A KINEMATIC AND QUALITATIVE EVALUATION TO PREDICT BALL VELOCITY IN BASEBALL PITCHING

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ABSTRACT

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Despite the considerable amount of research describing the biomechanics of pitching, little has been done to utilize these observations to develop an understanding of how to improve pitch velocity quantitatively and qualitatively. The purpose of this study was twofold: (1) Replicate and expand on previous kinematic descriptions of pitching performance, and (2) develop an effective qualitative analysis tool for analyzing pitching performance. Participants consisted of 16 pitchers from a NCAA Division II baseball team. Three-dimensional motion analysis was conducted to quantify six kinematic variables: peak rotational pelvic velocity (PPAV), hip to shoulder separation (HTS), coordination, stride length (SL), knee extension (KE), and ball velocity. The final regression model (R^2 = 0.361) included PPAV ($p = 0.00$), HTS (p=0.01), and KE (p=0.02) as significant predictors of ball velocity. Two-dimensional video of the pitching trials was used to complete the qualitative assessment. Three independent raters performed analyses of the video using a

qualitative assessment tool to identify movements that might indicate high velocity biomechanics. The tool allowed raters to give conditional (i.e., yes or no) responses for 5 specific landmarks within the pitching motion, giving each pitch a score out of 5. No significant association was found between the average rater score out of 5 for each pitch and ball velocity ($r_s = 0.167$; $p = 0.272$). Continued attempts to perfect qualitative analysis and reevaluation of the phase breakdown of the pitching motion are likely essential to unlocking the keys to velocity enhancement.

CHAPTER I

INTRODUCTION

In the world of athletics, there are few motions more biomechanically complex than that of the pitching motion in baseball. Due to this complexity, mastering the motion of pitching is one of the most difficult tasks in sports. Because there are many aspects of pitching that are vital to being successful, pitchers that can master the kinematics of pitching to maximize both velocity and accuracy are highly sought after at elite levels of baseball. With hope of understanding the mechanics of this highly complex movement, biomechanists have frequently analyzed the kinematics and kinetics of pitching which has resulted in an extensive body of research describing the biomechanics of the movement.

The majority of existing biomechanical research on pitching consists of descriptive, comparative, and correlational studies across various levels of baseball. This body of pitching biomechanics literature can usually be grouped into one of two categories:

1) Mechanical descriptions of the pitching motion with respect to injury risk.
2) Mechanical descriptions of pitchers competing at various levels (e.g. professional, collegiate, and youth).

As a result of this wealth of research, biomechanists have a general understanding of the biomechanics of the pitching motion. The first general area of research involves investigating aspects of the movement that may be putting athletes at a greater risk of injury. Examples include examining joint loads specifically in the upper extremity (Oyama, 2012) and analyzing and interpreting the kinetics of the pitching motion in light of known injury mechanisms (Fleisig, Andrews, Dillman, & Escamilla, 1995). This brand of biomechanical research is very important for understanding the safety of the pitching motion and allows for professionals who might work with pitchers (e.g., athletic trainers, coaches, physicians, etc.) to make educated and informed decisions regarding injury rehabilitation, injury prevention, and strength and conditioning.

The second general area of research includes the observation and identification of the characteristics of elite pitchers who exhibit a high production of ball velocity. Examples of this type of research include identifying specific kinematic and kinetic differences across different levels of pitchers (Fleisig et al., 1999) or quantifying specific ground reaction force values produced by elite pitchers (Macwilliams, Choi, Perezous, Chao, & McFarland, 1998). Specifically, kinematic variables such as coordination of the pitch, stride length, pelvis angular velocity, and front knee extension at release have been shown to be related to greater ball velocity (Dun, Fleisig, Loftice, Kingsley, & Andrews, 2007; Escamilla, Fleisig, Barrentine, Andrews, & Moorman, 2002). Understanding the relationship between various kinematic variables and ball velocity could be valuable in developing methods to help pitchers improve performance.

The importance of some kinematic variables in developing high ball velocity has been repeatedly demonstrated, however, the evidence is less clear for other variables. For example, high velocity pitchers have been shown to exhibit greater hip to shoulder separation than low velocity pitchers (Matsuo, Escamilla, Fleisig, Barrentine, & Andrews, 2001; Robb, Fleisig, Wilk, Macrina, Bolt, & Pajaczkowski, 2010). Matsuo et al. (2001) determined that elbow extension angular velocity occurred earlier in a high velocity group compared to a low velocity group, suggesting a more sequential coordination pattern is related to greater ball velocity. However, evidence regarding stride length and its’ relationship with ball velocity is somewhat conflicted. For example, Dun et al. (2007) found a longer stride length as a percentage of body height was found in older, higher level pitchers when compared to younger, lower level pitchers. However, there was no significant difference in velocity between these groups. Fleisig et al. (1999) found stride length as a percentage of height not to be related to ball velocity across various levels of development. Escamilla et al. (2002) showed that a greater maximal pelvis angular velocity was related to a greater ball velocity, and that a lower degree of knee flexion at the moment of ball release was related to greater ball velocity when comparing high velocity and low velocity groups. The wealth of knowledge that has resulted from these descriptive studies is key to understanding the pitching movement and has led to many breakthroughs related to the mechanics of pitching and specificity of training.

Though, the knowledge that has been gained through these lines of biomechanical research in pitching is extensive, the majority of this knowledge is observational in nature. This provides researchers with powerful insight into the mechanics of the pitching motion, but it does not necessarily provide coaches and athletes with an understanding of how to teach or execute these movements. Because of this, a new opportunity for research presents itself in the form of developing an efficient means of applying our thorough quantitative understanding of the biomechanics of pitching in a qualitative fashion. Developing this third group of research within pitching biomechanics would allow for the assembly of a qualitative coaching model that utilizes existing quantitative knowledge in a practical way. Such as qualitative model would give players the opportunity to learn the movement patterns conducive to producing an elite level of ball velocity from their pitching motion.

While there is a considerable amount of research dedicated to the different groups of pitching literature, little work has been done to use the biomechanical observations from the descriptive studies of elite pitchers to bridge the gap between low velocity pitchers and high velocity pitchers. Specifically, how can we use our current biomechanical knowledge of skilled pitching to help less skilled pitchers throw with greater ball velocity, while maintaining accuracy? Currently, many anecdotal accounts from the professional baseball world classify an elite level of pitching as something an individual can only achieve if they are naturally gifted. That is, many believe that one cannot teach an individual to throw with elite kinematics. Following this belief, every year in the Major League Baseball Draft, professional clubs draft young pitchers who can throw with high velocity over pitchers who throw with lower velocity but arguably better control and consistency. The commonly held belief is that a pitcher who can throw with high velocity and poor control can be taught to pitch with accuracy and control, but a pitcher who throws with low velocity and high marks in the other areas of pitching (i.e. accuracy and control) can't be taught to throw with high velocity.

From a biomechanical perspective, the second part of this previous statement does not make sense due to its lack of agreement with the rest of the world of movement and biomechanics. For example, Mache (2005) was able to employ visual and verbal feedback to elicit changes in movement that resulted in enhanced performance. Specifically, participants who received feedback were able to reduce the range of motion used in the propulsive phase of the jump and this reduction in range of motion was related to an increase in vertical jump height. This improvement in performance that was associated with kinematic changes in the jumping motion indicates that the kinematics of motion are indeed modifiable. If jumping performance can be influenced by biomechanical changes, why should pitching be any different? In order to reach this level of practice, we must first formulate a system of qualitative analysis that is efficient at identifying relevant landmarks in the pitching motion. Once a group of performance-related qualitative landmarks are identified within the pitching motion, experimentation with intervention and modification of actual pitching technique can occur.

Nicholls, Fleisig, Elliott, Lyman, & Osinski (2007) attempted to develop such a qualitative system and tested the accuracy of the qualitative analysis of independent raters when assessing baseball pitching technique with two-dimensional video and concluded that "*a complete and accurate profile of an athlete's pitching mechanics cannot be made using the Qualitative Analysis of Baseball Pitching (QAP) in its current form, but it is possible such simple forms of biomechanical analysis could yield accurate results before 3-D methods become obligatory*" (p.213). Thus, the present study aimed to expand upon the ideas incorporated in the methods of Nicholls et al. (2007) by utilizing a camera with a faster frame rate and by simplifying the movement landmarks the raters will be looking for while qualitatively analyzing the video with hopes of developing a more effective qualitative analysis tool

Statement of the Problem

The present researcher examined the possibility of bridging the gap between quantitative pitching research and qualitative assessment and coaching. The two objectives of the study were to (1) replicate kinematic predictors of ball velocity identified in previous research, and (2) develop and qualitative system of assessment that could be linked to quantitative data and then test the efficacy of this assessment tool.

