *S6 | S2 / S5 / *S6 | S7 |
| **140** | S2 / *S4 / *S5 / S8 | *S6 / S7 | S1 / S2 / *S6 | |
| **150** | *S4 / *S5 | S3 / *S6 | S5 / *S6 | |

**Table 14: *Significant and not Significant Changes within the Pitch Count at Late Cocking**

| | Shoulder Rotation | Shoulder Abduction | Shoulder Horizontal Abduction | Elbow Flexion |
|---|---|---|---|---|
| **Pitch Count** | | | | |
| **1** | | | | |
| **10** | | | | |
| **20** | | | | |
| **30** | | | | |
| **40** | | S6 | | |
| **50** | | | | |
| **60** | | | | |
| **70** | | | S7 | |
| **80** | | | | |
| **90** | | | | |
| **100** | | | | |
| **110** | | | | |
| **120** | | | | |
| **130** | | | | |
| **140** | | | *S8 | *S8 |
| **150** | | | *S8 | *S8 |

**Table 15: *Significant and Not Significant Changes within the Pitch Count at Ball Release**

| | Shoulder Rotation | Shoulder Abduction | Shoulder Horizontal Abduction | Elbow Flexion |
|---|---|---|---|---|
| **Pitch Count** | | | | |
| **1** | | | | |
| **10** | | | | |
| **20** | | | | |
| **30** | | | | |
| **40** | | | | |
| **50** | | | S1 | |
| **60** | | | S1 | |
| **70** | | | | |
| **80** | | | | |
| **90** | | S6 | | S3 |
| **100** | | | | S3 |
| **110** | | | S1 | |
| **120** | | | | |
| **130** | | | | |
| **140** | | *S6 | | |
| **150** | | *S6 | | |

**Table 16: *Significant and Not Significant Changes within the Pitch Count at Deceleration**

| | Shoulder Rotation | Shoulder Abduction | Shoulder Horizontal Abduction | Elbow Flexion |
|---|---|---|---|---|
| Pitch Count | | | | |
| 1 | | | | |
| 10 | | | | |
| 20 | | | | |
| 30 | | | | |
| 40 | | S6 | | |
| 50 | | S6 | | |
| 60 | | | | |
| 70 | *S3 / S7 | | | |
| 80 | *S3 / S5 | | | |
| 90 | *S3 / S7 | S6 | | |
| 100 | *S3 / S5 / S7 | | | |
| 110 | *S3 / S7 | | | |
| 120 | *S3 | S6 | | |
| 130 | *S3 / *S7 | | | |
| 140 | *S3 / *S7 | | | |
| 150 | *S3 / *S7 | S6 | | |

### 4.1.5 Accuracy Measurements

#### 4.1.5.1 Pitch Velocity

Pitch velocity was measured using a radar gun. The descriptive statistics (mean and standard deviation) for each pitcher appear in **Table 17**. Graphical representation of velocity within subject for each subject appears in **Figure 46**.

**Table 17: Pitch Velocity (Mean and SD)**

| | Pitcher 1 | Pitcher 2 | Pitcher 3 | Pitcher 4 | Pitcher 5 | Pitcher 6 | Pitcher 7 | Pitcher 8 |
|---|---|---|---|---|---|---|---|---|
| **Mean** | 66.68 | 71.46 | 66.69 | 72.75 | 70.41 | 68.44 | 72.69 | 72.45 |
| **SD** | 1.85 | 2.39 | 2.32 | 1.751 | 2.58 | 1.41 | 1.54 | 6.18 |

