INTRA-ATHLETE VARIABILITY IN PITCHING BIOMECHANICS AT THE SHOULDER JOINT

By

Kyle Sheaffer, B.S.
East Stroudsburg University of Pennsylvania

A Thesis submitted in Partial Fulfillment of
The Requirements for the Degree of
Master of Science in Exercise Science
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ABSTRACT

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Exercise Science to the Office of Graduate and Extended Studies of East Stroudsburg University of Pennsylvania

Students Name: Kyle Sheaffer

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Thesis Chair: Gavin Moir, Ph.D.

Thesis Member: Shala E. Davis, Ph.D.

Thesis Member: Donald Cummings, Ph.D.

Abstract
Introduction*:* Human variability is defined as the possible values for any measurable inconsistent characteristics in human beings. New studies are showing that elite athletes are not able to perform skills without variability in their movements. Many coaching techniques stress repetitious training which can lead to overuse injuries. The discovery of variability in athletes form may help to change training techniques to exercises that will help promote variability in athletes form and prevent overuse injuries. **Purpose:** The purpose of this study is to evaluate the variability in the shoulder biomechanics of DII college baseball pitchers during their pitching motion**. Subjects:** Five NCAA division II baseball pitchers (mean age: 19.4 ± 1.5 yrs; mean mass: 83.4 ± 3.3 kg) from a university in the northeast part of the United States participated in the study. Each pitcher performed between 12 and 15 pitches with their motion recorded using an 8-camera 3D system (Vicon). Three dimensional angles at the shoulder, elbow, and wrist were calculated and comparisons were made between maximal external rotation of the shoulder, maximal elbow flexion and maximal wrist flexion of each trial for each individual athlete. The average joint angles and standard deviations across the trials were then calculated. **Results:** The average values for maximal external shoulder rotation were greater than for both elbow flexion and wrist flexion for all subjects. The variability in the joint angles ranged from small (1.09 degrees) to large (4.87 degrees), with no joint demonstrating greater variability than any other across the five subjects. Similarly, each subject demonstrated their largest variation at a different joint. **Conclusion:** The existence of variability in the motion of these trained pitchers implies that consistency is not achieved in terms of the upper-body kinematics. Furthermore, each subject appeared to demonstrate an individual movement pattern despite the goal of the skill being consistent. This suggests that coaches should avoid relying on a single ‘optimal model’ when skill acquisition is required in multi-joint, ballistic movements.

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INTRODUCTION

Human variability is defined as the possible values for any measurable inconsistent characteristic in human beings (Bartlett, Wheat, & Robins, 2007). In the past, sports biomechanists assumed that intra-individual variability in movement patterns was not an important issue to research when looking at elite training and coaching methods of movement patterns and coordination. More recent studies have demonstrated that high performing athletes, while producing the same outcomes, have variability in their form and movement patterns (Bartlett et. al 2007). If variability becomes a common theme in elite athletes, the coaching techniques may start to move away from repetitious muscle memory training to a wider scope of exercises that will help promote variability in mechanics. This may also prevent overuse injuries that can occur from repetitious exercises (Matt, 2002).

In the sport of baseball, a pitcher's goal is to make an accurate, hard throw. This involves a synchronized sequence of four motions: a stride, hip rotation, trunk rotation, and arm movement. The goal of these sequences of motions is to achieve maximal hand velocity which in return creates maximal ball velocity (Vaughn, 1996).

The movements that occur at the shoulder when going through a pitching motion are complex and can be more easily understood when broken down into six phases, the wind up, stride, arm cocking, arm acceleration, arm deceleration, and the follow through. The windup phase begins when the pitcher steps back with his front foot and positions his back foot against the rubber. The windup phase ends when the front leg is at its maximum height and the two hands begin to separate. During the stride phase, a pitcher moves his front foot toward home plate as the two arms swing down and apart from each other. The stride phase ends when the front foot touches the mound. During the arm cocking phase, the pelvis and then upper trunk rotate to face home plate as the throwing arm externally rotates at the shoulder. The arm cocking phase ends when the shoulder reaches its maximum external rotation. The arm acceleration phase is from the instant of maximum shoulder external rotation until ball release. From ball release until the arm stops internally rotating is defined as the arm deceleration phase. Follow-through begins with maximum shoulder internal rotation and ends when the pitcher regains a balanced position (The American Sports Medicine Institute, 2007).

A 3-D camera system can be used to analyze the kinematics of the pitching movement and assess the variability during the pitching movement of college baseball players.

Purpose

The purpose of this study is to evaluate the variability in the shoulder biomechanics of DII college baseball pitchers during their pitching motion.

Delimitations

For this study, the following delimitations will apply.

- DII college baseball pitchers between the ages of 18 and 23
- 15 pitches thrown to a catch net in a game like atmosphere
- Athletes must be on the current baseball roster at the university they attend

Limitations

For this study, these limitations apply.

- Availability of athletes in their preseason
- Current injuries to athletes pitching shoulder
- Participant compliance to pre-conditions

Operational Definitions

- Division II - institution that sponsors at least five sports for men and five for women, (or four for men and six for women), with two team sports for each gender, and each playing season represented by each gender. There are contest and participant minimums for each sport, as well as scheduling criteria -- football and men's and women's basketball teams must play at least 50 percent of their games against Division II, I-A or I-AA opponents. There are no attendance requirements.
- Pitching Variability – the standard deviation of the joint angles calculated across 12 to 15 pitches performed by the subject.

Chapter II

REVIEW OF LITERATURE

The purpose of this study is to evaluate the variability in the shoulder biomechanics of DII college baseball pitchers during their pitching motion**.** This chapter will review literature pertaining to this study under the following headings: The anatomy of the shoulder, Injuries that occur at the shoulder from pitching, Coordination and Pitching Mechanics, Is Movement variability Important for Sports Biomechanists to Study, and A Central Source of Movement Variability.

The Anatomy of the Shoulder

A brief review of the shoulder anatomy will include the bone structure and muscular makeup of the shoulder and shoulder girdle. Starting with the bone structure, the shoulder is made up of the humerus and the scapula. That joint is then stabilized by the clavicles. The musculature around the shoulder is complex. The larger muscles of the shoulder are the deltoid, which covers the shoulder joint and contracts to allow shoulder flexion, extension and abduction. The biceps and triceps cross the shoulder joint and help flex and abduct and extend and adduct the arm. The latissimus dorsi extends and adducts as well as slightly helps internally rotate the shoulder joint. The coracobrachialis helps the shoulder perform flexion and adduction. The final large muscle that helps mobilize the shoulder joint is the pectoralis major which helps provide horizontal adduction, slight flexion and internal rotation.

The smaller muscles that help provide the shoulder with mobility, are fewer in number but still very important. There are four muscles that make up the rotator cuff, which is responsible for helping the shoulder rotate internally and externally as well as stabilizes the humeral head into the joint when other muscles are pulling on the humerus to move it around. Specifically, the supraspinatus helps with abduction and external rotation. The infraspinatus helps with external rotation and horizontal abduction. The teres minor helps with external rotation and horizontal abduction and finally the subscapularis helps with internal rotation. All of the muscles of the shoulder work collectively to maintain its range of motion while providing it stability (Starkey & Ryan, 2002).

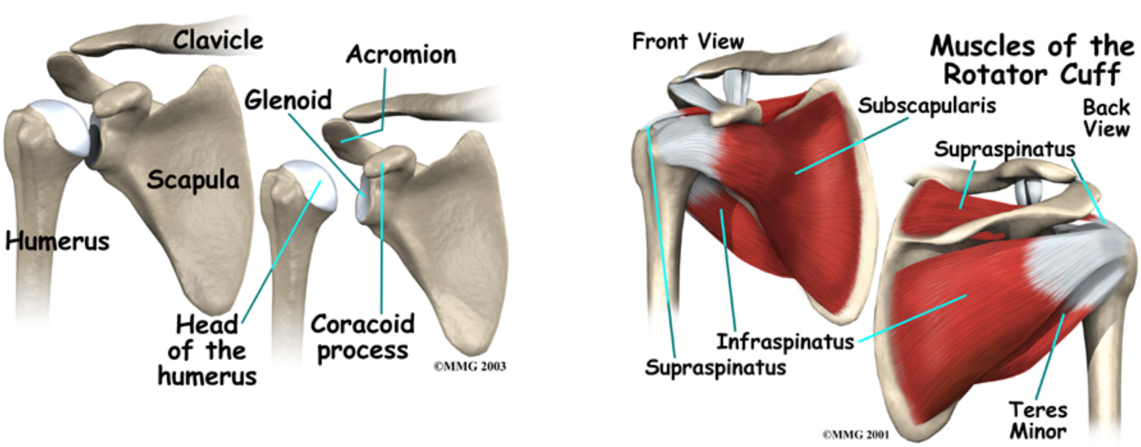


Figure 2.1 – View of Shoulder Bony Structure and Rotator Cuff (Matt, 2002)

Injuries that Occur at the Shoulder from Pitching

The overhand pitch is an unnatural movement that places great amounts of stress on the stabilizing structures of the shoulder (Tripp, 2007). When a pitcher is in season, he may repeat this unnatural motion more than 100 times a day. The extreme forced external rotation required for pitching, combined with the number of repetitions that are performed makes the shoulder prone to injury (Nyman, 2008). Shoulder injury is a potentially career-ending problem for baseball pitchers and represents a significant clinical challenge for health care professionals responsible for prevention (Downar, 2005). This makes it very important to understand what common causes of pitching injuries are and what could possibly help prevent these common causes.

At maximum external rotation, the posterior rotator cuff may become impinged between the glenoid labrum and the humeral head. This slight impingement can cause degeneration of both the superior labrum and the rotator cuff (The American Sports Medicine Institute, 2007). Most injuries that occur at the shoulder from pitching involve the rotator cuff. The four muscles that make up the cuff are small in size but are used as primary movers and stabilizers during the pitching motion. There small size leave them prone to injury as they become fatigued more easily when compared to the larger muscles that act on the shoulder joint (Starkey, 2002). Starkey & Ryan (2002) agreed that most commonly the rotator cuff becomes strained from the repetitious motion, but these four muscles are susceptible to tears if proper rest and treatment is not administered to a pitcher with a rotator cuff strain. Shoulder joint laxity and instability are also caused by a fatigued rotator cuff. Again, this can lead to the impingement of different structures around the shoulder and cause a lack of blood flow to supply nutrients that will keep the shoulder structure healthy. Chronic impingement can lead to necrosis of tissues and cause more pain and micro tears in the musculature that is used to stabilize the shoulder.