Research Hypotheses

1) The measured kinematic variables would significantly predict ball velocity.
    a. A greater magnitude of peak pelvic angular velocity would be predictive of greater ball velocity
    b. A greater stride length would be predictive of greater ball velocity.

c. A greater magnitude of hip to shoulder separation would be predictive of greater ball velocity.

d. A smaller timing gap between front foot strike and peak rotational pelvic velocity would be predictive of greater ball velocity.

e. A smaller magnitude of lead knee flexion would be predictive of greater ball velocity.

2) A higher average rater score on the Qualitative Assessment of Pitch Velocity (QAPV) sheet (Appendix A) would be predictive of greater ball velocity.

Purpose of the Study

One aspect of the present study was to replicate the findings from the conglomeration of observational data explaining how an elite pitcher moves. In order to do so, the present researcher quantified the following variables: peak pelvic angular velocity, hip to shoulder separation, coordination of the pitching motion, stride length, and lead knee extension. The relationship between these five kinematic variables and ball velocity were examined in an attempt to confirm previous findings in biomechanical pitching research. These results were intended to provide the quantitative basis necessary to move forward and attempt to more accurately utilize qualitative assessment to analyze the pitching motion.

The second aspect of the present study involved the evaluation of a qualitative system of assessment, grounded in quantitative biomechanical findings that can be used via 2-D video to qualitatively assess a pitcher's mechanics with the purpose of helping the pitcher achieve maximal ball velocity. The model involved a yes or no assessment sheet for independent raters to score each landmark in the assessment model for each pitcher. Each pitcher then received a total score for the pitch from the raters calculated as the total number of "Yes" assessments out of 5 from each rater. If effective, this applied biomechanical assessment tool could eventually be used by coaches and athletes to enhance pitching performance. The establishment of an evidence-based system of qualitative analysis would allow coaches and athletes alike to look at an athlete's mechanics via video and potentially make direct changes to kinematics which could result in improvements in ball velocity. This kind of system would provide an alternative method to 3-D motion analysis for the examination of pitching mechanics. This would allow an individual without the biomechanical training required to execute and comprehend a 3-D motion analysis session, or without access to a biomechanical facility with 3-D instruments, to wield the same analytical power as someone with all of the aforementioned biomechanical "toys" at their disposal. Furthermore, this system could be applied by coaches and athletes to improve ball velocity in a manner which does not put the pitcher at an elevated risk for arm injury.

Limitations of the Study

There were a few limitations to this research. First, the subject pool was relatively small and therefore the results might be less powerful than that of a study containing a greater number of participants. Although this group is smaller than ideal for a statistical analysis, it is still sufficient to analyze the quantitative aspects of this research. Second, the volunteers for this research came from only the college level and therefore results of this study may be limited to only college level athletes and may not reflect what might occur in other populations of pitchers. This uniformity in the level of competition of the participants does not diminish the importance of this research however, the results should be interpreted in light of this fact. Third, the pitches executed in the data collection for this study were performed on a portable turf mound while wearing tennis shoes, neither of which are exactly congruous with the game environment for a pitcher. This could possibly have swayed results from what might occur on an actual dirt mound while wearing baseball cleats. This limitation is inevitable with most pitching research and is present in the majority of previous research. Finally, the independent raters used for this research had previous experience with the pitchers involved in the study and this might have influenced their qualitative analyses. However, as the raters chosen were all highly experienced and able to analyze the video for the desired landmarks objectively the researcher is confident that minimal bias was introduced in this process.

Definition of Terms

Ball Release

The instant at which the baseball leaves the pitcher's hand during the pitch. This will be defined as the second video frame (0.0083 s) after the dominant wrist passes the dominant elbow in the sagittal plane (XZ plane).

Ball Velocity

The maximal resultant velocity attained by the baseball when it is thrown by the pitcher. Typically measured using a radar gun and recorded in miles per hour.

Coordination

The timing with which segments of the body perform their respective movements within the pitching motion. This will be defined in this study by measuring the amount of time between front foot strike and peak pelvic angular velocity.

Front Foot Strike

The moment the stride foot makes contact with the mound during the pitching motion. An instant in time calculated as the moment when lead ankle velocity decreases to less than 1.5 m/s after foot contact with the mound.

GoPro Hero 3+

2-D video recording device capable of capturing video at a resolution of 720p and 120 frames per second.

Hip to Shoulder Separation

The angle at which the hips and shoulders disassociate from one another in the transverse plane.

Lead Knee Extension

The extension angle of the lead knee at the moment of ball release.

Peak Pelvic Angular Velocity

Peak pelvic angular velocity is a calculated value that refers to the velocity with which the pelvis rotates in the transverse plane during the pitching motion.

Portable Pitching Mound

Turf pitching mound measuring 1.524 m wide x 2.95 m long x 0.254 m high.

Radar Gun

Device used to measure the maximal velocity at which a ball is thrown by a pitcher (Stalker Radar, Plano, Texas).

Stride Length

The distance the front foot travels forward during the movement. The distance, in the throwing direction, between the pitching rubber and the lead heel at the moment of front foot strike.

CHAPTER II

REVIEW OF LITERATURE

The purpose of the present research was first, to reproduce existing quantitative findings related to pitching kinematics and ball velocity, and second, to determine the effectiveness of a qualitative system of analysis for the baseball pitch. To better understand existing information related to the mechanics of baseball pitching, both the quantitative and qualitative aspects, the following review of relevant literature is broken into four primary sections: 1) quantitative mechanical analyses related to skill in the pitching motion, specific to lower body kinematics, 2) qualitative analyses, coaching techniques, and instructional methods related to the baseball pitch, 3) a direct comparison of the available quantitative and qualitative baseball pitching information, and 4) effectiveness of qualitative raters utilizing 2-D video in baseball pitching. Furthermore, the third section of the literature review will provide justification for the landmarks that will be utilized in the present study to qualitatively assess pitching performance.

Quantitative Mechanical Analyses of the Baseball Pitch

Phases of the Pitching Motion

The biomechanical research concerned with the mechanics of pitching is extensive and covers many aspects of the kinematics and kinetics of the motion of pitching. Most of these analyses of the pitch begin by breaking the motion into chronological phases from start to finish. Dillman, Fleisig, and Andrews (1993) break the pitching motion into 6 phases: windup, stride, arm cocking, arm acceleration, arm deceleration, and follow-through. These phases of the pitching motion are described by Dillman et al (1993) as follows.

Windup Phase

The windup phase is initiated when the pitcher, initially facing the catcher, takes a step laterally with what will eventually become the stride leg. The drive leg then rotates into position flush and parallel with the pitching rubber. The pitcher then turns their entire body, so they are now perpendicular to the catcher and lifts their stride leg up into a balanced position. This balanced position signifies the end of the windup phase.

Stride Phase

After the windup phase, the drive leg flexes and the entire body is lowered, thus beginning the stride phase. As the pitcher strides towards the catcher and down the pitching mound, they remove the ball from the glove into the pitching hand to prepare for the pitch. The pitcher continues moving down the mound into the stride until the front foot strikes the ground in line with the back foot (Dillman et al. 1993). This moment is known as front foot strike and signifies the end of the stride phase.

Arm Cocking Phase

Once the stride phase is completed, the hips, trunk and shoulders begin to rotate sequentially with the throwing arm undergoing elbow flexion and shoulder external rotation into its “cocked” position. Once this position has been attained, the arm cocking phase ends.

Arm Acceleration Phase

Following the arm cocking phase is the arm acceleration phase, which involves the arm rotating forward about the trunk and extending through the moment of ball release.

Arm Deceleration Phase

Once the ball is released, the arm deceleration phase begins, which involves continued shoulder internal rotation, extension at the elbow, and pronation of the forearm. Once these motions have significantly decreased, the arm deceleration phase ends.

Follow Through Phase

This phase entails extension of the front knee, continued hip flexion, trunk flexion, shoulder adduction and horizontal adduction, and forearm supination (Dillman et al. 1993).

These pitching phase definitions will help to piece together the existing quantitative data related to ball velocity and understand where each of these instances lie within the pitching motion.

Pitching Research with Respect to Phases

Stride Phase

A good place to start when analyzing the relevant literature for baseball pitching performance is the beginning of the stride phase. This moment in the pitching motion is believed to be a potentially key moment for the production of force towards home plate and thus the moment at which forward momentum begins. The first aspect of the stride phase that is important to observe and understand is the distance from the pitching rubber, in the direction of home plate, that the stride foot strikes the ground. This distance is commonly referred to as the stride length of the pitcher. Ramsey, Crotin, and White (2014) looked at variations of stride length in pitching as it relates to linear momentum in the direction of the catcher. The researchers performed this study with the idea that if a change in stride length causes a change in the linear velocity of the body, then stride length may be an indicator of how much ball velocity a pitcher can produce. The authors confirmed that indeed, pitchers with a shorter stride length generated lower anterior momentum before front foot contact when compared to pitchers with a longer stride length. However, upward and lateral momentum values were found to be greater among pitchers with a shorter stride length than that of pitchers with a longer stride length. The researchers concluded that insufficient total body momentum in the intended direction of the throw may negatively influence the velocity at which the pitcher can pitch the baseball. These findings suggest that stride length is a good indicator of the direction of the total body momentum and that a greater stride length may result in the pitcher generating more momentum towards the intended target.