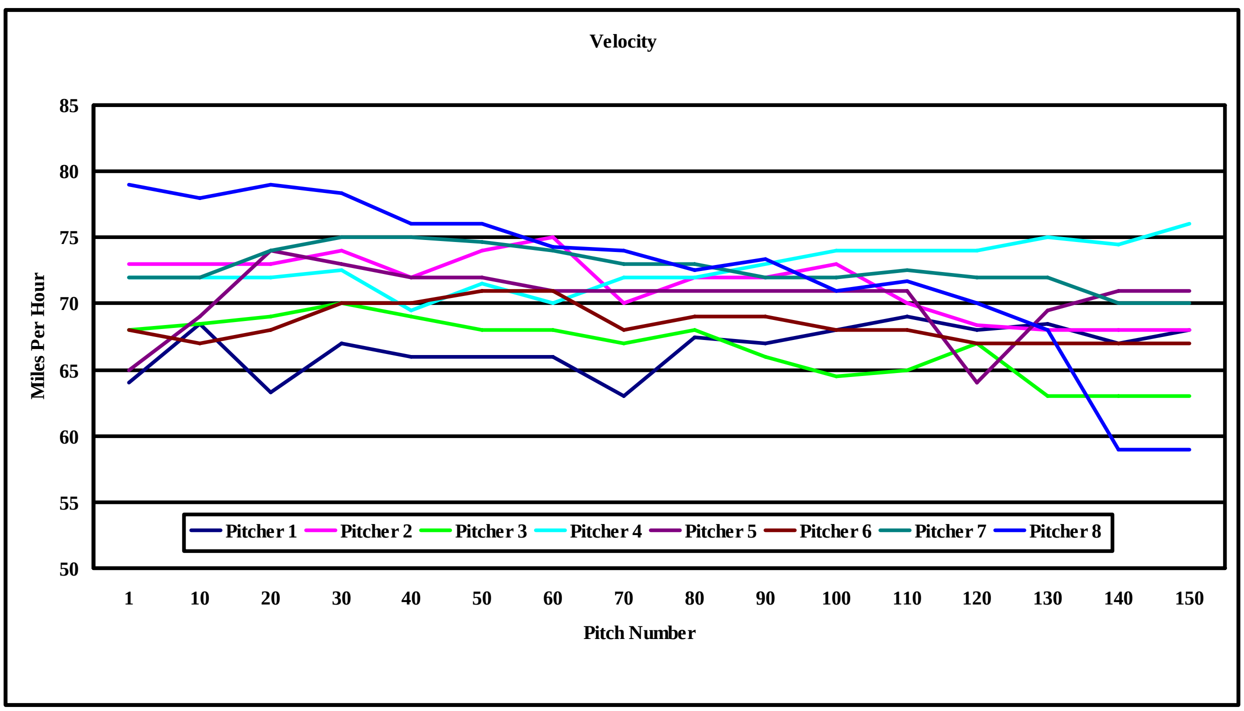


**Figure 46: Velocity for Each Pitcher (Pitches 1-150)**

### 4.1.5.2 Strike Accuracy

Strike accuracy was measured by consistency of the ball hitting a strike zone on a pocket net distanced at 40 feet. Graphical representation of strike percentage for fastball during collection appears in **Figure 47.** Graphical representation of strike percentage for all pitches (i.e. fastball, curve ball and change-up) during the simulated game appears in **Figure 48**. Performance of strike accuracy for each pitcher over the course of the game appears in **Figures 49, 50, 51, 52, 53, 54, 55, and 56.**