The American Sports Medicine Institute (2007) studied another common shoulder injury that occurs in pitchers, the SLAP lesion. SLAP, which stands for superior labrum from anterior to posterior, describes this specific tear pattern of the labrum. Originally it was thought that the SLAP lesion was only common to a mechanism of falling on an outstretched arm but a study of 73 baseball pitchers and other overhand throwing athletes showed that a SLAP lesion can occur without a traumatic episode. It was determined that in pitchers the SLAP lesion can result from the force of the long head of the biceps pulling the labrum away from the glenoid. Biceps force is particularly strong during the arm deceleration phase, as the biceps contracts to both decelerate elbow extension and resist glenohumeral distraction. EMG findings showed that in a comparison between professional and amateur pitchers, biceps activity was greater for the amateurs. A greater force from the biceps was also required for pitchers with poor mechanics.

Improper mechanics are believed to increase the stress on the throwing shoulder and elbow, resulting in an increased chance of injury (The American Sports Medicine Institute, 2007).

Proper Pitching Mechanics

Throwing is a fundamental skill that is often overlooked by coaches at all levels. Many coaches believe that throwing ability is innate; you have it, or you do not (Vaughn, 1996). Although some athletes have more natural ability than others, almost anyone can improve their throwing by understanding and practicing proper throwing mechanics (Vaughn, 1996). Baseball players must achieve a delicate balance between shoulder mobility and stability to attain optimal sports performance (Downar, 2005).

According to Vaughn (1996) the proper throwing sequence begins with a stride in the direction of the throw. The length of the stride will vary according to the athlete's height. Technically stride length should be about 80% of the athlete's height. Over striding is a common fault that reduces proper hip rotation and detracts from the velocity of the throw. As the stride foot hits the ground, the other (pivot) foot braces against the ground to provide stability and leverage for the remaining movements of the throw.

Hip rotation is the next element in the throwing sequence. Hip rotation simply refers to the natural tendency for the hips to open toward the thrower's target. It is important to remember that hip rotation must occur before trunk rotation. Unskilled throwers tend to rotate the hips and trunk at the same time. Rotation of the hips before the trunk is important because it serves to stretch the muscles across the trunk eventually causing these muscles to contract more forcefully. This preloading of the trunk muscles enables the trunk to rotate rapidly setting the stage for proper arm action. As the trunk begins to rotate toward the target, the throwing arm should lag behind. The lagging arm stretches the shoulder muscles, which in turn further helps accelerate the arm.

As the upper arm begins its forward movement, the elbow should be bent to enable the upper arm to move more quickly. Two other arm actions also contribute to a very rapid increase in ball velocity. The first of these actions is the turning of the upper arm around its long axis. This action is technically called inward rotation of the humerus; this is the same movement that occurs when an extended arm is turned from a position where the palm of the hand faces the sky to where the palm faces the ground.

The second action accompanying the forward movement of the arm is the straightening or extension of the elbow joint. To make certain that maximal hand velocity is achieved, it is essential that the forward movement of the upper arm, the inward turning of the upper arm, and the extension of the elbow occur simultaneously.

A commonly held belief is that a good wrist snap is the secret to throwing hard (Nyman, 2008). However, research indicates that the importance of the wrist snap has been overrated. High-speed photography shows that the ball is actually released from the thrower's hand before most of the wrist flexion occurs. Nonetheless, the wrist snap does contribute somewhat to the velocity of the throw and should be considered an important final component of the throwing motion (Nyman, 2008).

Vaughn et al. (1996) concludes that a high-velocity throw is made possible by rapidly accelerating the arm and hand. The most rapid acceleration of the arm and hand occurs when the thrower’s hips and trunk rotate in the proper order. Coaches should help athletes understand and practice the mechanics by ensuring that they:

1) Stride in the direction of the throw and keep the stride short enough to allow maximum hip rotation.

2) Allow the arm to lag behind the hips and trunk so the athlete feels a slight stretch in the trunk and arm muscles.

3) Extend the elbow at the same time that the upper arm is moving forward and turning inward.

Is Movement Variability Important for Sports Biomechanists?

Bartlett, Wheat, and Robins (2007) conducted a review study looking at intra-individual variability in elite athletic movements. Bartlett et al. believe that movement variability is, or could be, functional and such functionality could allow environmental adaptations, reduce injury risk, and facilitate changes in coordination patterns. These authors suggest that variability in movement patterns might provide a broader distribution of stresses among different tissues, potentially reducing cumulative load on internal structures of the body.

One of the focuses of the article was on the four javelin finalists from the 1996 Olympics. Each of the finalists had slightly different form that was noticeable to the naked eye. This is expected, as no two people are alike in body structure and muscular strength. In contrast though, when the finalists three throws were analyzed, Bartlett et al. found that none of the four finalists were able to reproduce an invariant throw when comparing each of their own throws. It appeared that even elite athletes with years of practice could not reproduce an exact movement. The motion a javelin thrower uses has many similarities to that of a pitcher. It is expected that if elite javelin throwers have variability in their motion then so too should baseball pitchers. Javelin throwers have just as much stress placed on the shoulder as pitchers do but do not go through the same number of repetitions. It would be significant if variability could be emphasized more in training so that individual tissues would not get the repetitive accumulative stress from hundreds of repetitions that pitchers must go through.

From the study above, the question was raised; do all athletes need variability in their mechanics in order to become elite? This thought would seem counter to the 'proper pitching mechanics' approach of coaching that is so prevalent in sports today. To find more information out about the variability in movement paterns, Bartlett et al. reviewed articles that allowed them to look at variability in basketball shooting and in general locomotion. Their aim was at the possibility of either enhanicing performance or of identifying biomechanical factors that might contribute to the causes of overuse injury.

They found that there is variability in general locomotion which means that for any movement including a basketball shot there is variability. For a highly practiced task, the ability to repeatedly plan the same movement limits our ability to repeatedly execute the same movement (Churchland, 2006). Though they belive that analyzing discrete variables from isolated joints does not always effectively capture the complexity of the coordinated motions of components of the body.

The article is concluded by recommending that sports biomechanists start to focus more of their research on movement variability and important related topics such as control and coordination of movements and implications for practice and skill learning. If movements are repeated identically, it is more likely that the same tissues would be maximally loaded each time. Adding in movement variability probably modifies tissue loads from repetition to repetition, reducing injury risk. This remains hypothetical at present (Bartlett et al. 2007).

Chapter III

METHODOLOGY

The purpose of this study is to evaluate the variability in the shoulder biomechanics of the throwing motion in DII college baseball players. This chapter presents information under the following headings: subjects, general procedures, instruments, and data analysis.

Subjects

Five NCAA division II baseball pitchers (mean age: 19.4 ± 1.5 yrs; mean mass: 83.4 ± 3.3 kg) from a university in the northeastern United States agreed to participate in the present study. This study received approval from the Institutional Review Board for the protection of the human subjects. The subjects were pitchers on the current roster at the university they attended. Previous injuries did not prevent the subjects from participating, but during the testing, the subjects were free of injury so that a full and normal pitching motion was achieved. Consent was obtained prior to the initiation of this study. Each subject was introduced and familiarized to the test procedures and equipment that was used to collect the data in order to create a comfort level that ensured the most accurate data collection.

General Procedures

Subjects were recruited for this study after a meeting with the pitching coach of the baseball team. The coach helped to identify potential subjects who met all the above criteria. After the selection process, the pitchers were introduced to the 8 camera Vicon system and the markers that were placed on them in specific anatomical locations during their pitching. When they were familiar with the feeling of pitching with markers placed on them they were free to begin their trial pitches. In order to have the pitchers perform at their top performance the study imitated a game performance. One at a time the subjects went through a warmup that consisted of some stretching and running routinely performed at the beginning of their daily practices. They also warmed their arms up with a throwing routine they were familiar with. After the warmup they had a few minutes to rest before starting the trials in which their pitching motion was analyzed. They threw 15 fastballs at 100% of their ability just as if it were the first inning of a game they were starting.

The markers on the subject's body were placed in locations according to the manual of the Plug-in-Gait markers (Appendix B) that are preset with the cameras so that correct readings for each placement can be achieved. The markers allowed the investigator to analyze 3D angles at the shoulder, elbow, and wrist. Comparisons were made between maximal external rotation of the shoulder, maximal elbow flexion and maximal wrist flexion of each trial for each individual athlete. Comparing each individual's trials allowed the investigator to find the intra-athlete variability. These three joint angles were chosen to gather information from based on the study that Chu et al. (2009) performed, stating that these are the most important joints when it comes to a pitchers velocity and control. Maximal shoulder external rotation is measured during the arm cocking phase and is the point at which the shoulder reaches max external rotation right before accelerating forward into the arm acceleration phase. External rotation is directly related to pitching velocity. Max elbow flexion is reached and measured in the beginning of the arm acceleration phase and also relates to pitch velocity. Wrist felxion was recorded at the point in which the ball left the pitchers hand. This is an important angle when talking about accuracy for pitchers Chu et al. (2009). These wrist angles are reached at the beginning of the arm decelaration phase.