Another aspect of the stride phase that is important to observe and understand is the actual force being produced by the lower body. Macwilliams, Choi, Perezous, Chao, and McFarland (1998) measured the ground reaction forces of both the drive foot and the stride foot in baseball pitching. This measurement was performed using force plates along with a reflective marker set in order to determine the correlation between ground reaction force values and various kinematic variables during the pitch. Macwilliams et al. (1998) found that the magnitude of the resultant force from the drive leg during the stride phase was highly correlated to peak wrist velocity. That is, a greater resultant ground reaction force from the drive leg during the stride phase was directly related to a greater peak wrist velocity. Furthermore, the researchers found that a greater anterior-posterior shear force was highly correlated to greater peak wrist velocity, and the correlation was much stronger than that observed for the medial-lateral shear force and vertical ground reaction force. These findings indicate that when a pitcher uses a larger absolute force from their lower body, they will exhibit a greater ball velocity. Perhaps equally important, these results indicate that the direction of this force is also important when attempting to elicit an increase in ball velocity. At the beginning of the stride phase in pitching, the larger the amount of drive leg force and the more linearly directed towards the catcher it can be, the greater the resulting ball velocity output will be.

Arm Cocking Phase

Immediately following the culmination of the stride phase comes the arm cocking phase. One of the first variables to look at during these phases is hip to shoulder separation during the arm cocking phase and its relationship with ball velocity. The means by which researchers measure and analyze hip to shoulder separation is detailed below.

Some researchers define hip to shoulder separation in kinematic terms. For example, Robb et al. (2010) and Dun, Fleisig, Loftice, Kingsley, and Andrews (2007) both measured the rate of change in angle between the pelvic and torso vectors, respectively. The pelvic vector was defined as a line connecting adjacent points on the posterior sacroiliac crests in the frontal plane and the torso vector was defined as a line connecting the right and left acromioclavicular joints in the frontal plane (Robb et al., 2010). This velocity value is indicative of the speed with which the hips and shoulders are separating from each other during the pitching motion, not necessarily the speed of either vector individually.. Robb et al. (2010) and Dun et al. (2007) both found a greater magnitude of this separation angular velocity to be associated with greater ball velocity produced by the pitcher.

Another important aspect of the pitching motion during the arm cocking phase is the gap in timing between front foot strike and peak rotational hip velocity. This timing gap is typically assessed by measuring either the absolute or relative difference in time between these two events. For example, Fleisig et al. (1999), Escamilla, Fleisig, Barrentine, Andrews, and Moorman (2002), Urbin, Fleisig, Abebe, & Andrews (2012), and Matsuo et al. (2001) looked at the relative timing differences by normalizing the pitch cycle from 0 to 100, time 0 equated to front foot contact and time 100 corresponded to the instant of ball release. Using this temporal continuum Escamilla et al. (2002) determined the instant of peak pelvic angular velocity to occur at 28% and 35% of the normalized pitching cycle for the high and low velocity groups, respectively. Similarly, Matsuo et al. (2001) determined the separation-timing to be 6% lower on the continuum in the high-velocity group than the low velocity group. A smaller timing gap here appears to benefit pitch velocity by creating a more sequential coordination throughout the pitch.

A main piece of measuring the timing gap discussed above is measuring angular pelvic velocity and establishing when the peak pelvic angular velocity occurs. Escamilla et al. (2002) analyzed kinematic, kinetic, and temporal differences between American and Korean pitchers. The authors found that American pitchers exhibited a significantly greater peak pelvis angular velocity. This difference is important because the American pitchers also exhibited greater ball velocities than the Korean pitchers, allowing the authors to draw the conclusion that greater peak pelvis angular velocity is directly related to greater ball velocity.

<u>Arm Acceleration Phase</u>

The first important kinematic piece to consider during the arm acceleration phase is the bracing of the front leg to stop forward momentum and help transfer energy up the kinetic chain and eventually to the arm. Werner, Suri, Guido, Meister, and Jones (2008) looked at ball velocity and its relationship to various aspects of the pitcher and pitching mechanics. Along with body weight of the pitcher and 6 other kinematic and temporal aspects of the pitching motion, front knee angle at the moment of ball release was found to be highly correlated to ball velocity. More specifically, a lesser degree of knee flexion at the moment of ball release was found to be directly related to greater ball velocity. This implicates the front leg as a key link in the chain of the pitching motion. The components discussed above concerning the production of force and the rotational separation of the hips and shoulders are important in terms of creating the necessary momentum to produce a high velocity pitch, but if the front knee flexes too much and or the knee position of the front leg is not maintained through ball release, the momentum created cannot be transferred up the kinetic chain to the ball and thus it is lost.

Conclusion

When taken together existing biomechanical literature highlights several kinematic variables during the baseball pitch that appear to be key determinants of ball velocity. After reviewing the relevant literature, it would appear that coaches and athletes should be particularly concerned with achieving the following kinematics during the pitching motion if they wish to maximize pitch velocity: maximal linear momentum (i.e., maximum forward velocity of the body), maximal hip to shoulder separation, greater stride length, greater peak pelvic angular velocity, sequential coordination, and a greater front knee extension angle at ball release. With these kinematic variables in mind, the question remains how can this information be provided to coaches and athletes in a useable manner?

Qualitative Descriptions of Proper Pitching Mechanics

In addition to the host of quantitative data available for the movement of pitching, there is also a long-standing tradition of a more qualitative approach to analyzing the pitching motion. Interestingly, the quantitative descriptions of the characteristics of high velocity pitching do not always align well with some of the qualitative coaching methods used by coaches and athletes. The subsequent discussion will include a review of some existing qualitative coaching practices and how they can be applied to the previously described phases of the pitching motion to enhance baseball pitching performance.

Windup Phase

The main focus of much of the qualitative coaching information regarding the windup phase focuses on what is referred to as the balance point. The common usage of the term balance point refers to the end of the windup phase when the knee of the stride leg reaches its highest point. Keller (2001) describes this point in the motion by indicating that it requires balance, specifically stability, and that the posture of the pitcher must remain tall and still at this instant. Keller (2001) states that the balance position should be achieved and held with the toe pointing down in order to allow the pitcher to properly execute the remainder of the pitching motion. Similarly, Ellis (2015) encouraged pitchers to take their time and to not rush through the balance point. House, Heil, and Johnson (2006) also stated that the balance point is an important preliminary step in consistently setting up the pitching motion. Most qualitative coaching techniques reference this balance point as a key to ensuring consistency and performance within a pitching motion.

Stride Phase to Arm Acceleration Phase

The stride phase of the pitching motion is addressed in different ways among pitching coaches. The most traditional modes of coaching use one of two strategies to describe the stride phase, the tall and fall method or the drop and drive method (House, Rosenthal, & Ryan,1991). House et al. (1991) explain the tall and fall method as a pitcher reaching the balance point described above and then falling towards home plate slowly. House et al. (1991) describe the drop and drive as an alternative method that involves a pitcher flexing the knee of the drive leg significantly before ever moving towards the plate. Once the vertical drop has been achieved through drive leg knee flexion the pitchers should include a slight pause to separate the drop from the drive, following the brief pause the pitcher then executes the drive towards the plate and completes the pitch. Though these two schools of thought have been expanded on slightly in recent attempts to improve the coaching of the lower body aspects of the stride phase, they remain a foundation of anecdotal descriptions from coaches describing how the lower body should contribute to the pitching motion. While these two strategies seem strikingly different and incompatible, they are both attempting to accomplish the common goal of maximizing production of velocity from the pitching motion.

Another qualitative aspect of pitching instruction relates to the use of the upper body during the stride phase and throughout the arm acceleration phase. House et. al. (2006) stated that hip to shoulder separation accounts for 80% of ball velocity in pitching and therefore is the main determinant of how a pitcher produces ball velocity. Another anecdotal coaching strategy commonly used involves a technique during the stride phase while travelling towards home plate. The pitcher is instructed to position their arms horizontally away from the body and opposite of one another, with the lead arm pointing towards the plate and the throwing arm pointing backwards towards second base. This technique is echoed in the statements of Keller (2001) when he stated that the glove arm and throwing arm should extend out opposite of each other, to home plate and second base respectively. Aside from the equal and opposite arm technique, an effective qualitative description on how to instruct a pitcher to achieve the desired hip to shoulder separation and maximal ball velocity remains fairly vague.

<u>Arm Deceleration and Follow Through Phases</u>

Another thought about the pitching motion that is commonly encountered is that the pitcher must follow through towards the catcher and that the pitcher must do so over a firm front leg. Gotch (2012) explains that once the ball is released, the knee of the front leg should no longer be flexed and the upper body should be completely bent over this leg. Gotch (2012) also states that once the pitch is delivered the front leg should brace the body and the movement towards home plate should stop. These examples of coaching the arm deceleration and follow through phases, as well as anecdotal coaching interactions seem to agree and adequately explain what a pitcher should be doing once the ball has been released.