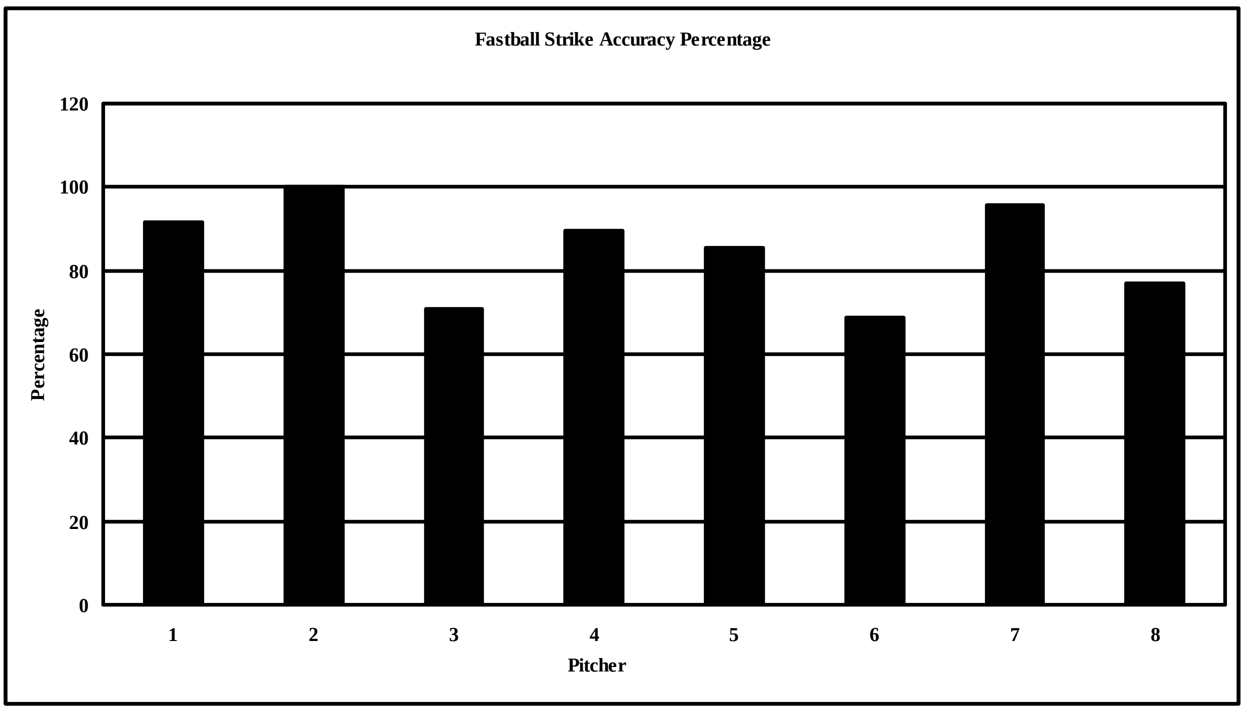


**Figure 47: Strike Accuracy Percentage for Fastballs**

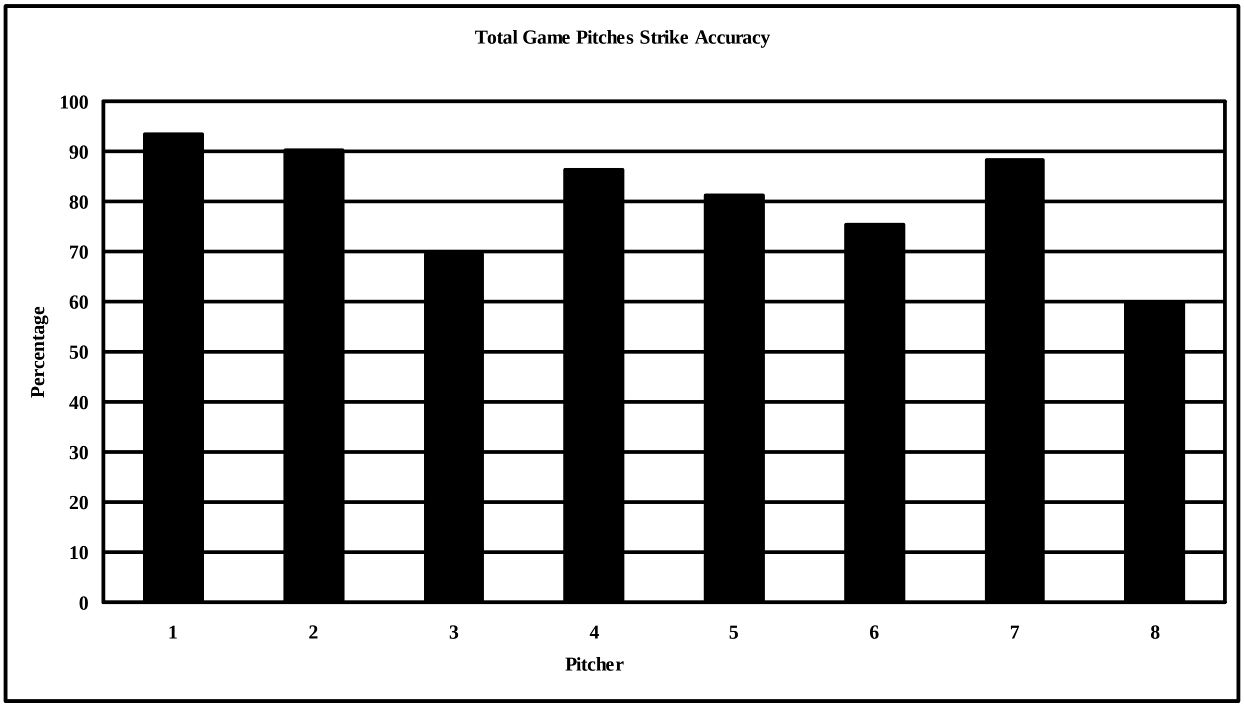


**Figure 48: Strike Accuracy Percentage for Fastball, Curveball, and Change-up**

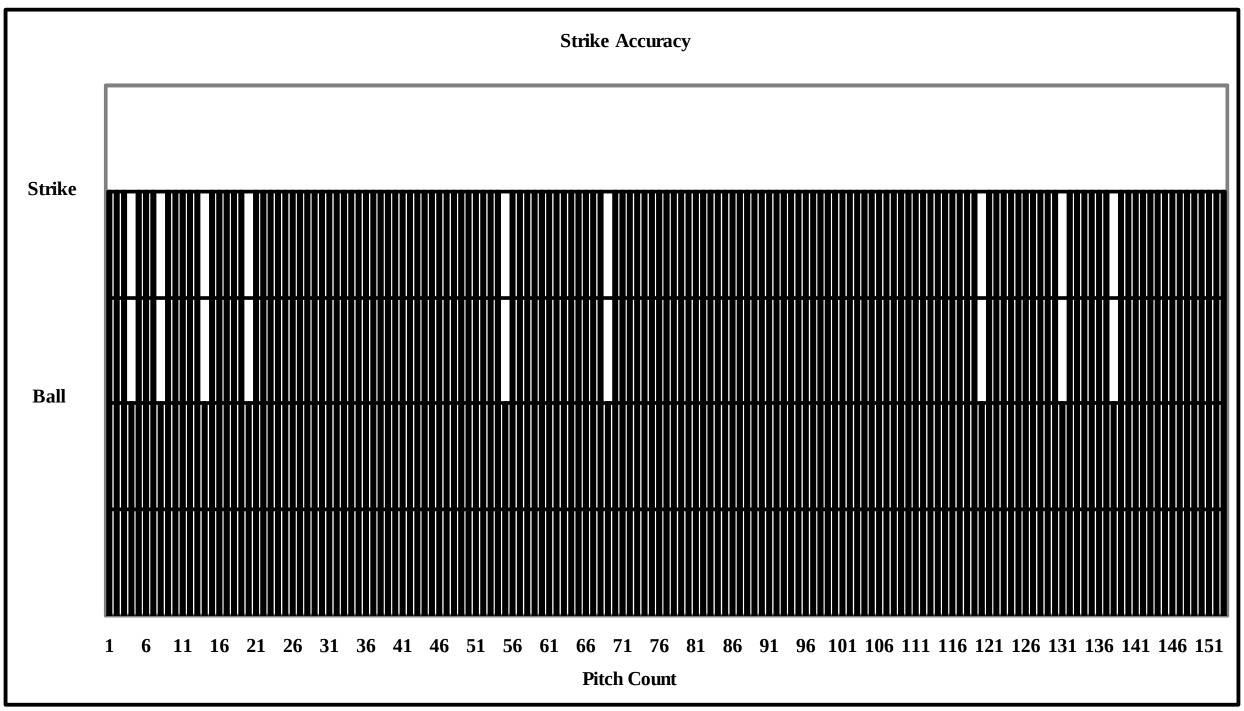


**Figure 49: Strike Accuracy for Entire Game for Pitcher 1**

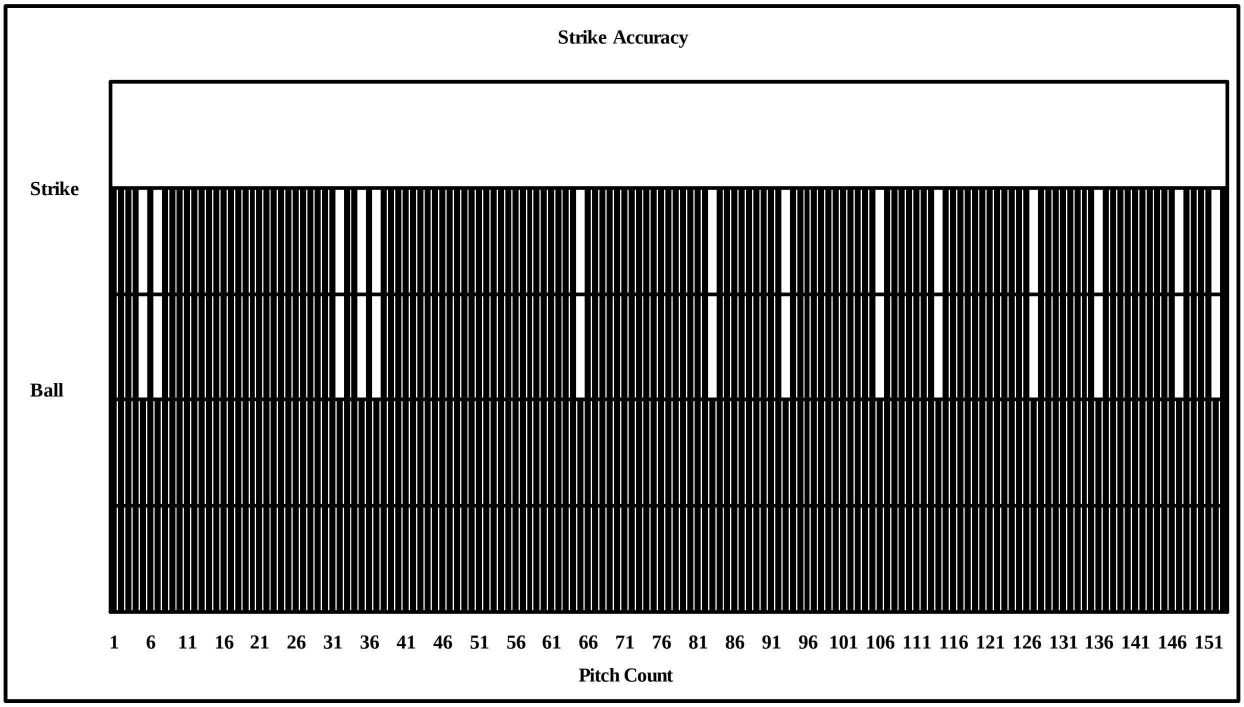


**Figure 50: Strike Accuracy for Entire Game for Pitcher 2**

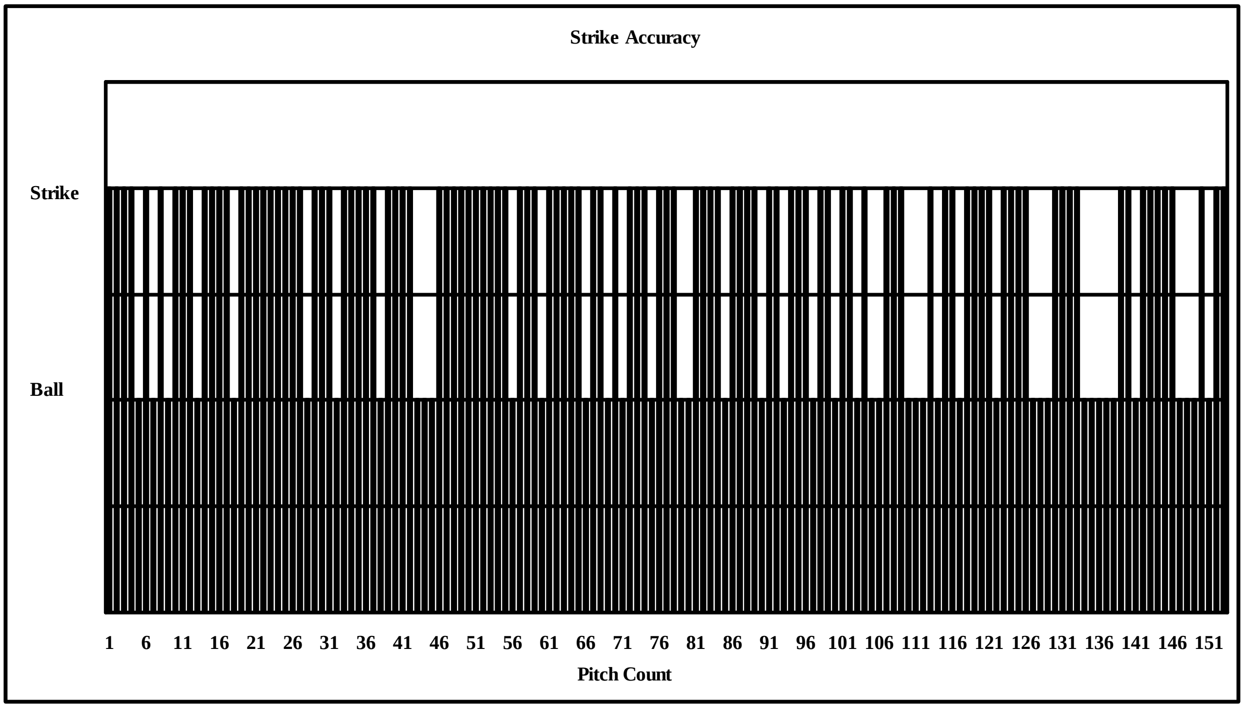


**Figure 51: Strike Accuracy for Entire Game for Pitcher 3**

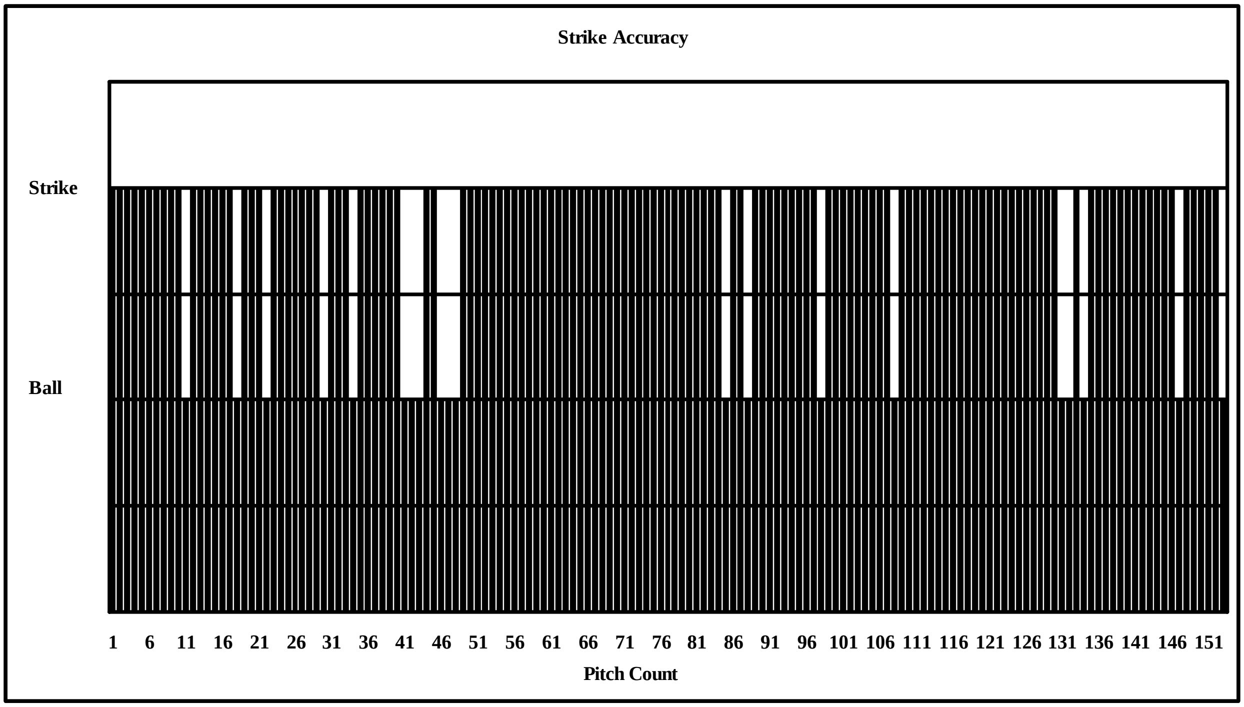


**Figure 52: Strike Accuracy for Entire Game for Pitcher 4**

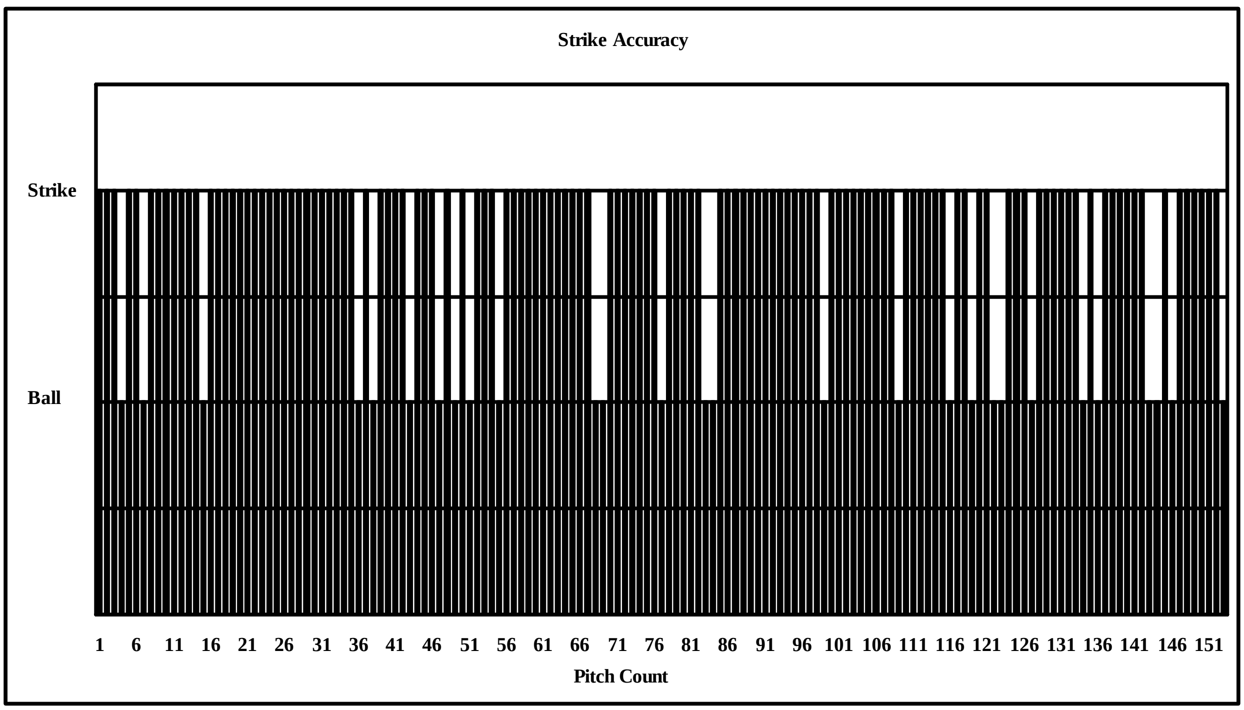


**Figure 53: Strike Accuracy for Entire Game for Pitcher 5**

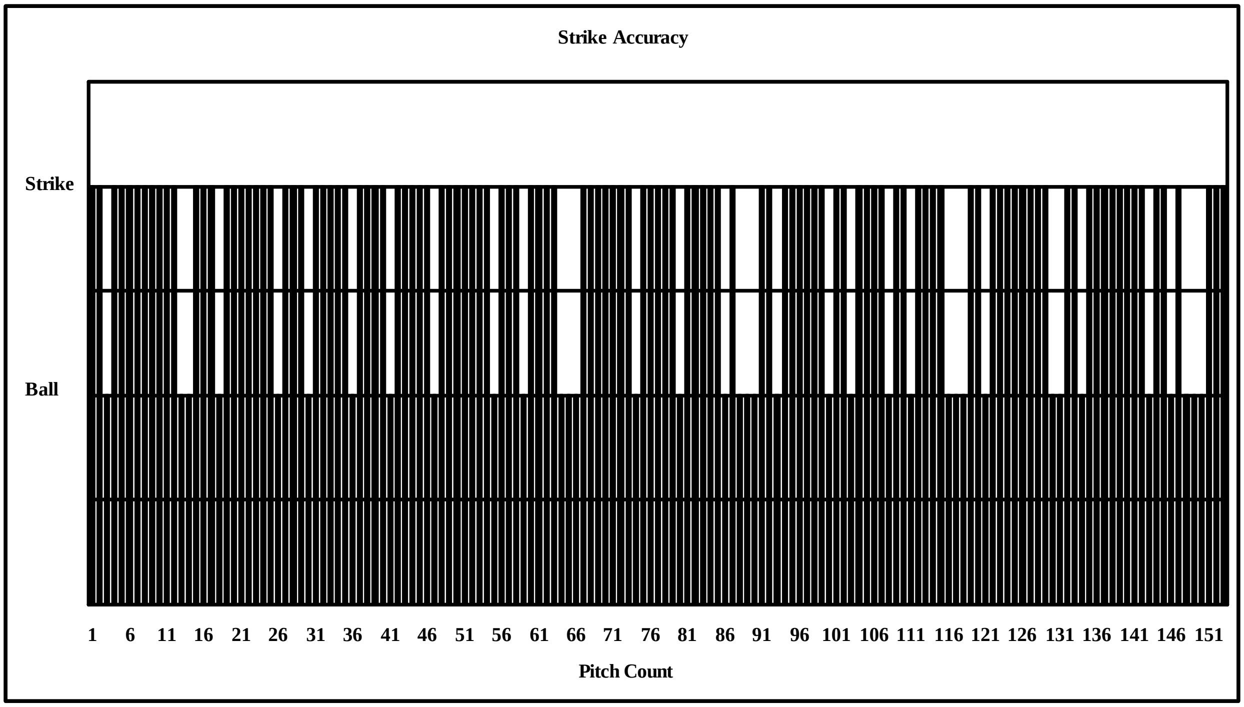


**Figure 54: Strike Accuracy for Entire Game for Pitcher 6**

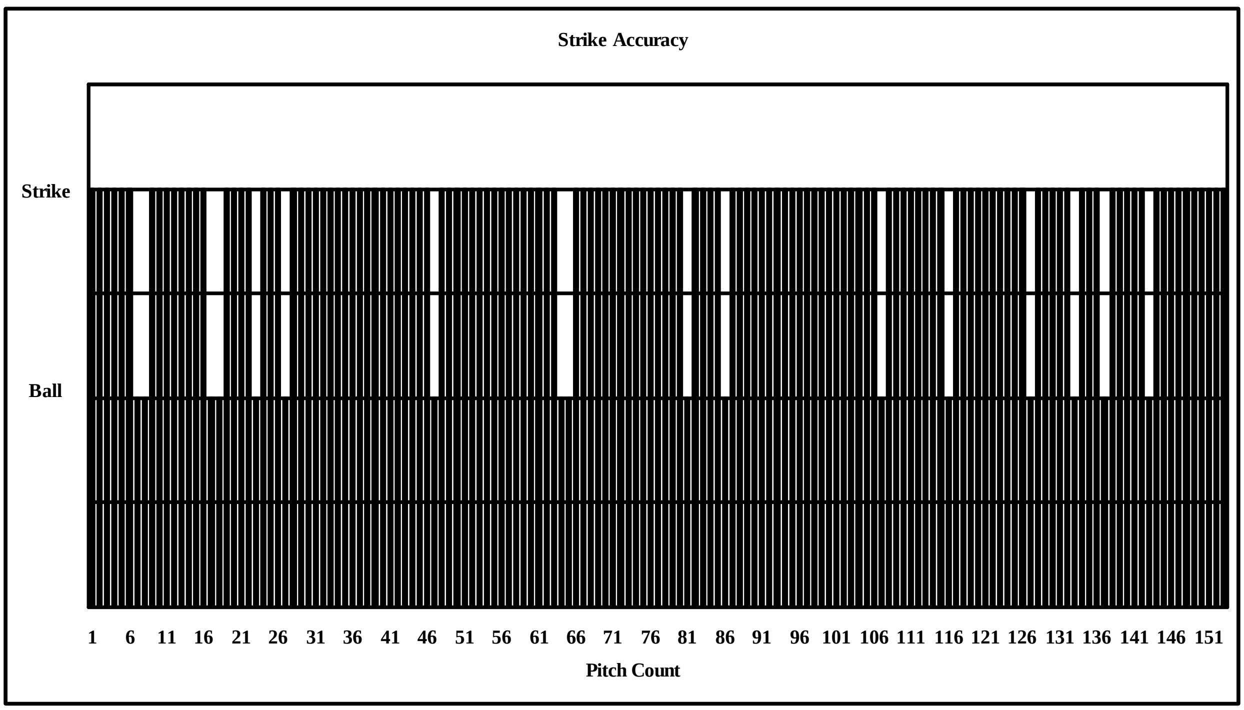


**Figure 55: Strike Accuracy for Entire Game for Pitcher 7**

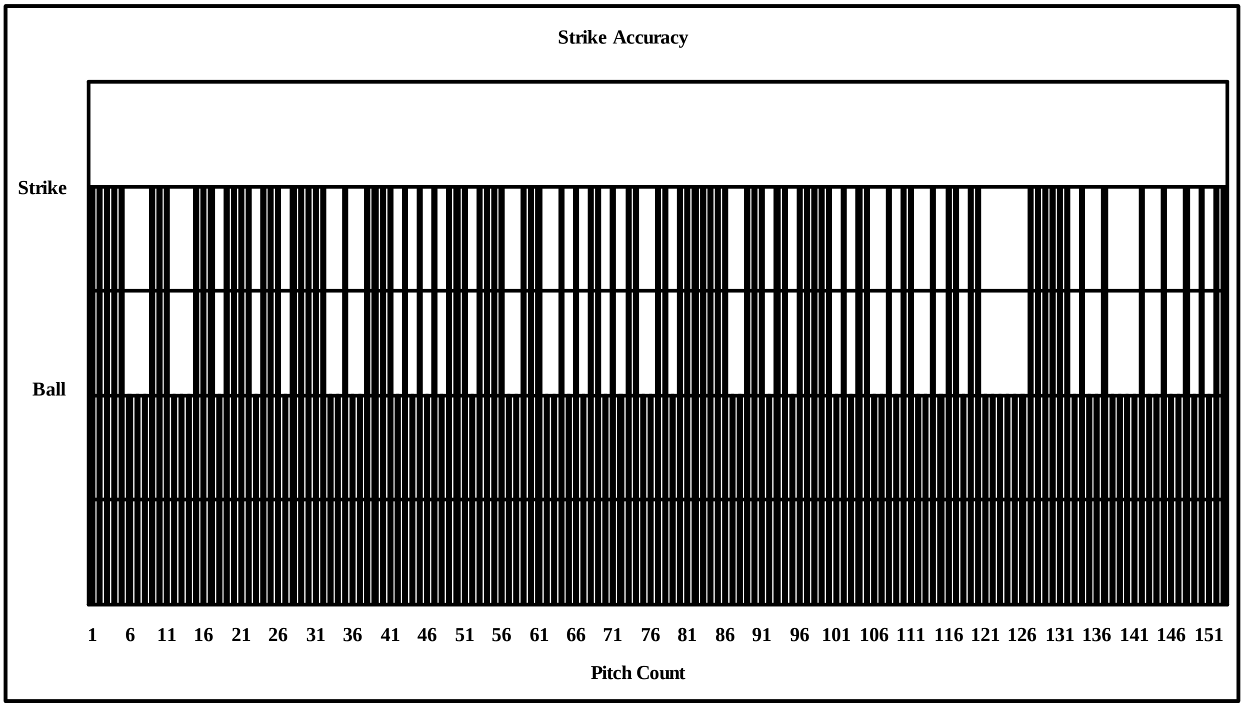


**Figure 56: Strike Accuracy for Entire Game for Pitcher 8**

# 5 Chapter 5

## 5.1 Discussion

Several studies have been conducted investigating the biomechanics of pitching [1, 5, 7-9]. These previous studies all reported high compressive and distractive forces for shoulder external rotation, elbow flexion with