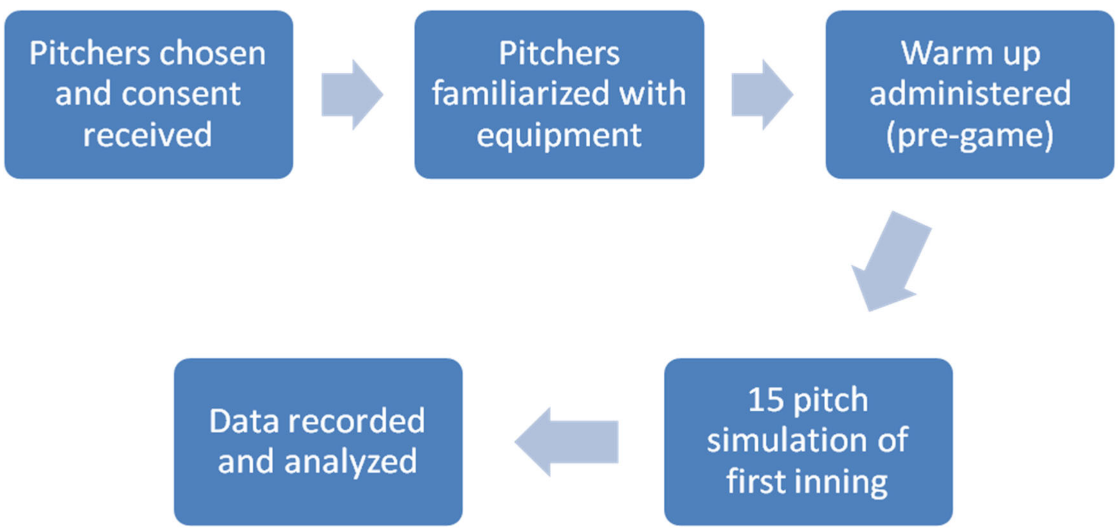


Figure 3.1 – Flow Chart of General Procedures

Instrumentation

The cameras collecting the data were a system of 8 100 Hz Vicon cameras from Oxford, UK. They have Nexus software installed that allows for 3D angles and phase angles to be calculated.

A catch net was used to receive the pitches and the pitcher was throwing certified collegiate game baseballs. The catch net has a strike zone highlighted in the center to give the pitchers a good target to throw at. The pitchers use this same catch net in practice so they were familiar with it. The pitcher threw from an artificial mound that they use for indoor winter practices. The mound is raised to the height of a regulation college pitching mound which is about 10 inches in height. The pitchers threw from a distance of 20 feet due to the lack of space in the camera room. A radar gun was used to calculate the speed of each pitch thrown for the sole purpose of motivating the pitchers to throw their hardest.

Data Analysis

Descriptive data were calculated on the angles of each joint during each trial pitch in order to record frequencies and standard deviations. The variability was defined as the standard deviation at each joint calculated across the 12-15 pitches that were analyzed for each of the five subjects. Due to the fact that only five subjects were able to get accurate readings for at least 12 pitches, the information for the five athletes will be looked at and reviewed in case study format.

Chapter IV

RESULTS

Subject Demographics

The purpose of this study is to evaluate the variability in the shoulder biomechanics of DII college baseball pitchers during their pitching motion. This chapter will present the data obtained from the pitchers' trials that were recorded.

The trials that were included and analyzed in this chapter were those that had complete data, consisting of at least 12 total pitches.

Subject 1

Subject 1, a 21-year-old pitcher with a mass of 88.5 kg, was participating in his third year of eligibility. He listed himself as a conference starter, or one of the top four pitchers on the team. His degrees of angle during his pitching movement are as follows.

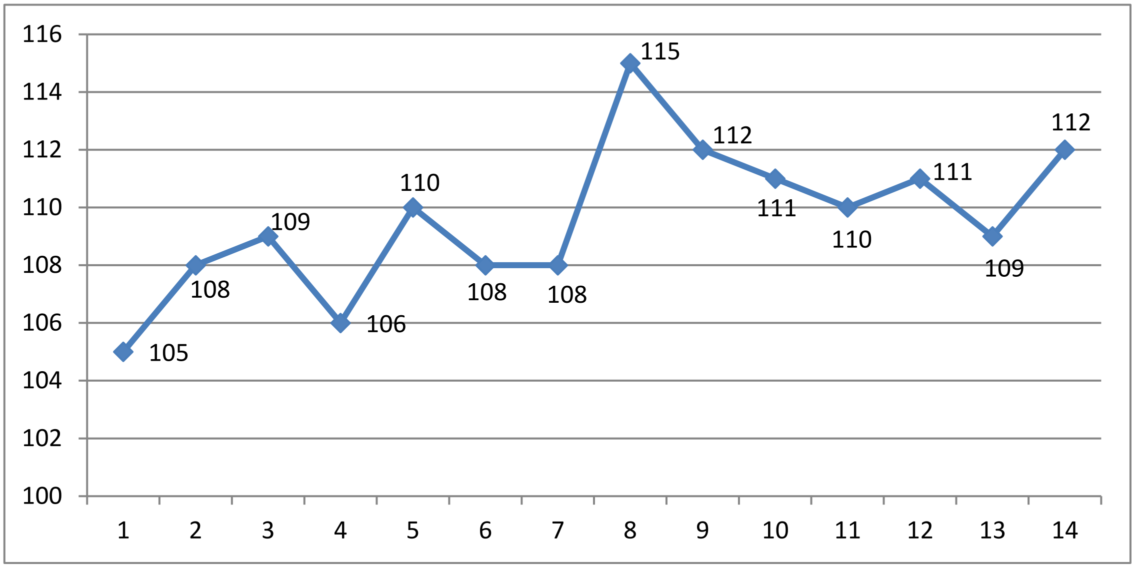


Figure 4.1. Maximal Degree of External Shoulder Rotation in each Pitching Trial

As depicted in Figure 4.1, subject 1 showed slight variation in max external rotation throughout his 14 pitches. The degrees ranged from 105 to 115 degrees. As compared to the other four, subject 1 had the greatest amount of shoulder external rotation.

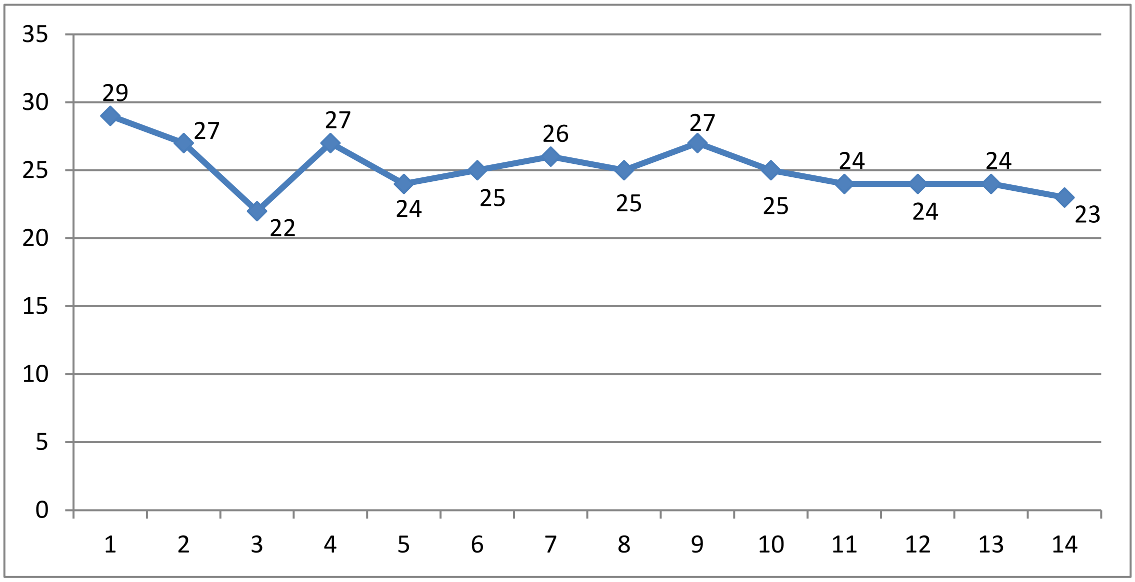


Figure 4.2. Degree of Wrist Flexion at Release in each Pitching Trial

The figure shows how wrist flexion varies within all the trials of subject 1. The degree recorded ranges from 22 to 29 degrees.

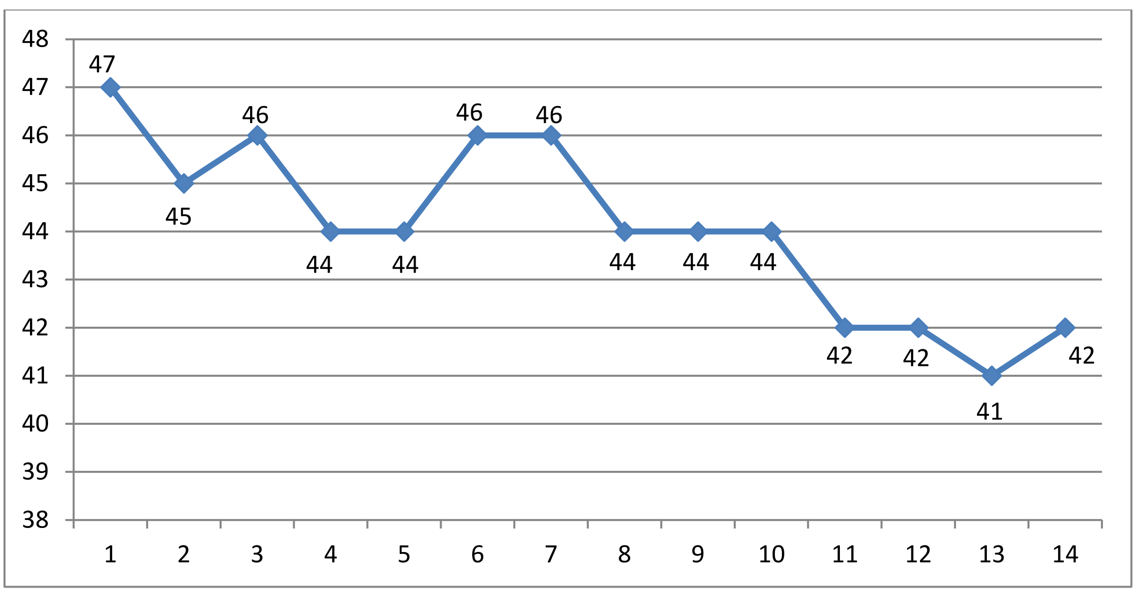


Figure 4.3. Maximal Degree of Elbow Flexion in each Pitching Trial

Subject 1 had the greatest amount of elbow flexion as compared to the other four subjects. His elbow angles ranged between 41 and 47 degrees.

Subject 2

Subject 2, a 19-year-old pitcher with a mass of 83 kg, was participating in his second year of eligibility. He listed himself as a conference starter on the team, another one of the top four pitchers on the team. His maximal degrees during his pitching movement are as follows.