Comprehensive Qualitative Approach

Aside from the previously described phases of the pitching motion and the existing qualitative coaching techniques that apply to each individual phase, there are also methods of qualitative coaching that attempt to address the pitching motion in a more comprehensive fashion. Examples include a step by step instructional book from a high-level pitching coach (Johnson, 2013), pitching instruction books for youth baseball players (Russell, 2013; Ellis, 2015), and online instructional publications on how to coach young pitchers (Youth Pitcher, n.d.; CAC, 2011). These various sources break down the pitching motion in an extensive qualitative manner, providing detailed explanations and instructions on how the pitching motion should be executed from start to finish. Many of their descriptions are basic level items aimed at those just learning the movement of pitching, but high-level aspects are targeted as well. The following will be an overview of this qualitative pitching mechanics instruction within the phasic structure put forth by Johnson (2013).

Pre-Mechanics

This section of the instructional approach provided by Johnson (2013), covers certain starting positions that should occur before the pitching motion occurs. The first of these starting positions addressed is that of the eyes. According to Johnson (2013), “the body follows the eyes” (p.15) and because of this, training the eyes on the target throughout the pitching motion will help align to the body properly and elicit a more consistent throwing motion. Ignoring the eyes as an element of focus and control will cause “poor posture and direction to the plate” (p.18). Youth Pitcher (n.d.) also deems it to be important for a pitcher to train the eyes to a specific target as a focal point, the specific target of choice in their instruction being the catcher’s mitt. Russell (2013) supports this strategy of focus by suggesting it is ideal to give young pitchers specific pieces of information to focus on rather than generalizations in order to elicit positive outcomes. Following along with eye position and focus is the next position mentioned in this instructional model, that of the head. Johnson (2013) states “the center of the body… is the energy source of movement and is most responsible for how the body moves in space, but the head should be thought of as the stabilizer” (p.19). This follows the same approach as the eyes technique listed above, with the position of the head being a controlling aspect of the posture of the pitcher. According to this model, the head should remain still directly above the spine, and the more still it can remain, the more consistently the pitcher will be able to maintain their balance.

The next starting position addressed is that of the feet. Johnson (2013) states “the back foot acts as a rudder used to steer a boat... If the heel of the back foot sweeps and leads the toe… alignment issues occur” (p.23). This model instructs pitchers to keep the heel close to the rubber as the pitching motion is beginning and not to allow the heel to lead the foots path off the rubber. This will allow a restriction of unwanted rotation resulting in inconsistent pitch location and execution. Youth Pitcher (n.d.) recommends that a pitcher start in the middle of the rubber and to make sure that the spot chosen remains consistent from pitch to pitch. Transitioning from the foot starting position to the next position, that of the knees and hips, Johnson (2013) states that the knees should be “bent evenly about shoulder-width or armpit-width apart” (p.26) and that the hips should be “completely perpendicular to the rubber and the plate” (p.25). The goal of these particular starting points is to allow the pitcher to remain balanced and aligned properly and to avoid any restriction of the subsequent movement in the pitching motion.

The next position addressed is that of the leg lift. This coaching model instructs pitchers to lift their lead leg to a comfortable height, with the foot inside the vertical barrier of the knee, and without excess rotation. According to Johnson (2013), “an efficient leg lift creates a better chance for the delivery to be connected” (p.27). This efficient leg lift will allow the movement towards the plate to be powerful and directed in the right path, allowing for maximal consistency of the execution of the pitch. Russell (2013) and Ellis (2015) both include the importance of a balanced leg lift in their pitching instruction as well, citing poor balance in the leg lift as one of the most common mechanical flaws in young pitchers. The last starting position addressed is that of the hand positioning and its action. According to Johnson (2013) “the pitcher’s hands travel up and break apart, giving the pitcher the opportunity to stay on time” (p.29). This timing mechanism links with the top of the leg lift and is an attempt by this coaching model to maintain timing between the upper body and the lower body during the beginning of the pitching motion.

Components of Pitching Motion

The next section of this comprehensive instruction is addressing the components of the pitching motion with respect to the lower body and upper body and instruction aimed at these specific body segments rather that targeted at the classic phases of pitching. This section deals mostly with defining the way different pitchers throw and what, according to various coaching examples, is the best approach.

Upper Body

The first upper body aspect addressed is arm slot, better defined as the angle at which the pitcher’s release of the ball occurs. Johnson (2013) claims that the arm slot of a pitcher is a naturally discovered position and shouldn't be changed unless unique circumstances arise. Proceeding from arm slot, this instructional model addresses the more specific aspect of arm action. Arm action is the manner with which the pitcher removes the ball from the glove and approaches the "arm cocking" phase. Johnson (2013) breaks different arm action types into five categories: classic, classic with elbow climb, horizontal W, inverted W, and inverted L. Classic arm action is defined as a long slow motion where the hand is the leader of the arm swing and the rest of the arm follows the path of the hand. Classic with elbow climb is similar to that of classic but differs in the sense that when the arm reaches full extension, hand drive is replaced by the vertical movement of the elbow. Horizontal W involves the arms being immediately driven up and into the form of a W, with the elbows staying parallel to the ground. Inverted W involves pronounced vertical movement of the elbows beyond the level of the shoulders and the forearms and hands following directly under. The inverted L arm action involves the arms moving asymmetrically out of the hand break, with the glove arm being straight and the throwing arm being bent into a similar position as the inverted W. Johnson (2013) states that these arm actions are all present in pitchers and that the inverted W is thought by some to elicit arm injury risk. Other publications aren't quite as detailed as this description of the upper body positioning, with many just referring to the importance of "staying closed" with the front shoulder (Russell, 2013; Youth Pitcher, n.d.).

The next upper body aspect is the action of the glove approaching the moment of ball release. Johnson (2013) suggests that the glove hand should undergo a "pinch and swivel" technique where the "glove-side hand closes to keep the desired drive line to the plate… and the spacing between the glove and chest will narrow as the pitcher arrives at his release point" (p.49). The idea behind this instruction is to use the glove arm as a guide to the path of the pitch and to assist in the rotary aspect of the pitch without causing excess rotation from the front side. Furthermore, Johnson (2013) states that the arm and glove should be synchronized during the delivery of the pitch. Specifically, “using both sides of the upper body in tandem should also increase power output… the pitcher uses the glove side to gain more leverage and produce more power” (p.52-53). This qualitative model describes this efficient balance of both sides of the upper body as a mechanism for creating power and velocity. CAC (2011) also stresses the importance of the front and back arms matching each other in their respective swing paths in order to maintain balance and efficiency throughout the motion. Proceeding from this, the model then addresses the finish of the upper body. Johnson (2013) states “At the release… the pitcher will want to finish with his upper body and chest over his front knee, his arm should be going to his opposite hip” (p.54). This coaching model instructs pitchers to finish their throw in this manner in order to properly slow down the throwing arm and allow for minimal deceleration muscle injury. This idea of an efficient follow through to decelerate the arm is echoed in numerous coaching sources (Russell, 2013; Ellis, 2015; Youth Pitcher, n.d.; CAC, 2011).

Lower Body

The third section of pitching mechanics addressed in this qualitative coaching model is that pertaining to the movements of the lower body during the pitching motion. This instruction is provided in a manner similar to the upper body instruction, proceeding from the beginning of the motion to the moment of ball release, and again attempts to address efficiency and repeatability of the pitching motion.

The first lower body mechanical aspect addressed by Johnson (2013) is that of the knee lift. This approach states “as the knee is lifted, the pitcher should feel the bulk of his weight on the ball of the rear foot and not the heel… the pitcher should lift the leg by using the quadriceps muscle only” (p.67). This portion of the instruction is an attempt to keep the lift of the leg as calm as possible and to limit excess motion that may inhibit proper direction or efficiency. Lifting the leg efficiently and in a straight line allows for proper positioning to move down the mound and into the pitching motion. The next aspect of that pitching motion in regard to the lower body is what this model refers to as the “hip set”. Johnson (2013) states, “as the leg is lifted… the back knee and back hip will push forward, causing the hip joint to be tilted toward home plate so that the front hip joint is leading the rest of the body” (p.69). This setting of the hip and lean with the hip towards the plate, according to this model, will allow for the pitcher to be on time with their motion and deliver the ball efficiently down the plane of the mound towards the plate. CAC (2011) also stresses this front hip lean idea, but instead utilizes the term “lead with the back pocket” as a way to help facilitate this movement. Along with this hip action, the angle of the shin is also addressed as a contributor to this proper direction and timing. Johnson (2013) states “the back knee turns in just when or just after the hip is set, helping the pitcher stay in line” (p.70). Again, this is another aspect observed and addressed in this qualitative model that is designed to help contribute to the efficiency of the movement.