a maximum varus torque, shoulder adduction torque, and elbow extension. However, these studies did not investigate the effect of true extended play during an entire game as pitch count increased. Instead they focused on the number of innings the pitcher threw and a limited amount of actual pitches. In no way did any of these investigators quantify a pitch count for any of the pitchers, nor did they capture where in the pitch count these pitchers were experiencing changes in their mechanics. The purpose of this research was to quantify kinematic arm motions as a result of increased pitch count of collegiate baseball pitchers, and to investigate where in the pitch count kinematic changes occurred. More specifically, changes in shoulder and elbow kinematics were investigated as the pitch count increased. Our overall hypothesis was that as pitch count increased, abnormal throwing mechanics would result.

The results of this investigation indicated that differences existed for shoulder rotation at early cocking, shoulder rotation at deceleration, shoulder abduction at early cocking, shoulder abduction at ball release, shoulder horizontal abduction at early cocking, shoulder horizontal abduction at maximum external rotation, and elbow flexion at maximum external rotation were evident in several of the pitching participants. No differences were observed for shoulder rotation at maximum external rotation or ball release; for shoulder abduction at maximum external rotation or deceleration; for shoulder horizontal abduction at ball release or deceleration; or for elbow flexion at early cocking, ball release, or deceleration. A detailed discussion of these results as they relate to increase in pitch count will follow.

### 5.1.1 Observed Changes in Shoulder Rotation

It was hypothesized shoulder external rotation would decrease during early cocking, late cocking, and acceleration phases. It was also hypothesized that internal rotation would increase during the deceleration phase. Significant differences for shoulder rotation existed for subjects 3, 4, 5, and 7. Subject 4 experienced an increase in shoulder external rotation for pitches 130-150 at foot contact. Subject 5 experienced a decrease in external rotation for pitches 140-150 at foot contact. Subject 3 experienced a decrease in external rotation for pitches 70-150 during deceleration. Subject 7 experienced a decrease in external rotation for pitches 130-150 during deceleration. While subject 2 does not support the hypothesis of this investigation, subject 5 did support the hypothesis that a decrease in external rotation during the early