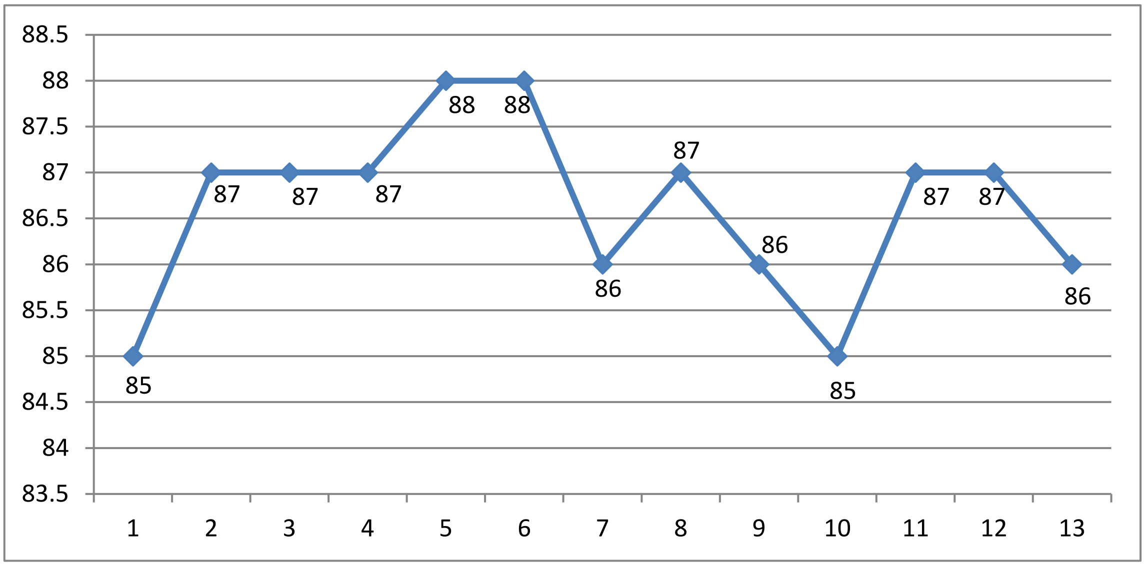


Figure 4.4. Maximal Degree of External Shoulder Rotation in each Pitching Trial.

Subject 2 had a range between 85 and 88 degrees. His three degrees of variability were the smallest amount of variability between all five subjects.

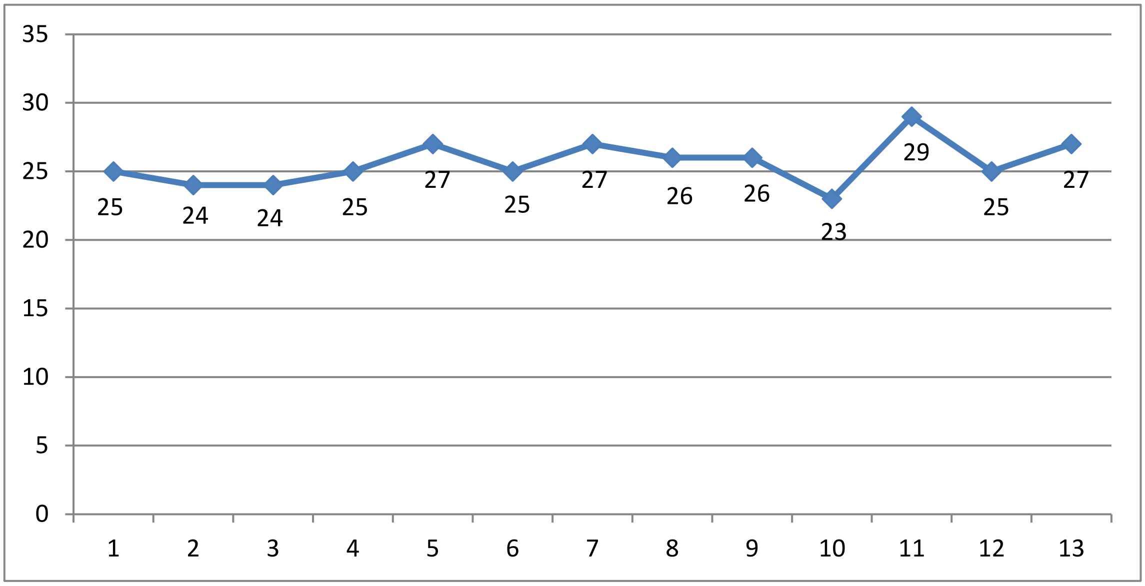


Figure 4.5. Degree of Wrist Flexion at Release in each Pitching Trial

Subject 2 had angles at ball release which ranged from 23 to 29 degrees.

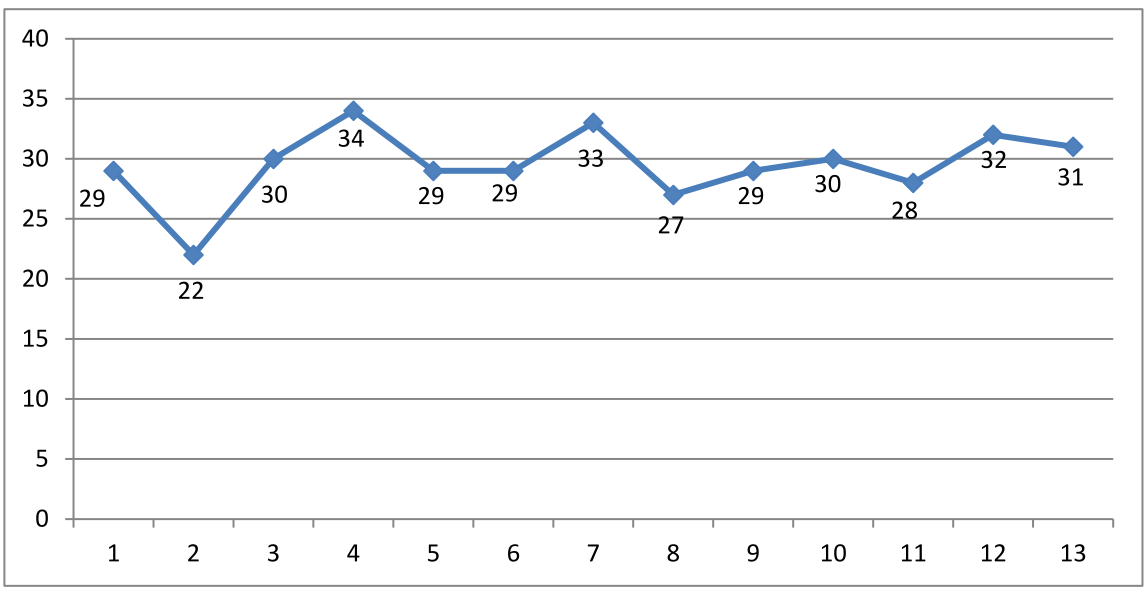


Figure 4.6. Maximal Degree of Elbow Flexion in each Pitching Trial

Subject 2 had relatively little variable in elbow flexion with his angles ranging between 22 and 34 degrees.

Subject 3

Subject 3, an 18-year-old pitcher with a mass of 82 kg, was participating in his first year of eligibility. He listed himself as a relief pitcher on the team. His maximal degrees during his pitching movement are as follows.

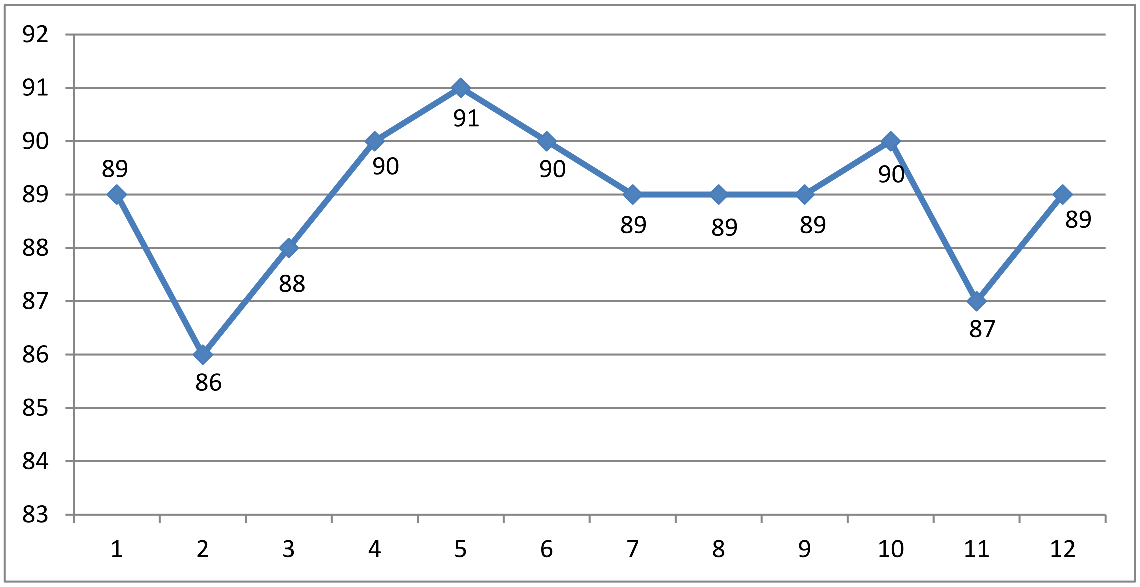


Figure 4.7. Maximal Degree of External Shoulder Rotation in each Pitching Trial

Subject 3 had numbers ranging between 86 and 91 degrees.