After these beginning lower body positions are addressed, the next portion looked at by this model is the idea of riding the back leg. Johnson (2013) states this portion as “carrying the load that was created…keeping the front leg from opening too early” (p.71). The idea of riding the back leg down the mound is this model’s attempt to instruct pitchers to maintain linear movement towards the plate as long as possible before allowing rotation to occur, with the idea that this waiting to rotate will allow for an optimal delivery. Youth Pitcher (n.d.) also mentions the importance of a powerful stride towards the catcher as the method by which power is created in the pitch. The next step is analyzing the stride of the front leg just before the moment of front foot strike. Johnson (2013) instructs this phase by saying “The pitcher’s back hip starts to rotate first, but the knee and foot remain closed off… keeps the pitcher from spinning too early” (p.72). The idea behind this instructional aspect is to teach pitchers to stride without turning the lead foot towards home plate too much, and specifically not to allow the front hip to “leak” open before the rest of the motion is ready for this rotation. Immediately after the stride is the landing of the front foot. Johnson (2013) states that “the foot should land slightly closed or with the toe pointing directly at the target, as opposed to landing extremely open or extremely closed” (p.73). This coaching model wants pitchers to land with a flat front foot, and with this slightly closed positioning of the foot in order to allow for as efficient a finish to the throwing motion as possible.

The last lower body aspect addressed by this coaching model is that of the finish of the lower body. The model describes what the author calls the “Backward C” position as the next landmark found in a proper pitching motion. “As the shoulders square up to release the ball, the lower back creates a backward C extension” (p.74). This position consists of the lower body in a lunge-like position, with the lower back and thoracic spine arched back, and the throwing shoulder experiencing external rotation behind the rest of the body. “As the arm moves forward, the chest is thrust out, and the front knee and leg begin to stabilize” (p.74). Russell (2013) also touches on this moment and the importance it holds in delivering the pitch with authority. The terminology used in that particular example is that of “driving the backside home”, which is essentially an instructional tool to help the pitcher use their lower body completely. The model then describes the pitcher releasing the ball, followed by flexion of the trunk and torso and the rear hip rotating over the front hip. This finish over the front leg involving flexion in the torso and rotation of the hips allows for a proper finish to the pitch and efficient deceleration of the pitching motion. CAC (2011) also describes a drag mark of the rear leg in the same direction of the pitch as a positive sign for a good “follow through” with the lower body.

These comprehensive coaching models are aimed at instructing the pitching motion in minute detail from start to finish. While the college and professional instructional book (Johnson, 2013) is the most in depth and detailed approach to qualitatively instructing the mechanics of pitching, the other sources above aim their instruction at an audience that is still learning the basics of the pitching motion. Both types of pitching instruction are valuable tools for a young athlete, or an athlete who is just beginning their pitching career. However, as far as addressing aspects within the motion that directly produce or inhibit velocity, these coaching tools still do not deliver in specific detail. These qualitative tools are useful for developing an efficient and “proper” delivery that will elicit consistency and the ability to throw strikes. In their current form they cannot be used as in full confidence that it will produce velocity. Further development of some aspects put forward in these coaching examples and an attempt to link these aspects more directly to ball velocity or specific quantitative aspects correlated to ball velocity, is a direct motivation for performing the present research.

Quantitative and Qualitative Descriptions of Pitching Performance

After exploring the quantitative data related to greater ball velocity and the qualitative coaching methods used to enhance pitching performance, it is important to evaluate how these two bodies of information align. Specifically, areas where the connection between qualitative coaching methods and available quantitative information can be strengthened will be identified.

The first disconnect that appears when comparing the quantitative data describing pitching performance and qualitative coaching practices lies in the windup phase and beginning of the stride phase. From a review of the quantitative data describing these phases it seems that stride length (Ramsey et al., 2014) and anterior-posterior shear force (Macwilliams et al., 1998) are both important factors in creating linear momentum (i.e., body velocity) towards home plate during the pitch. These factors indicate that the pitcher should move aggressively down the hill to produce the force required to create higher ball velocity. However, when we look at coaching practices we see that coaches want pitchers to reach a calm balance point (Keller, 2001) and then either fall towards the plate slowly, or drop down vertically before pushing towards home plate (House et al., 1991). These qualitative descriptions do not seem to represent the quantitative kinematics known to be associated with high ball velocity. Thus, qualitative coaching descriptions that better reflect the kinematic variables associated with producing velocity must be developed. A more appropriate qualitative description of this portion of the pitching motion should involve a new way to assess the balance point. Specifically, how should the pitcher be positioned at the top of the leg lift in order to elicit proper power production? Furthermore, qualitative landmarks during the stride phase should be developed to coach and assess how the force from the drive leg is being oriented and generated.

The second disconnect between the quantitative and qualitative information related to the pitching motion lies at the end of the stride phase after front foot strike. The quantitative research targeted at this point in the pitching motion shows that hip to shoulder separation (Robb et al., 2010), hip rotational velocity (Escamilla et al., 2002), and timing of hip rotation (Urbin et al. 2013) all contribute to the creating a sequential coordination pattern within the pitching motion and therefore result in higher ball velocities. Existing qualitative coaching practices simply state that maximal hip to shoulder separation is what must be achieved in order to attain greater ball velocity. This qualitative explanation however is too simple and deals only with the result of properly using the kinetic chain and to achieve a sequential coordination pattern, it does not provide a description of how a pitcher might go about accomplishing this. A new qualitative landmark should be created to properly assess the causal side of this separation rather than just the result. It is possible that looking at when the hips begin to rotate, rather than looking at the hip to shoulder separation, will allow a coach to effectively see whether or not a pitcher is doing what is needed to achieve the end goal of hip to shoulder separation and maximal ball velocity.

The third disconnect that exists between the quantitative and qualitative sides of pitching literature relates to the involvement of the lead knee in the pitching motion. While both quantitative and qualitative sides agree that the lead knee must be more extended than flexed towards the ends of the pitching motion, there is disagreement with when it is important for this knee angle to be more extended than flexed. Qualitative coaching practice deals with the lead knee angle well after the ball has been released and into the follow through (Gotch, 2012), whereas the quantitative findings show that the lead knee angle at the moment of ball release has a significant influence on ball velocity (Werner et al., 2008). In order to improve current coaching models, a new qualitative landmark should be created that addresses flexion of the front knee at the moment of ball release, as this has been shown to be related to greater ball velocity.

With the current disconnects between our quantitative knowledge of high velocity pitching and qualitative practices being identified, it is clear that some changes need to be made in order to both more accurately reflect what has been found in the quantitative research and to provide an effective qualitative model that contains what should be addressed by coaches and athletes throughout all points of the pitching motion. It is the hope of the present researcher to formulate a new, comprehensive qualitative model that can eventually be used with two-dimensional video to assess the pitching motion and facilitate performance enhancement through instruction. The qualitative landmarks that are described in detail in the subsequent methodology section have been developed with hopes of filling the gaps in current qualitative practices and provide a consistent model that can used practically by coaches to help assess their athletes more effectively and efficiently.

Qualitative Assessment Methods

Because the present research concerns the development of an effective qualitative system by which pitching mechanics can be accurately assessed, it is important to consider relevant literature regarding techniques in the actual implementation of qualitative assessment of movement. An example of existing literature involving qualitative assessment is Nicholls et al. (2007), where the researchers analyzed the accuracy of a specific qualitative assessment tool for the baseball pitch. In this study, independent raters analyzed pitching performance via 2-D video. The subject pool for the study consisted of youth pitchers, with a mean age of 12.86 ± 1.29 years. The study protocol included two sessions of throwing, one outside on a baseball field where the subjects were videoed with 2-D cameras and another session in a laboratory setting where data was collected using a 3-D motion analysis system. The 2-D cameras each had a frame rate of 60 frames per second and were set up behind the mound, behind home plate, and perpendicular to the pitch direction on the athlete’s open side (i.e., third base for right handed pitchers or first base for left handed pitchers). The researchers obtained 17 kinematic variables from the 3-D kinematic analysis of the pitching motion thought to be related to pitching performance. For each of the 17 kinematic variables, the independent raters were asked to qualitatively rate pitching performance. The two sets of data were then analyzed to determine if there was significant agreement between the quantitative data and the qualitative assessments of pitching performance. Significant differences were evident between the quantitative data and qualitative ratings. For only 4, or 23.5 %, of the 17 kinematic variables were the qualitative assessments of the raters in agreement with the kinematic data measured in the lab. Due to this low success rate, the researchers concluded that in its current form, their system of qualitative assessment was not effective as a tool for assessing pitching mechanics.