cocking phase would occur. Subjects 3 and 7 also support the hypothesis of this investigation that shoulder internal rotation would increase during deceleration. No significant differences existed for shoulder rotation during the late cocking or acceleration phases, which does not support our overall hypothesis that alterations in kinematics of the shoulder would be observed.

The results for subject 4 showed an increase in shoulder external rotation at foot contact. These results are supported by Barrentine et al., [27] whose group also observed an increase in shoulder external rotation at foot contact. However, the results of subject 5 do not mimic the study previously mentioned. None of these studies using a simulated game or live game reported results for shoulder external rotation during deceleration. Werner et al. [17] reported that a regression analysis revealed maximum external rotation to be statistically significant. It was also determined that throwers with more limited ranges of shoulder external rotation at the end of the cocking phase tended to have less distraction at the shoulder. Murray et al. [28] reported a 9° decrement for shoulder maximum external rotation between the first inning pitched (181°) and the last inning pitched (172°). Unlike Werner and Murray, this study did not find significant differences for shoulder rotation at maximum external rotation.

### 5.1.2 Observed Changes in Shoulder Abduction

It was hypothesized that shoulder abduction would decrease during deceleration at the instant of ball release. Significant differences existed for subject 6 for shoulder abduction for pitches 70-150 at foot contact and for pitches 140-150 at ball release. Shoulder abduction increased during the early cocking phase at foot contact and during acceleration at the instant of ball release. Although the results of this investigation does not support our hypothesis that shoulder abduction would decrease at the instant of ball release, it does support our hypothesis that shoulder abduction would alter as pitch count increased.

Barrentine et al. [27] reported an increase in shoulder abduction at foot contact (early cocking), but a decrease in shoulder abduction at ball release. This published data is similar to this study in that the results of this investigation showed an increase in shoulder abduction at early cocking. However, the results of this study for shoulder abduction at ball release from the previously mentioned study. This difference could suggest a change in mechanics due to fatigue because the significant differences occurred toward the end of the simulated game.