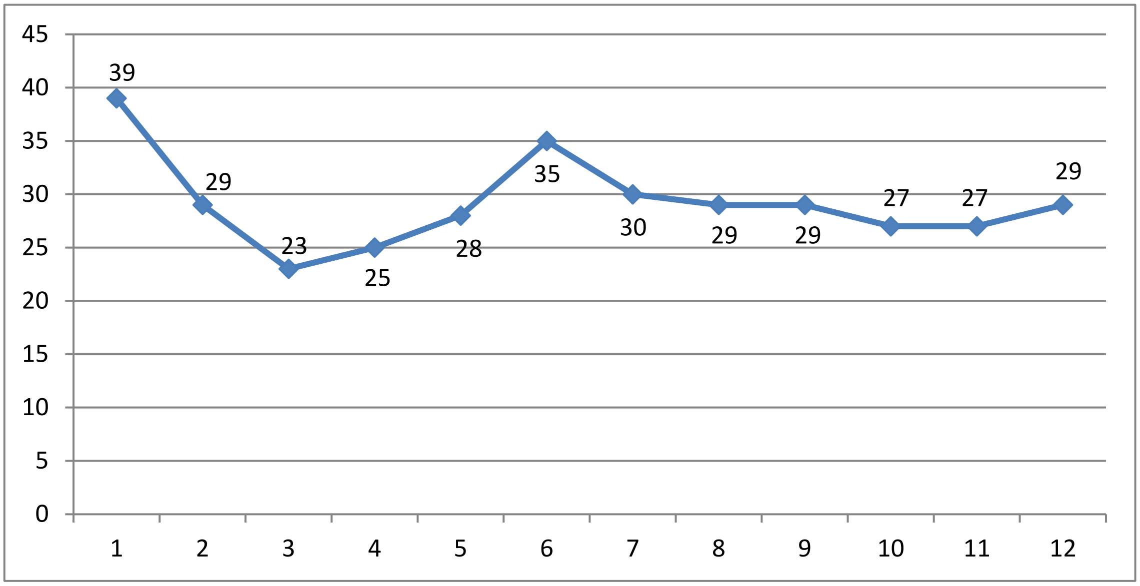


Figure 4.8. Degree of Wrist Flexion at Release in each Pitching Trial

Subject 3 had wrist angles ranging between 23 and 39 degrees at ball release.

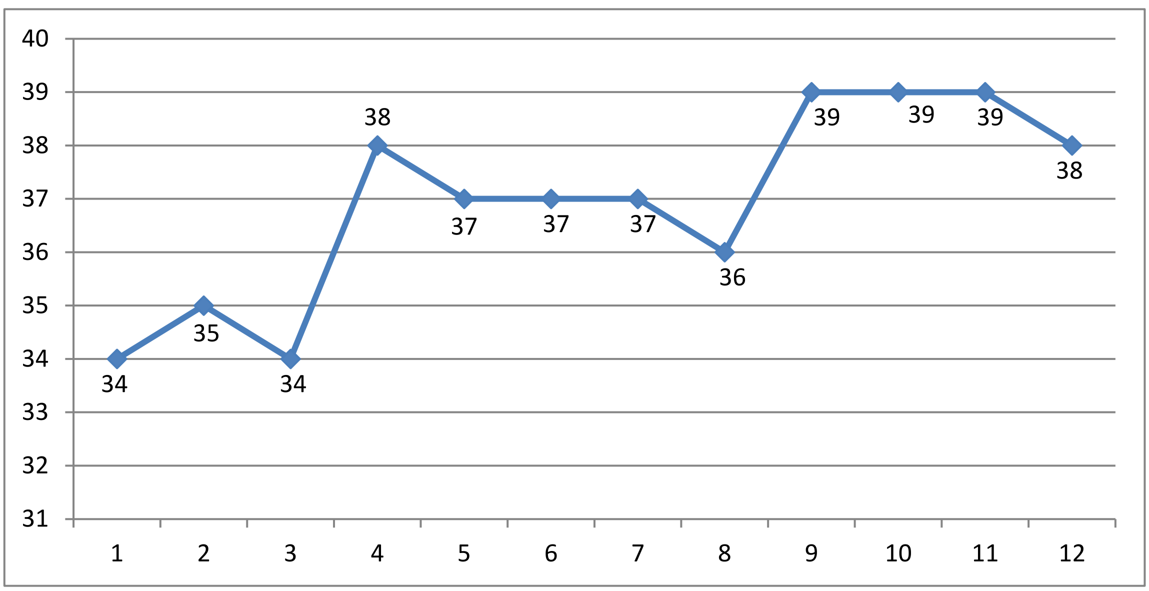


Figure 4.9. Maximal Degree of Elbow Flexion in each Pitching Trial

Subject 3 seemed to gain range of motion at the end of his trials. His range for elbow flexion was between 34 and 39 degrees.

Subject 4

Subject 4, a 21-year-old pitcher with a mass of 79.5 kg, was participating in his third year of eligibility. He listed himself as a starter on the team. His maximal degrees during his pitching movement are as follows.

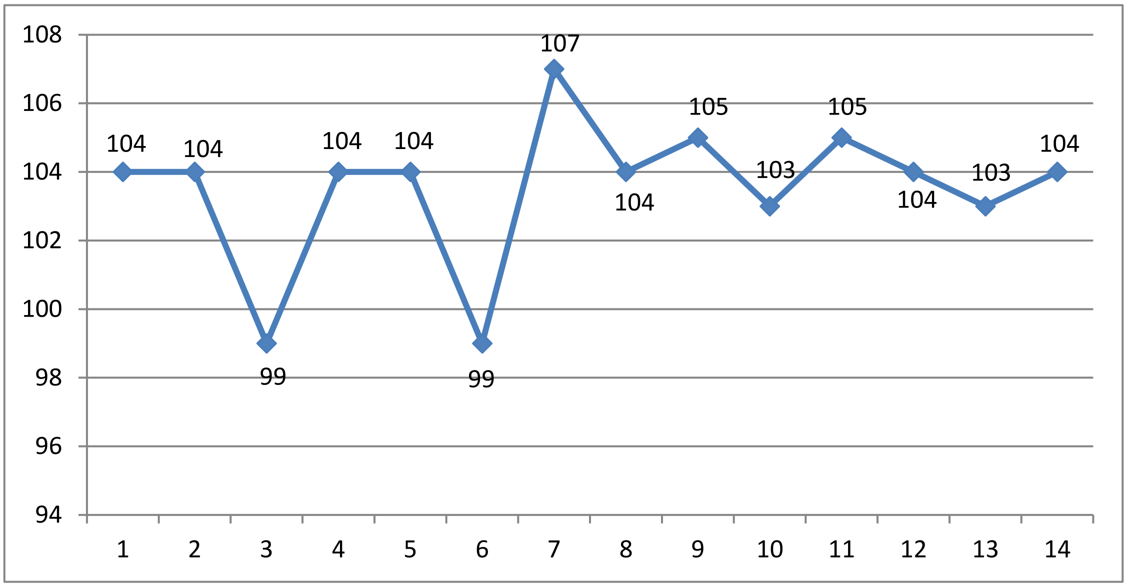


Figure 4.10. Maximal Degree of External Shoulder Rotation in each Pitching Trial

Subject 4 had a range from 99 to 107 degrees of shoulder external rotation.

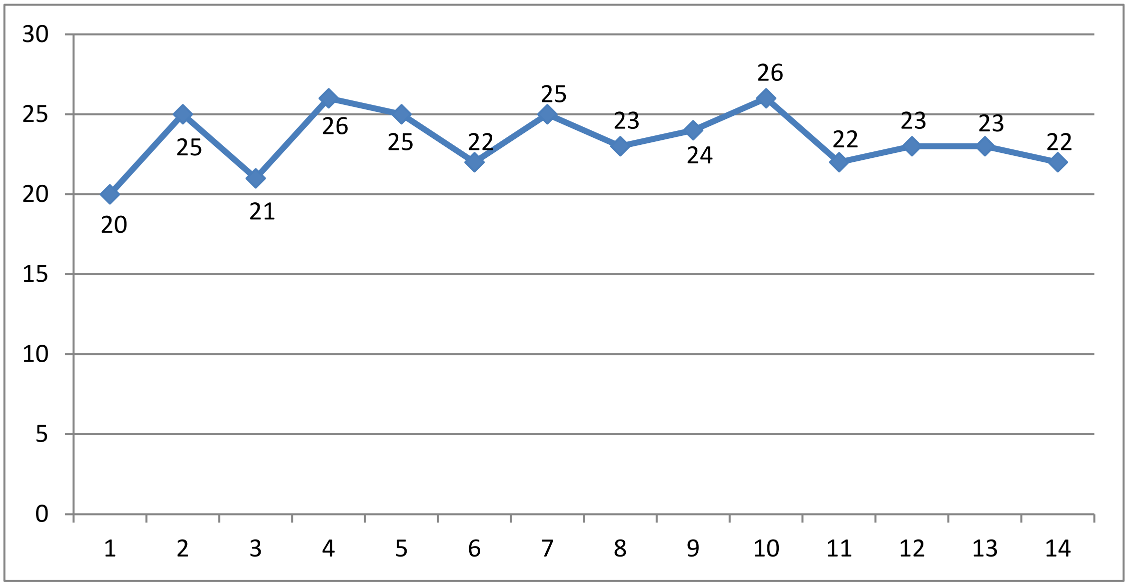


Figure 4.11. Degree of Wrist Flexion at Release in each Pitching Trial

Subject 4 had a range of 20 to 26 degrees of wrist flexion at ball release.

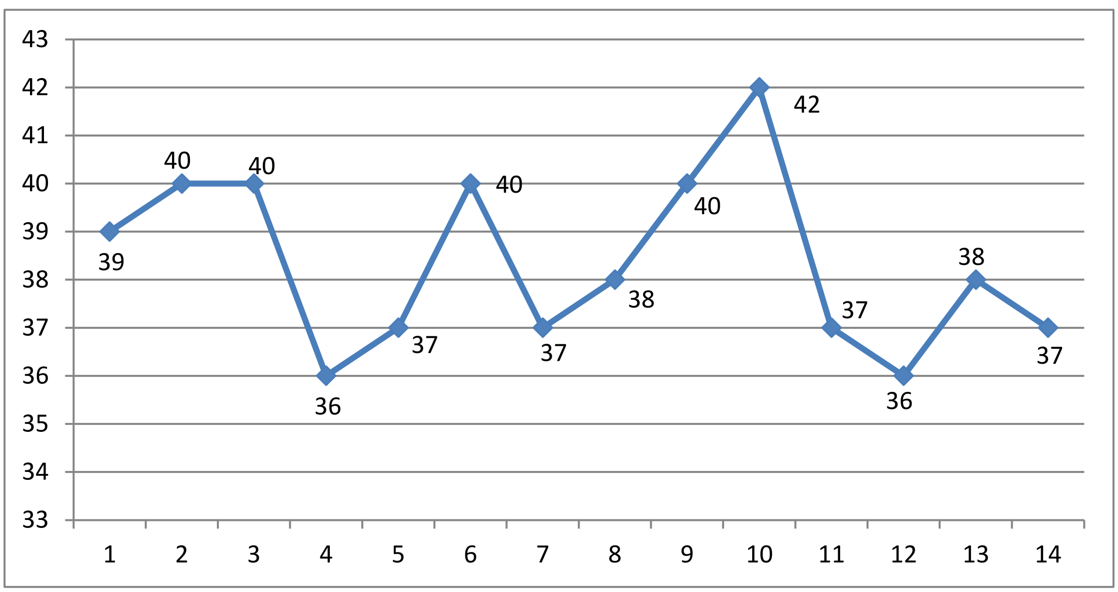


Figure 4.12. Maximal Degree of Elbow Flexion in each Pitching Trial

Subject 4 had a range of elbow flexion between 36 and 42 degrees.