Some of the limitations of the Nicholls et al. (2007) research that may account for the low success rate of that qualitative tool will be accounted for in the present research. For example, the age of the subjects (i.e., skill level), the frame rate of the 2-D cameras used, the low-light conditions during the field session, and the amount and type of kinematic variables used in the Nicholls et al. (2007) study could have contributed to the low success rate. The very young age of the subject pool in this study may not be indicative of how a qualitative assessment protocol can be best applied to pitching and baseball coaching. A more effective age may be high school or collegiate level pitchers as they are likely more skilled and perform the pitching motion with greater consistency than youth pitchers. Additionally, the cameras used in the Nicholls et. al. (2007) study had frame rates of 60 frames per second (fps) which, due to the fast and explosive nature of the movement, may be too slow to catch key events during the pitching motion. A more appropriate camera would be one with 120 fps capabilities or higher. Another factor that may have limited the effectiveness of the qualitative tool was the low-light conditions during filming of the 2-D video, resulting in low quality video (i.e., grainy or blurry). The final limitation is the large number and the somewhat random nature of the kinematic variables assessed. It may be too difficult for an assessor to focus on that many different aspects of the pitching motion. A more effective approach might be to assign fewer variables or landmarks and isolate one portion of the body or phase of the movement.

Conclusion

From the review of the available quantitative information regarding high velocity pitching, it seems that stride length (Ramsey et al., 2014) might be an important factor in creating linear momentum and therefore body velocity towards the plate. It is also apparent that hip to shoulder separation (Robb et al., 2010), pelvis rotational velocity (Escamilla et al., 2002), and timing of hip rotation (Urbin et al., 2013) are all vital to the creating a sequential coordination pattern within the pitching motion and therefore key to generating higher ball velocities. From the review of the qualitative coaching practices used in pitching we know that the balance point (Keller, 2001) and hip to shoulder separation (House et al., 1991) are discussed in qualitative coaching but perhaps could benefit from a more direct link to quantitative findings. Descriptions of front leg bracing found in current coaching literature (Gotch, 2012) adequately explain how a pitcher should use their front leg, but could benefit from a specification on the timing of when this movement should occur. It also seems that qualitative assessment can be at least partly effective when analyzing pitching; though, Nicholls et al. (2007) were only able to see a consistency in qualitative observation for 23.5 % of the variables used in their analysis. If the limitations of their study can be improved upon there may be a chance for greater success with a future qualitative assessment tool. After gathering and comparing the relevant literature, the results of the present research will help to apply this information to formulating a more concise, efficient, and effective qualitative pitching assessment system.

CHAPTER III

METHODS

Design

The purpose of the present research was two-fold: First to confirm previous quantitative findings (i.e. identify kinematic predictors of greater ball velocity) and second, to use a qualitative analysis tool to allow independent raters to evaluate pitching performance using 2-D video. Descriptive and observational research methods were implemented to test the research hypotheses.

Participants

Participants consisted of 16 experienced pitchers: [mean (SD) age: 20.7 (0.94) years; height: 186.9 (8.02) cm; mass: 87.5 (9.7) kg] from a NCAA Division II baseball team. Pitchers who were currently injured, had been injured severely within the last 6 months, or were actively engaged in an injury rehabilitation program of any sort were excluded from the subject pool. All participants read and signed an informed consent document approved by the Institutional Review Board of CSU, Chico prior to participation in the study.

Testing Procedures

The data collection occurred in the biomechanics lab in Yolo Hall on the campus of CSU, Chico. Information regarding height, weight, history of injury, and history of pitching (i.e., starter or reliever, years of experience, etc.) was gathered prior to data collection. The subjects were asked to wear tight shorts (i.e., compression shorts) and no shirt to allow for the reflective markers to be visible to the cameras. The subjects were also asked to wear tennis shoes or turf shoes to allow them to perform their pitches safely on a portable mound.

After providing informed consent and providing the described demographic information, participants were instructed to warmup as they normally would for a pitching outing in a game scenario. This warmup commonly included dynamic movement, static stretching, running, and light throwing gradually increasing towards game-speed throwing.

Following the completion of the warmup the researcher applied retro-reflective markers to the participant's skin and clothing on anatomical landmarks using a customized marker set consisting of 18 total markers. Marker locations included the bilateral acromion process, anterior and posterior iliac spines, and the lateral pelvis. Additional markers included the dominant side medial and lateral wrist, medial and lateral elbow, contralateral thigh, medial and lateral knee, shank, medial and lateral ankle, and heel. Lastly, a marker was used to identify the location of the pitching rubber.

After the markers were attached, the participants proceeded to throw 3 familiarization pitches. These pitches were intended to allow the pitcher to become familiar with the indoor pitching mound and the established target. All pitches were thrown from an indoor mound that was 1.22 m wide, 2.44 m long, and 0.31 m in height. For all pitches, the participants were instructed to aim at a target, 0.559 m high by 0.432 wide, elevated 0.508 m of the ground and located 18.44 m away from the pitching rubber (i.e., regulation target size and distance). The pitches were thrown into a stationary net and consisted of all fastballs.

After completing the three familiarization pitches the participants were asked to complete eight pitches in the manner previously described. To ensure consistency across the entire data collection and to allow for the highest possible velocity output pitchers were asked to throw fastballs for both the familiarization and data collection pitches. For the data collection pitches 3-D data, 2-D video, and ball velocity were collected during baseball pitching. Kinematic data was measured at 240 Hz using 6 Osprey Digital Real Time Cameras (Motion Analysis Corporation, Santa Rosa, CA, USA). Video data was collected using a GoPro Hero 3+ video camera (GoPro, San Mateo, CA) set to a resolution of 720p and a frame rate of 120 fps. The video camera was positioned on a tripod at distances of 3.04 m perpendicular to the path of the ball on the open side of the pitcher (i.e., third base side for right-handed pitchers and first base side for left-handed pitchers) and 0.91 m towards home plate from the rubber. Directly opposite the camera was a calibration object with markings signifying 0.76 m, 0.91 m, and 1.07 m from the rubber towards home plate respectively. Peak ball velocity was measured and recorded using a Stalker Pro II radar gun (Stalker Radar, Richardson, TX), which was operated by a researcher who was positioned directly behind the net into which the participants threw their pitches.

Data Analysis Procedures

Of the eight pitches thrown for data collection by each participant, the three pitches with the greatest radar gun velocity were chosen for data analysis. The data collected in the lab session was analyzed using Cortex motion analysis software (Motion Analysis, Santa Rosa, CA, USA) and a custom written MatLab program (MathWorks, Natick, MA, USA). For the data analysis, the pelvis, contralateral thigh, and contralateral shank were modeled as a three-dimension system of rigid links (SkeletonBuilder, Motion Analysis, Santa Rosa, CA). The paths of the reflective markers attached to the participants was filtered with a fourth order zero-lag Butterworth filter at 12 Hz. The position of the hip joint center relative to the anterior superior iliac spine (ASIS) in the anatomical coordinate system of the pelvis was determined as a function of pelvis width (i.e., the distance between the left and right ASIS) and pelvis depth (i.e., the distance between the midpoints of the left and right ASIS and left and right posterior superior iliac spines), using proportions derived by Seidel, Marchinda, Dijkers, & Soutas-Little (1995).The position of the knee joint center relative to the lateral femoral epicondyle was found by traveling medially half the distance between the lateral and medial knee markers, as proposed by Davis, Ounpuu, Tyburski, & Gage (1991). Similarly, the position of the ankle joint center relative to the lateral malleolus was found by traveling half the distance between the lateral and medial ankle markers. Orientations of the anatomical coordinate systems of the thigh and leg were found from a reference trial of quiet standing. A Cardan rotation sequence beginning with flexion/extension was used to compute the knee joint angles.

Kinematic Data Analysis. To complete the kinematic analysis of the pitching motion the propulsive phase of the pitch, the instant of ball release, and the instant of front foot strike were first identified. The propulsive phase was defined as the time from maximal height of the lead knee to ball release. Ball release was defined in accordance with Matsuo et al. (2001) as the second video frame (0.0083 s) after the dominant wrist passes the dominant elbow in the XZ plane, with X being in the direction of the throw and Z being vertical. Front foot strike was identified as the instant when lead ankle velocity decreased to less than 1.5 m/s (Matsuo et al., 2001; Fleisig et al., 1999; Escamilla et al., 1998).

The present researcher quantified the following kinematic variables:

1. Peak Pelvic Angular Velocity

    Pelvis and shoulder vectors were defined using SkeltonBuilder (Motion Analysis, Santa Rosa, CA) as straight lines connecting both ASIS markers and both acromion markers, respectively (Robb et al 2010). Peak pelvic angular velocity was defined as the derivative of the cross product of these two vectors similar to methodology used by Urbin et al. (2013). This velocity was calculated as a maximal instantaneous value during the propulsive phase of the pitch.

2. Hip to Shoulder Separation

Hip to shoulder separation was quantified by measuring the angle between the previously described vectors between the acromion and ASIS markers. The maximal angle between these vectors during the previously described propulsive phase was used for the purpose of the present analysis.