### 5.1.3 Observed Changes in Shoulder Horizontal Abduction

It was hypothesized that shoulder horizontal abduction would increase during the acceleration phase. Significant differences for shoulder horizontal abduction existed for subjects 2, 6, and 8. Subject 2 experienced a decrease in shoulder horizontal abduction for pitches 110-150 at early cocking. Subject 6 experienced a decrease in shoulder horizontal abduction for pitches 90-150 at early cocking. Subject 8 experienced a decrease in shoulder horizontal abduction for pitches 140-150 at maximum external rotation. While the results of this investigation do not support our specific hypothesis that shoulder horizontal abduction would increase during the acceleration phase, it does support the overall hypothesis that kinematic alterations of the shoulder would be observed.

The results of this investigation are comparable to Barrentine et al. [27], who reported a decrease in shoulder horizontal abduction at foot contact (early cocking). Subject 2 and subject 6 both experienced a decrease in shoulder horizontal abduction at early cocking. Subject 8 experienced a decrease in shoulder horizontal abduction later in the game at maximum external rotation.

Werner et al. [17] and Murray et al. [28] both reported a decrease in the horizontal abduction torque over the course of the game. The significant decrease in shoulder horizontal abduction may be due to altered mechanics due to a decrease in horizontal adduction torque. It has been suggested by other authors that as the shoulder horizontally adducts and internally rotates through the deceleration phase that distraction forces may make the joint susceptible to pathologic conditions of both the rotator cuff and glenoid labrum [45, 47, 58, 67, 68, 84, 85]. Further research correlating kinematics and kinetics is needed to determine what is happening with forces at the shoulder as horizontal abduction is decreasing over the course of the game.

### 5.1.4 Observed Changes for Elbow Flexion

It was hypothesized that kinematic alterations of the elbow would be observed. Significant differences for elbow flexion existed for subject 8. Subject 8 experienced a decrease in elbow flexion at maximum external rotation during the late cocking phase of throwing for pitches 140-150. While the results of subject 8 supports our hypothesis, there were no significant differences for elbow flexion observed during the early cocking, acceleration, and deceleration phases for subject 8 or the other seven subjects.

Both Werner et al. [21] and Feltner and Dapena [86] reported elbow flexion to remain nearly constant until shortly before maximum external rotation. The elbow then extended from 85° of flexion to 20° of extension (Werner et al.) and 89° of flexion to 20° of extension(Feltner and Dapena) near the time of ball release. The results of subject 8 in this investigation are comparable to the change in flexion for maximum external rotation. This decrease might account for any increased extension in during ball release. Werner et al. [21] also reported that pitchers with more flexed elbows at foot contact incurred less shoulder distraction. Pitchers who demonstrated increased elbow flexion as the ball was released also appeared to have lesser degrees of shoulder distractions. Based on these studies, it is possible to assume that mechanism of injury due to less degrees of elbow flexion increases as extension of the elbow increases at foot contact and at ball release.

### 5.1.5 Observed Changes in Pitching Performance

Ball velocity appeared to follow a similar trend for all pitchers, decreasing in speed as the pitch count increased. As reported in Table 16, the velocities for each pitcher appear low in speed. Each pitcher was asked what their usual clocked speed for a fastball was during collegiate competition. All reported throwing 10 to 15 miles per hour faster than what they were clocked by our radar gun. This may be due to the shortened distance from the pitcher to the net in the laboratory setting. Also, the assistant recording the radar gun was unable to stand far enough away from the pitcher, allowing human error which may have detected the speed of the moving limb. Pitchers 3, 4, 5, 6, 7, and 8 demonstrated a decrease in performance for strike accuracy as the pitch count increased **(Figures 51, 52, 53, 54, 55, 56)**.

### 5.1.6 Limitations of Study

Limitations of this study include but are not limited to a laboratory setting simulated game, length of testing session, low number of subject participation, and kinematic and kinetic analysis for other parameters. This simulated game was conducted in a laboratory setting. Although measures were taken to best reproduce a game situation, it was still a simulated game indoors, without encouragement from coaches, teammates, or fans. Also, this study was conducted on a flat surface. Pitching mechanics may have been altered if the subject had thrown from a mound and threw regulation distance. The testing session took approximately 2-1/2 hours to complete. This is a long period of time to stay focused. Subjects may have been distracted by outside factors such as lack of concentration as the pitch count increased. The investigators continued to encourage subjects to try to account for the lack of outside encouragement and to keep subjects focused on the task. Kinematic and kinetic analysis of other parameters for both upper and lower extremity would have add greatly to the knowledge and information that this study had already reported. This data was collected but not analyzed for the current document. Finally, the low number of subject recruitment is a limitation of this study. Based on the data from this study, a power analysis determined that a p value of .80 yielded 31.65 subjects to be statistically significant.

### 5.1.7 Clinical Significance

The results of this study indicate that overuse injuries may be lessened if proper recommendations are followed by the athletic trainer, coach, and the athlete.
This study indicated that significant differences in pitching mechanics are occurring around pitch 70 of the pitch count. It is imperative to use this quantification of the pitch count as a guide for better assessment of fatigue and kinematic and kinetic changes that result in alterations in pitching mechanics. It is important for athletic trainers, coaches, and athletes to watch for changes in mechanics that may result in micro-trauma injuries from repetitive improper mechanics. If pitch count is used to gauge individual pitching time, injury potential, need for surgical interventions, and time spent for rehabilitation may all decrease. This will result in a healthier, longer career for not just the elite baseball player, but for players of all ages.

### 5.1.8 Conclusion

This investigation demonstrated that differences manifested for shoulder rotation at early cocking, shoulder rotation at deceleration, shoulder abduction at early cocking, shoulder abduction at ball release, shoulder horizontal abduction at early cocking, shoulder horizontal abduction at maximum external rotation, and elbow flexion at maximum external rotation, as pitch count increased. These results demonstrate the importance of the pitch count as a guide for better assessments for fatigue and changes in pitching mechanics. Future research investigating kinematics and kinetics parameters of both the upper and lower body would better enforce the results of this study and provide coaches, athletic trainers, and players with more information that may prevent injury.

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