Subject 5

Subject 5, an 18-year-old pitcher with a mass of 84 kg, was participating in his first year of eligibility. He listed himself as a relief pitcher on the team. His maximal degrees during his pitching movement are as follows.

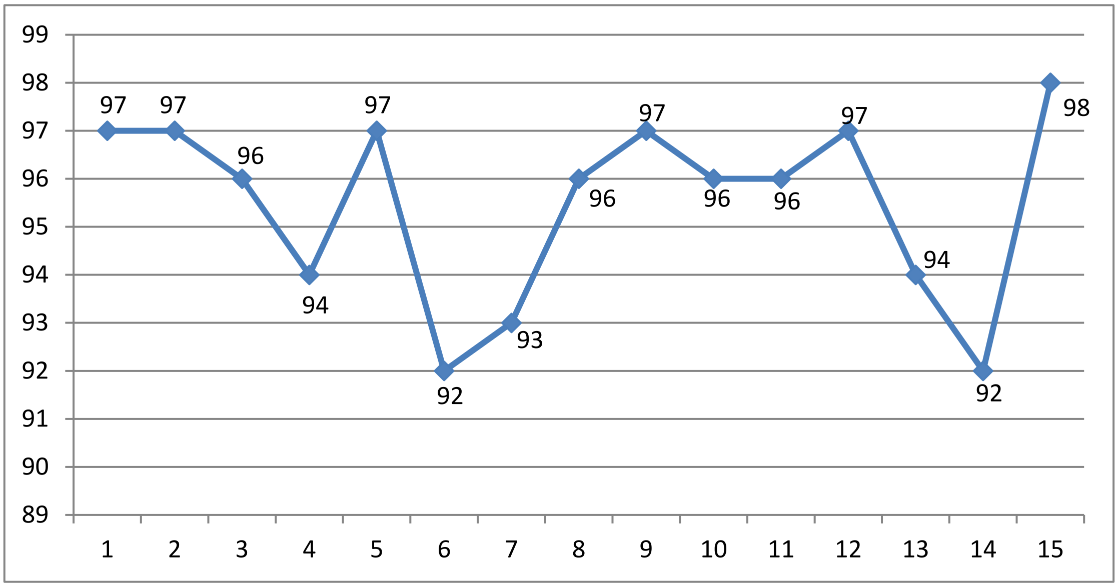


Figure 4.13. Maximal Degree of External Shoulder Rotation in each Pitching Trial

Subject 5 completed his trials with a range between 92 and 98 degrees of maximal external shoulder rotation.

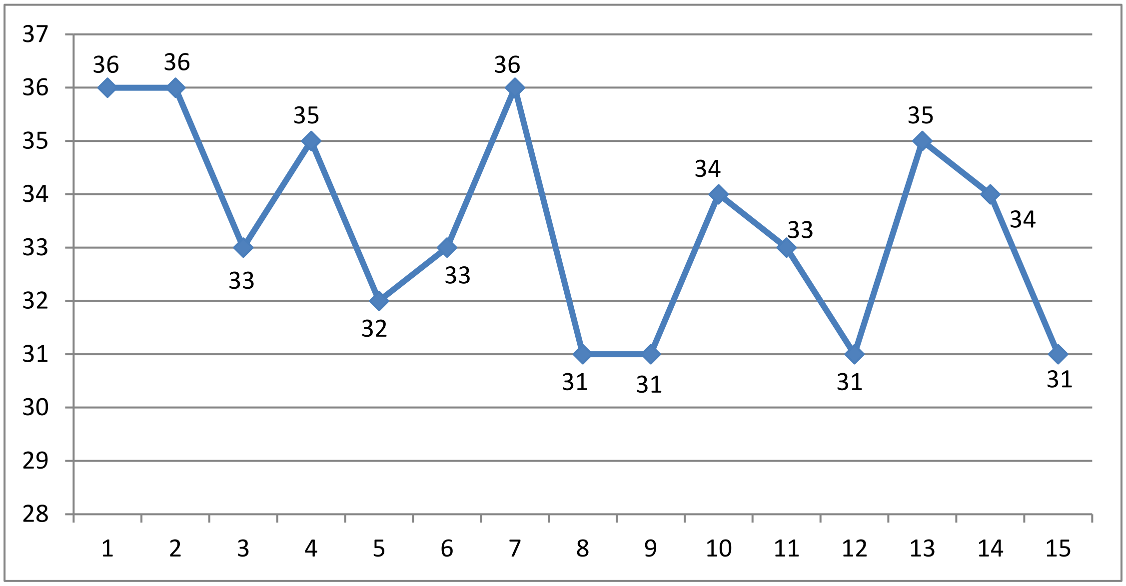


Figure 4.14. Degree of Wrist Flexion at Release in each Pitching Trial

Subject 5 recorded wrist angles that ranged between 31 and 36 degrees.

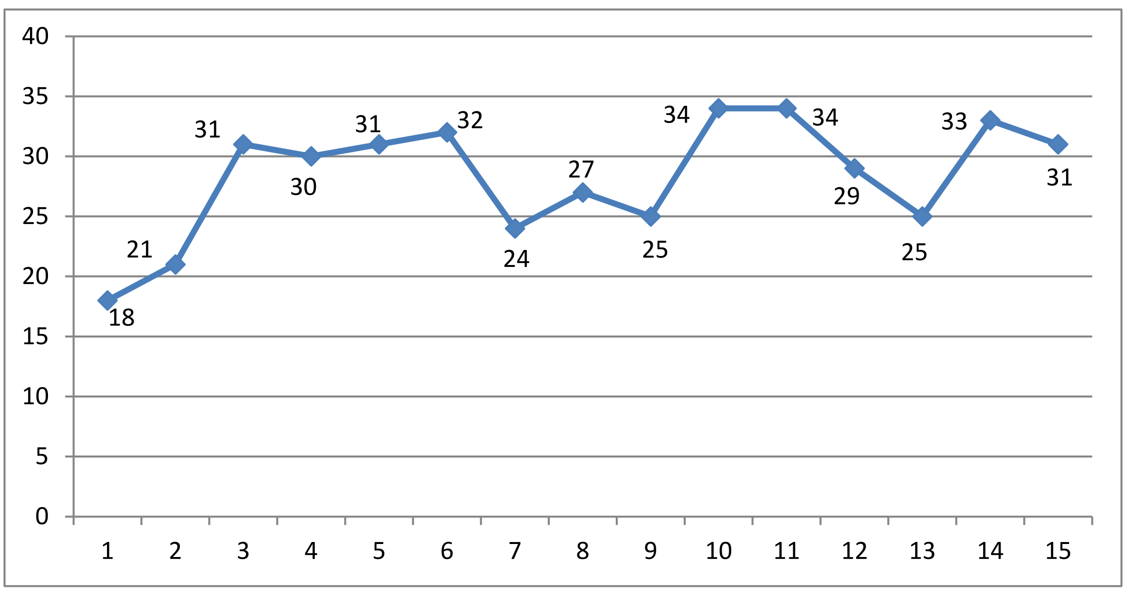


Figure 4.15. Maximal Degree of Elbow Flexion in each Pitching Trial

Subject 5 finished with elbow angles ranging from 17 to 34 degrees.

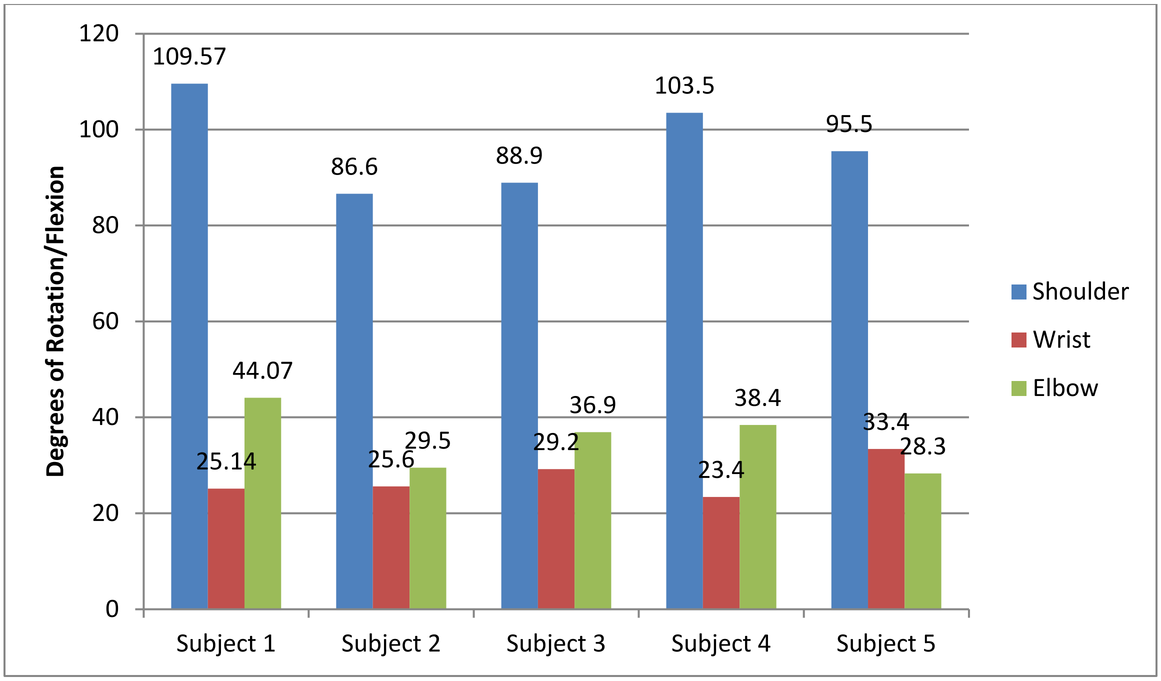


Figure 4.16. Comparison of Average Values for each Subject Across the Trials

For each subject, the mean of the angles for each joint are compared here (Figure 4.16).