3. Coordination

The coordination of the pitching motion was determined by measuring the amount of time between front foot strike and peak pelvic angular velocity. This value was calculated as an absolute time value. A smaller absolute time value signified an attainment of peak rotational pelvic velocity closer to front foot strike, signifying a more sequential overall pitching motion and thus a higher pitch velocity. A larger absolute time value signified this event occurring farther away from front foot strike and closer to ball release, thus creating a less sequential, more simultaneous pitching motion and lower pitch velocity. The determination of this value aided in determining what role the coordination of the hips plays in the production of velocity in pitching.

4. Stride Length

Stride length was calculated as the distance in the throwing direction between the rubber marker and the lead heel marker at the moment of front foot strike.

5. Knee Extension

Lead knee extension was calculated as the angle of the lead knee at the moment of ball release.

Qualitative Data Analysis. The 2D video of the pitching trials was used to complete the qualitative portion of this analysis. Three raters performed independent analyses of the 2D video. The first rater was an athletic trainer with over 30 years of experience in professional baseball and college athletics along with considerable experience in video analysis of human movement. The second rater was a collegiate head baseball coach with 25 years of baseball coaching experience and specific familiarity with the coaching of pitchers. The third rater was a biomechanics graduate student with 15 years of experience as a pitcher at youth, high school, and college levels, along with experience with video analysis of pitchers and other athletic movements. These raters had no knowledge of each other's ratings to help ensure completely independent analyses. Furthermore, the raters had no knowledge of the ball velocity for each of the pitches that they qualitatively analyzed. The raters were looking for the following landmarks during the execution of the pitch:

1) The pitcher had started to lean towards the plate at the top of the leg lift (front hip inside the rubber)

2) The front hip reached the 0.9 m line on the distance gauge before the front knee crossed the front hip.

3) At the moment the front knee crossed the front hip, the angle between the ground and

the tibia of the drive leg was close to 45 degrees.

4) At the moment of front foot contact, the hip of the drive leg had begun to turn towards the target.

5) The lead knee was extended at the moment of ball release.

With these landmarks in mind, the raters completed the Qualitative Assessment of Pitch Velocity (Appendix A). This assessment sheet was created by the researcher with a “Yes or No” conditional format similar to that of the TGMD-2 qualitative assessment instrument produced by Ulrich et al. (2000). Using this sheet and the given criteria, the raters evaluated three pitches for each pitcher. Raters had the opportunity to watch each pitch at regular speed and in slow motion. In addition, they were permitted to observe each pitch as many times as they wished in order to accurately identify the given criteria for each pitch. For each of the four criteria in a given pitch the rater indicated a “yes” or “no” condition for each of the five landmarks. A “yes” was represented by a “1” and a “no” was represented by a “0.” For example, if the rater believed Pitch 1 for Subject 1 satisfied the requirements for landmark 1 involving the pitcher leaning towards the plate at the top of the leg lift, then the rater marked a “1” for Subject 1: Pitch 1: Landmark 1 on the assessment sheet. This process was completed for three pitches for each pitcher. Once all pitches had been qualitatively analyzed, the researcher totaled the scores for each pitch, giving the pitcher a score out of 5 on the qualitative assessment sheet for each of their three pitches.

Statistical Analysis

Kinematic Data Statistical Analysis. Descriptive statistics (i.e., means and standard deviations) were calculated and reported for the present subjects. These variables included age, height, and mass. The data from each of the three selected data collection trials for each pitcher were averaged across trials for the purpose of the statistical analysis. Once the averages were calculated, a backward elimination multiple regression analysis was used to identify the variables that were predictive of ball velocity. The following predictor variables were included in the regression analysis: peak pelvic angular velocity, peak hip to shoulder separation, coordination, stride length, and lead knee extension. Predictor variables were deemed significant when $p < 0.05$. This statistical analysis was performed using SPSS 24.0 (SPSS, Chicago, IL, USA).

Qualitative Assessment Statistical Analysis. For the statistical analysis of the qualitative data, the researcher investigated the relationship between the average qualitative score out of 5 provided by the independent raters and ordinal ball velocity for each pitch. Ordinal ball velocity was calculated as a percentile velocity of the highest velocity in the data set. This investigation was performed using the Spearman Rho correlation coefficient using a significance level of $p<0.05$. This analysis was performed using Microsoft Excel with the Real Statistics Resource Pack software ((Release 5.4.) Copyright (2013-2018) Charles Zaiontz. www.realstatistics.com).

CHAPTER IV

MANUSCRIPT

A Kinematic and Qualitative Evaluation to Predict Ball Velocity in Baseball Pitching

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Abstract

Despite the considerable amount of research describing the biomechanics of pitching, little has been done to utilize these observations to develop an understanding of how to improve pitch velocity quantitatively and qualitatively. The purpose of this study was twofold: (1) Replicate and expand on previous kinematic descriptions of pitching performance, and (2) develop a qualitative analysis tool for pitching performance and test its' efficacy. Participants consisted of 16 pitchers from a NCAA Division II baseball team. Three-dimensional motion analysis was conducted to quantify six kinematic variables: peak rotational pelvic velocity (PPAV), hip to shoulder separation (HTS), coordination, stride length (SL), knee extension (KE), and ball velocity. PPAV ($p = 0.00$), HTS ($p=0.01$), and KE ($p=0.02$), were found to be significant predictors of ball velocity. Two-dimensional video of the pitching trials was used to complete the qualitative assessment. Three independent raters performed analyses of the video using a qualitative assessment tool to locate movements that might indicate high velocity biomechanics. The tool allowed raters to give conditional (i.e., YES/NO) responses for 5 specific landmarks within the pitching motion, giving each pitch a score out of 5. No significant association was found between the average rater score out of 5 for each pitch and ball velocity ($r_s = 0.167$; $p = 0.272$). Continued attempts to perfect qualitative analysis methods and reevaluation of the phase breakdown of the pitching motion are likely essential to unlocking the keys to velocity enhancement.

Introduction

In the world of athletics, there are few sports skills more biomechanically complex than baseball pitching. Due to this complexity, mastering the motion of pitching is one of the most difficult tasks in sports. Pitchers that can develop proficient mechanics to maximize both ball velocity and accuracy are highly sought after at all levels of baseball.

With hopes of understanding the mechanics of this highly complex movement, biomechanists, such as Robb et al. (2010) and Dun et al. (2007), have frequently analyzed the kinematics and kinetics of the pitching motion. These analyses have resulted in biomechanical research on pitching that is primarily descriptive in nature and consists of studies across various levels of baseball. Examples of this type of research include identifying specific kinematic and kinetic differences across various skill levels of pitchers (Fleisig et al., 1999) or quantifying specific ground reaction force values produced by elite pitchers (Macwilliams et al., 1998). As a result of these types of studies variables such as, hip to shoulder separation (Matsuo et al. (2001) Robb et al. 2010), stride length (Ramsey et al., (2014), lead knee extension (Werner et al. (2008), and coordination of the movement (Matsuo et al. (2001) all appear to be key to producing high ball velocities in pitching.

Despite the considerable amount of research describing the biomechanics of pitching, little has been done to utilize these biomechanical observations to develop an understanding of how to improve pitch velocity. At present, most research in this field has required access to a biomechanical laboratory and has included the use of 3-dimensional analysis instruments. For most players and coaches this is not a setting that is either feasible or readily available. With this issue in mind, Nicholls et al. (2007) created a more accessible mode of pitching assessment by using video to qualitatively analyze the pitching motion. However, the qualitative tool developed by Nicholls et al. (2007) only resulted in good reproduction of three-dimensional (3-D) motion analysis results for 4 of the 17 (i.e., 22%) variables tested. In other words, of the 17 variables their qualitative raters evaluated, only 4 of these showed an association with the results of their quantitative 3-D motion analysis. The four variables they found to be valid when compared with the quantitative data were elbow flexion at foot contact, sequence of hip-shoulder rotation during the arm cocking phase, trunk flexion at ball release, and shoulder horizontal adduction at ball release. Possible reasons for the overall ineffectiveness of their qualitative tool include too many qualitative variables chosen for observation (i.e., 17 kinematic variables in total) and a low camera frame rate (i.e., 60 fps).

The shortcomings of the Nicholls et al. (2007) work were part of the motivation for the present study. That is, we wanted to attempt to improve on the idea of the qualitative analysis tool presented by Nicholls et al. (2007) and thus enhance our ability to effectively complete meaningful qualitative analyses of baseball pitching. The ultimate goal of this line of research is to develop a qualitative analysis tool that will allow for an effective evaluation of pitching skill and the identification of areas for improvement. Given that we know it is possible to use biomechanical feedback to elicit changes in movement that result in enhanced performance (Mache, 2005) it seems reasonable to hypothesize that biomechanical knowledge and specific feedback could also be used to improve pitching mechanics and subsequently increase ball velocity. However, before we can attempt to implement such practices we must first develop a solid understanding of the factors that have the greatest influence on ball velocity.