Subject 1 had an average angle of 109.57 degrees of external rotation at the shoulder, 25.14 degrees of flexion at the wrist when the ball was released and an average of 44.07 degrees of maximal flexion at the elbow.

Subject 2 had the least amount of average shoulder external rotation with an angle of 86.6 degrees. His average wrist flexion was 25.6 degrees and his average elbow flexion was 29.5 degrees.

Subject 3 had an average of 88.9 degrees of shoulder external rotation, 29.2 degrees of wrist flexion and 36.9 degrees of elbow flexion.

Subject 4 had an average of 103.5 degrees of maximal shoulder external rotation, with averages of 23.4 and 38.4 degrees of maximal flexion at the wrist and elbow joints.

Subject 5 finished the study with an average of 95.5 degrees of external shoulder rotation, 33.4 degrees of wrist flexion, and 28.3 degrees of elbow flexion.

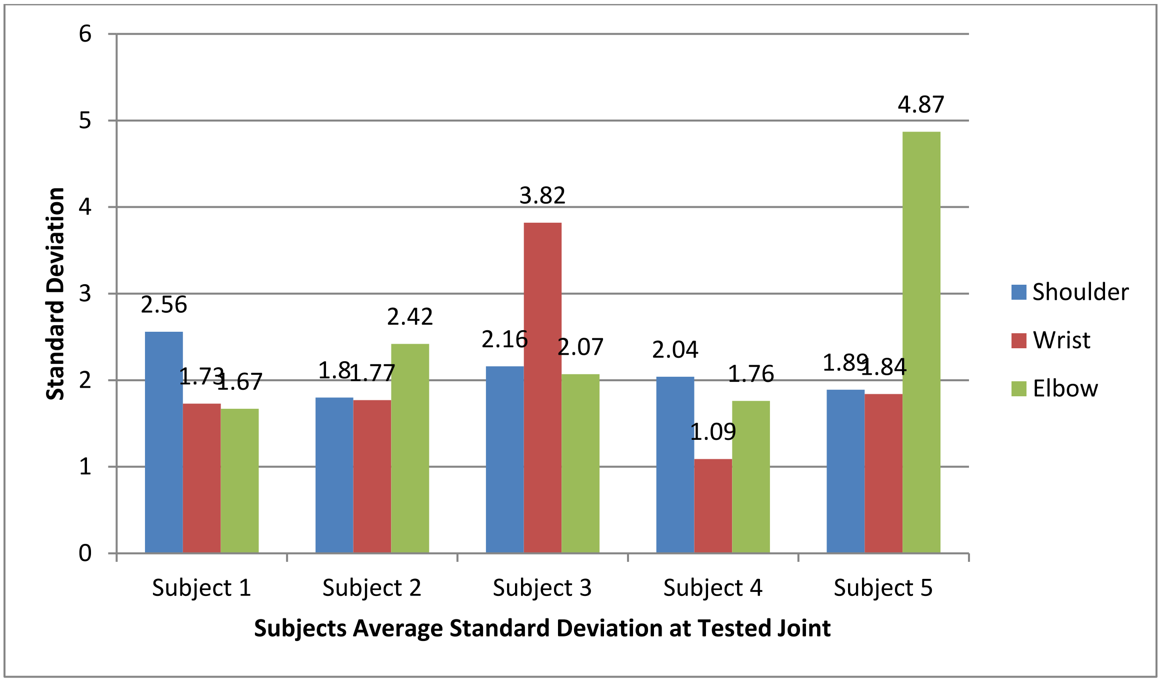


Figure 4.17. Standard Deviation for each Subject Across the Trials

For each of the five subjects the standard deviation was calculated to determine the variation for the pitching motion across the pitching trials (Figure 4.17).

Subject 1 had a standard deviation of 2.56 degrees at the shoulder joint and just 1.73 and 1.67 degrees of deviation at the wrist and elbow joints between all 14 of his trials.

Subject 2 had deviations of 1.8 degrees at the shoulder joint, 1.77 degrees at the wrist joint, and 2.42 degrees at the elbow joint.

Subject 3 had deviations of 2.16 degrees at the shoulder joint, 3.82 degrees at the wrist and 2.07 degrees at the elbow joint.

Subject 4 had deviations of 2.04 degrees at the shoulder joint, 1.09 degrees at the wrist and 1.76 degrees at the elbow.

Subject 5 finished with 1.89 degrees of deviation during shoulder external rotation, 1.84 degrees of wrist flexion and 4.87 degrees of deviation during elbow flexion.

Chapter V

DISCUSSION, CONCLUSION, AND RECOMMENDATIONS

The purpose of this study is to evaluate the variability in pitching biomechanics of DII college baseball pitchers. In this chapter the results will be analyzed and a conclusion will be made as well as recommendations for future studies.

Discussion

The study was aimed to evaluate the amount of variability that a pitcher had in his biomechanics between each pitch. Intra-athlete variability was found and compared using standard deviation to determine its importance and role during the pitching motion. Each subject had measurable variations in their pitching motion. This was measured by the degree of deviation that was recorded at the three joints that angles were analyzed. The recorded deviations were different between each joint ranging from 4 degrees of deviation down to just above 1 degree of deviation depending on which joint was being analyzed.

Subject 1 is a left-handed, conference starter with a reputation as the hardest throwing pitcher on his team. He was able to complete 14 pitches that were correctly recorded and analyzed. The average degree of external rotation at the shoulder for subject 1 was 109.57 degrees. This is six degrees greater of external rotation than the next closest subject. External rotation is thought to be very important in determining velocity for a pitcher (Chu et. al 2009). Subject 1 had a range of 10 degrees of external rotation at the shoulder joint between his 14 pitches. This was also the greatest range at the shoulder joint when compared to the other four subjects. His standard deviation was 2.56 degrees of external rotation at the shoulder. That value is almost 1 degree more than the amount of deviation that he achieved at either the wrist or elbow joint. At the elbow joint, subject 1 also had the greatest average angle 40.8 degrees. The large degree of external rotation and elbow flexion could be the reason why subject 1 is the hardest thrower on his team do you mean produced the greatest pitching speeds? Show this data in the Results. The amount of variability at the shoulder joint might have something to with adjusting to pitching from a different distance than normal. It may also relate to accuracy, but that was not measured in this study.

Subject 2 is a right-handed, conference starter and is also known as one of the hardest throwers on the team. He was able to complete 13 trials that were useful in this study. Subject 2 had an average of 86.6 degrees of external shoulder rotation which was actually the lowest average degree of external rotation at the shoulder. He also had the least amount of variability at the shoulder joint with a range of just 3 degrees. At the elbow joint subject 2 had the most variability with a range of 12 degrees difference between all 13 of his trials. Like the shoulder joint, his average degree of elbow flexion was also the lowest in the group. This seems to contradict the thought that larger angles at the shoulder and elbow will generate higher ball velocity. Subject 2 also had the least variation in all three joints. All of his standard deviation values were low, between 1.8 and 2.42 degrees of variance across all three joints, but still measurable.

Subject 3 is a right-handed pitcher that is used as a relief pitcher out of the bull pen in certain situations. On the team, he is known more for accuracy with his off speed pitches, or pitches other than a fastball, rather than a high velocity thrower. His average degree of external rotation at the shoulder was 88.92 degrees. This is the second lowest degree of angle at the shoulder joint when compared to the other four subjects. At the wrist, subject 3 had the largest average degree of flexion at the point of ball release, 29.04. His range at the wrist was also the largest along with subject 5 spanning 16 degrees. All three of his standard deviation values were above 2 degrees. The deviation values at his wrist were plus or minus 3.82 degrees, the most deviation at the wrist of all five subjects. The wrist angles could be the reason he has better off speed pitches. Larger wrist angles will create more opportunity to induce ball spin which is key in getting movement and accuracy with pitches other than a fastball (Chu et. al 2009).

Subject 4 is a left-hand starter for the team and is known to have a good fastball but very good accuracy with all his pitches. His average degree of external rotation at the shoulder was 103.5 degrees. This was the second highest average angle at the shoulder. The standard deviation value at the shoulder joint was plus or minus 2.04 degrees. Again there was measurable variability between each trial pitch at each joint. His shoulder angles had a range of 8 degrees between his 14 trials which is also the second largest amount at the shoulder joint. His average elbow angles, 38.36 degrees, are also the second largest just behind the results of subject 1. His average wrist flexion at ball release was just 23.36 degrees which was the lowest angle in the group. He also had the lowest standard of deviation at the wrist joint, with values of plus or minus 1.09 degrees of deviation. This seems to contradict the findings of Chu et al. (2009) and the results of subject 3.

Subject 5 is a left-hand pitcher that is used in relief by his team. He was able to complete 15 pitches that results were found for. His average external rotation at the shoulder was 95.46 degrees. He did not have the highest or lowest totals for any of the joints that were studied. His ranges also fell in the middle of the five subjects that were studied. The standard deviation values found for his shoulder and wrist joints were low and similar with values of 1.89 and 1.84 degrees. At the elbow joint, his standard deviation jumped to 4.87 degrees. This was by far the largest amount of variability measured at any joint.

Bartlett et al. (2007) found that high level athletes show more inter-trial variability between each of their athletic movements. This could be pertinent to this study because each of the five subjects had measurable amounts of variability. Just because the variability was measurable does not mean that it was necessarily significant. There is no scale in which to compare amounts of variability between studied groups. Having a larger number of subjects is needed in order to find correlations that may help define variability better. At the same time, there is no clear definition of high-level athletes.

In this study it is very difficult to determine the order of skill level between the five subjects. According to the coaches of the baseball team these players came from, being a conference starter would make that pitcher one of the four best on the team. There are four conference games in a weekend and the four best pitchers start those games in hopes of giving the team the best chance to win important games. This study was also performed in the pre-season which means that the freshmen have not had a chance to prove themselves or their skills in a live game yet. Other ways of determining skill level can be velocity and control but neither of these was measured in this study. Therefore, it is difficult to reason why one subject may have had more variability than the next.

The nature of the testing was a controlled environment which was made to simulate a game like atmosphere in order to make the pitchers comfortable and get as realistic results as possible while being restricted to a small indoor facility. The results could either be magnified or minimized when pitchers throw outside on a field from a real dirt mound at the correct distance. There is no way to tell from this study if there would be significant changes in the data if the pitchers were throwing outside.

Conclusion

The results that were collected for the 5 subjects above were clearly readable and very informative. It would have been great to have three or four times as many subjects in order to recognize any correlations that may have been present in their results and determine confidence intervals between each of the subject's results.

The study, although no concrete results were produced, was a success and hopefully will spark interest and future studies that will produce important information. The athletes were very cooperative and worked hard to give the best results they could produce for the study. As long as athletes compete, people will be looking for ways to train smarter and prevent injuries by understanding exactly how the body works.

Future Recommendations

In the future it would be beneficial to have multiple people working on a study like this. Handling all the equipment involved with the camera system would be much easier and quicker with the help of a team of three or four members. This would help the athletes warm up, prepare, and get through their testing periods in less time and allow many more subjects to be tested overall for the study.

Having a larger sample size and possibly one that included many universities of different sizes and levels would allow a study to further analyze the data associated and make correlations which could show significant information about athlete's variability. With a larger subject pool, the information could provide definitions for high level athletes and scales could be created to help validity and reliability of future studies.

A study that included data collection at each joint in the body would help get a more complete understanding of pitching. This would also help determine total variability as pitching is much more complicated than just shoulder, elbow and wrist angles. The legs and trunk contribute to a lot of power when it comes to pitching. Evaluating how the body works together to produce this power could result in more variability in different pitchers.

Including a questionnaire that would collect data about previous injury history could be beneficial in future studies. Knowing an athlete's injury history could help prove or disprove the variability overuse hypothesis which basically says with more variability there is less chance of overuse injuries.

In the future this type of study has potential to answer a lot of questions and possibly change the way athlete and coaches train for competitive seasons.

Appendix A

Informed Consent

***Title of investigation**:* Intra-Athlete Variability in Pitching Biomechanics at the Shoulder Joint

***Principle investigator**:* Kyle Sheaffer

Overview of study

Human variability is defined as the possible values for any measurable inconsistent characteristics in human beings. New studies are showing that elite athletes are not able to perform skills without variability in their movements. Movement variability is, or could be, functional and such functionality could allow environmental adaptations, reduce injury risk, and facilitate changes in coordination patterns. Variability in movement patterns might provide a broader distribution of stresses among different tissues, potentially reducing cumulative load on internal structures of the body. A study to evaluate the variability of college pitchers would provide useful information for coaches and athletes, allowing them to develop more efficient practices.

Testing sessions

There will be one orientation session and one testing session during the study. The orientation session will be performed in the 3-D Motion Analysis Laboratory at East Stroudsburg University. During the orientation session, you will be marked up in the correct anatomical locations with reflective markers. Measurements will be taken to locate joint axis's and you will be familiarized with moving around while having the anatomical markers on. The testing session will be on a separate day and will also be performed in the 3-D Motion Analysis Laboratory at East Stroudsburg University. During the testing session you will be asked to perform 15 pitches on an artificial surface, throwing into a catch net with a strike zone. The markers that you are wearing will be tracked by the motion analyzer to compute the mechanical data associated with your pitching motion.

Although you will be undergoing physical testing, there is very little risk if you are a normal healthy individual. Individual information obtained from this study will remain confidential. Non-identifiable data will be used for scientific presentations and publications. You may withdraw from the study at any time. If you have any questions, please ask Dr Moir before signing this consent form.

If you have any additional questions during or after the study, Kyle Sheaffer can be contacted at:

kyle.sheaffer@pennmedicine.upenn.edu Tel: (215) 554 4916
YOU ARE MAKING A DECISION WHETHER OR NOT TO PARTICIPATE. YOUR SIGNITURE INDICATES THAT YOU HAVE READ THE INFORMATION PROVIDED AND YOU HAVE DECIDED TO PARTICIPATE IN THE STUDY.

I have read and understood the above explanation of the purpose and procedures for this study and agree to participate. I also understand that I am free to withdraw my consent at any time.

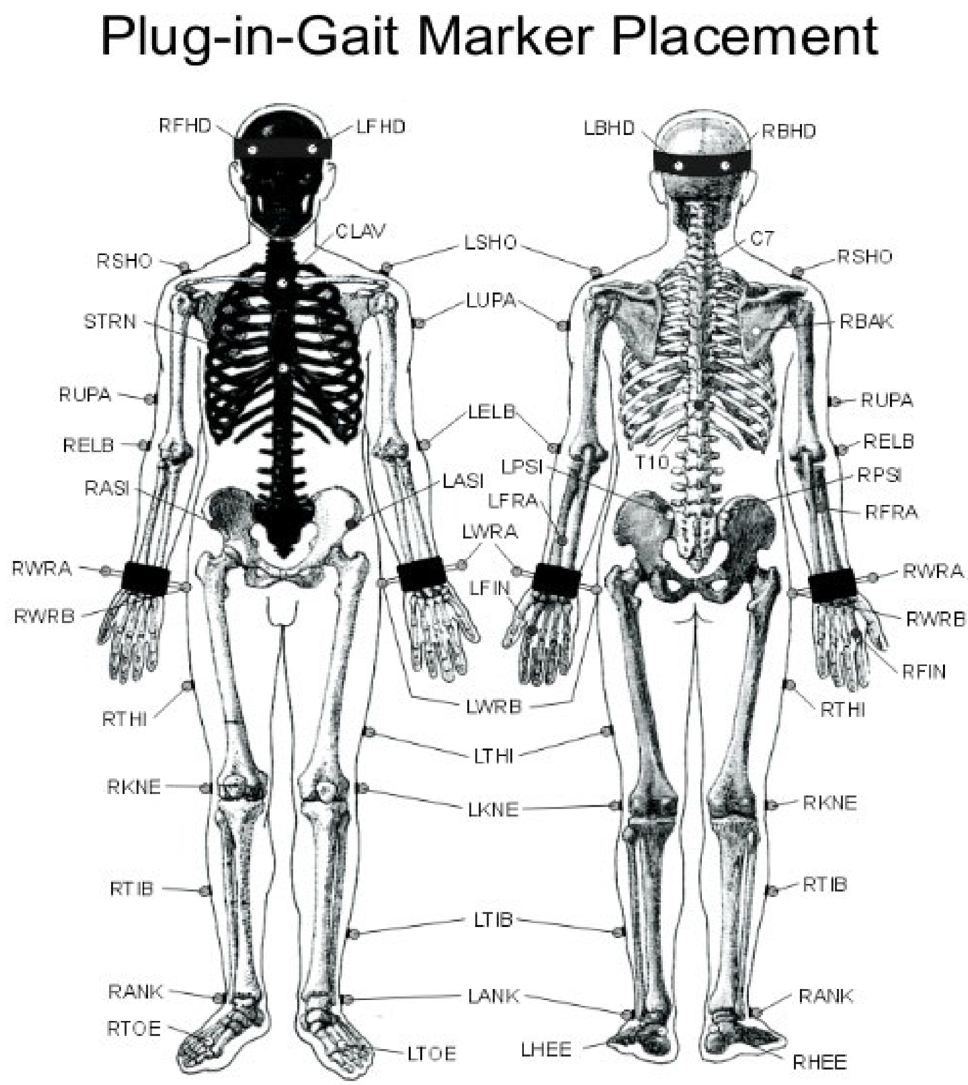
____

Print Name

______________________ ___________________ ____________

Signature Witness Signature Date

Appendix B



The following describes in detail where the Plug-in-Gait markers should be placed on the subject. Where left side markers only are listed, the positioning is identical for the right side.

Appendix C

200 Prospect Street
East Stroudsburg, PA
1830 1-2999

East Stroudsburg University Institutional Review Board
Human Research Review
Protocol # ESU-IRB-042-0809

Date: **February 13, 2009**
To: **Gavin Moir and Kyle Sheaffer**
From: **Shala E. Davis, Ph.D., IRB Chair**
Proposal Title: "Intra-athlete Variability in Pitching Biomechanics as the Shoulder Joint"
Review Requested: Exempted X Expedited Full Review
Review Approved: Exempted X Expedited Full Review

FULL RESEARCH

_____ Your full review research proposal has been approved by the University JRB (12 months). Please provide the University IRB a copy of your Final Report at the completion of your research. (Extension granted)

_____ Your full review research proposal has been approved with recommendations by the University IRB. Please review recommendations provided by the reviewers and **submit necessary documentation for full approval.**

_____ Your full review research proposal has not been approved by the University IRB. Please review recommendations provided by the reviewers and resubmit.

EXEMPTED RESEARCH

___X__ Your exempted review research proposal has been approved by the University IRB (12 months). Please provide the University IRB a copy of your Final Report at the completion of your research.

______ Your exempted review research proposal has been approved with recommendations by the University IRB.. Please review recommendations provided by the reviewers and **submit necessary documentation for full approval.**

______ Your exempted review research proposal has not been approved by the University IRB. Please review recommendations provided by the reviewers and resubmit, if appropriate.

EXPEDITED RESEARCH

_____ Your expedited review research proposal has been approved by the University IRB (12 months). Please provide the University IRB a copy of your Final Report at the completion of your research.

______ Your expedited review research proposal has been approved with recommendations by the University IRB. Please review recommendations provided by the reviewers and **submit necessary documentation for full approval.**

______ Your expedited review research proposal has not been approved by the University IRB. Please review recommendations provided by the reviewers and resubmit, if appropriate.

Please revise or submit the following:

Please note that federal law requires that you notify the IRB promptly regarding: (1) any additions or changes in procedures (must be approved by IRB prior to implementation) and (2) any events that affect the safety or well-being of the subjects.

East Stroudsburg University of Pennsylvania
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An Equal Opportunity/Affirmative Action Employer

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