In an attempt to bridge the quantitative findings and practical application of qualitative analysis for coaches and pitchers, the aim of this study was twofold. The first objective was to replicate and potentially expand on previous biomechanical descriptions of the pitching motion.

To do so peak pelvic angular velocity (PPAV), hip to shoulder separation (HTS), coordination, stride length (SL), and lead knee extension (KE) were computed and their relationship with ball velocity was examined. These variables were chosen due to their emphasis on the lower body's contributions to the pitching motion, as well as the ability to move in the desired sequential coordination for a high velocity movement. It was hypothesized that the quantitative variables analyzed would positively predict ball velocity. The second aim of this study involved the creation and evaluation of a qualitative tool, the Qualitative Assessment of Pitch Velocity (QAPV). The QAPV used in this study was developed based on previous quantitative biomechanical findings, and was intended to be used by coaches and athletes alike to qualitatively analyze and improve velocity performance in pitching. The five variables chosen for the QAPV differ from those utilized in the Nicholls et al. (2007) study in that there are only five variables for raters to analyze, and these five variables were all chosen with a specific quantitative variable in mind. It was hypothesized that the QAPV ratings would be predictive of ball velocity.

Methods

Participants consisted of 16 experienced pitchers: [mean (SD) age: 20.7 (0.94) years; height: 186.9 (8.02) cm; mass: 87.5 (9.7) kg] from a NCAA Division II baseball team. Pitchers who were currently injured, had missed at least one month of pitching due to injury within the previous 6 months, or were actively engaged in an injury rehabilitation program of any sort were excluded from the subject pool. All participants volunteered and provided informed consent prior to participating in this that was approved by the University Institutional Review Board.

The quantitative research hypothesis of this study was that a group of five kinematic variables chosen from prior research (i.e., PPAV, HTS, coordination, SL, and KE) would be significant predictors of ball velocity in pitching. In order to test this hypothesis, 3-D kinematic data, 2-D digital video, and ball velocity were collected during indoor baseball pitching. Kinematic data were measured at 240 Hz using 6 Osprey Digital Real Time Cameras (Motion Analysis Corporation, Santa Rosa, CA, USA). Two-dimensional video data were collected using a GoPro Hero 3+ video camera (GoPro, San Mateo, CA, USA) set to a resolution of 720p and a frame rate of 120 frames per second. The GoPro camera was positioned on a tripod 3.04 m from the pitcher, perpendicular to the path of the ball on the open side of the pitcher (i.e., third base side for right-handed pitchers or first base side for left-handed pitchers) and 0.91 m towards home plate from the pitching rubber. Directly opposite the GoPro camera was a calibration object with markings signifying distances of 0.76 m, 0.91 m, and 1.07 m from the pitching rubber to home plate, respectively. Peak ball velocity was recorded using a Stalker Pro II radar gun (Stalker, Richardson, TX, USA), which was operated by a researcher who stood directly behind the net into which the participants threw their pitches.

Prior to kinematic data collection information regarding height, weight, history of injury, and pitching experience (i.e., starter or reliever, years of experience, etc.) was gathered. Participants were then asked to complete a warm-up that was similar to their typical pre-game warm-up. Warm-ups were self-prescribed, but generally included a variety of stretching, running, and throwing exercises.

Upon completing their warm-up 18 retro-reflective markers were applied to the participant. The customized marker set included markers bilaterally at the acromion process, anterior and posterior iliac spines, and lateral pelvis. Additional markers included dominant side medial epicondyles of the wrist and elbow, contralateral lateral thigh, medial and lateral femoral epicondyles, lateral shank, medial and lateral malleoli, and the heel. Lastly, a marker was used to identify the location of the pitching rubber.

After marker application, participants threw 3 familiarization pitches. All pitches were thrown from an indoor mound that was 1.22 m wide, 2.44 m long, and 0.31 m in height. Participants were asked to aim at a target, 0.559 m high by 0.432 m wide that was elevated 0.508 m off the ground. The target was located 18.44 m from the pitching rubber for all pitchers. The target dimensions and location were chosen to match the size of the strike zone and the distance from the pitching mound to home plate used in a regulation baseball game. Pitches were thrown into a stationary net. Following the familiarization pitches, pitchers were asked to throw 8 consecutive fastballs during which time 3-D kinematic data, 2-D digital video, and radar gun ball velocity data were recorded. The pitchers were asked to perform these pitches at game pace in order to accurately simulate a game-like velocity reading. Upon completion of pitching the 8 fastballs the data collection session was ended.

Kinematic Data Analysis

The three pitches with the highest velocity for each pitcher were chosen for kinematic data analysis. For the data analysis, the pelvis, contralateral thigh, and contralateral shank were modeled as a three-dimensional system of rigid links (Skeleton Builder, Motion Analysis, Santa Rosa, CA). Reflective markers were first labeled in Cortex for each of the 3 trials and the paths of the labeled reflective markers were then filtered with a fourth order zero-lag Butterworth filter at 12 Hz. The orientations of each segment and joint center locations were determined from the filtered marker trajectories and transformations derived from a trial of quiet standing. A cardan rotation sequence of flexion/extension, abduction/adduction, and external/internal rotation of the distal segments were used to compute joint angles. Hip and knee joint centers were calculated in accordance with Seidel, Marchinda, Dijkers, and Soutas-Little (1995) and Davis, Ounpuu, Tyburski, and Gage (1991)), respectively. Body segment masses and center of mass locations were determined using published data (de Leva, 1996) and measured anthropometrics.

To complete the kinematic analysis of the pitching motion the propulsive phase of the pitch, the instant of ball release, and the instant of front foot strike were first identified. The propulsive phase was defined as the time from maximal height of the lead knee to ball release. Ball release was defined in accordance with Matsuo et al. (2001) as the second video frame (0.0083 s) after the dominant wrist passes the dominant elbow in the XZ plane, with X being in the direction of the throw and Z being vertical. Front foot strike was identified as the instant when lead ankle velocity decreases to less than 1.5 m/s (Matsuo et al. (2001) Fleisig et al. (1999); Escamilla et al. (1998).

In order to examine various predictors of ball velocity, the following dependent variables were chosen for analysis: PPAV, HTS, coordination, SL, and KE. PPAV was computed using Skeleton Builder (Motion Analysis, Santa Rosa, CA) by first defining pelvis and shoulder vectors as straight lines connecting both ASIS markers and both acromion markers, respectively (Robb et al. 2010). Peak rotational pelvic velocity was then computed by finding the derivative of the cross product of these two vectors similar to methodology used by Urbin et al. (2013). This velocity was calculated as a maximal instantaneous value during the propulsive phase of the pitch. HTS separation was quantified by measuring the peak value of the angle between the previously described vectors between the acromion and ASIS markers, during the propulsive phase. Coordination of the pitching motion was determined by measuring the amount of elapsed time between front foot strike and maximum hip to shoulder separation. This value was calculated as an absolute time value. Stride length was calculated as the distance, in the throwing direction, between the rubber marker and the lead heel marker at the moment of front foot strike. Lead knee extension was calculated as the angle of the lead knee at the moment of ball release.

QAPV Data Analysis

The GoPro video of the pitching trials was used to complete the QAPV portion of this analysis. Three raters performed independent analyses of the 2D video. The three qualitative raters included an athletic trainer with 35 years of collegiate and professional baseball experience, a head college baseball coach with 25 years of collegiate experience, and a kinesiology graduate student with 8 years of combined collegiate and professional playing experience and 4 years of collegiate coaching experience. To help ensure completely independent analyses, these raters had no knowledge of each other's ratings or the velocities of the pitches. The raters were given the QAPV sheet (Appendix A) and asked to look for the following landmarks during the execution of the pitch:

1) Pitcher had started lean towards the plate at the top of the leg lift (i.e., was the lead hip inside the rubber?)

2) Front hip reached 0.9 m line on distance gauge (Image 1) before front knee crossed front hip (Image 2).

3) At the moment lead knee crossed lead hip the angle between the ground and the tibia of the drive leg was close to 45 degrees. (Image 2)

4) At the moment of front foot contact rear shoulder and rear hip appeared to be rotating together.

5) Lead knee was extended at the moment of ball release.

Image 1. Distance Gauge Placement

Shows the distance gauge behind the mound early in the motion near the top of the leg lift.

Image 2. Front Hip Crosses Midline

-Shows the moment described for this qualitative landmark where the front hip crosses the midline of the distance gauge.

With these landmarks in mind, the raters completed the QAPV sheet. This was a “Yes or

No" conditional format of evaluation similar to that of the TGMD-2 qualitative assessment sheet produced by Ulrich (2000). Using this sheet and the given criteria, the raters evaluated the three pitches for each pitcher. Raters were able to observe each pitch as many times as they wished in both regular and slow motion in order to accurately identify the criteria. While evaluating each pitch, the rater awarded a "yes" or "no" for each of the five landmarks. A "yes" was represented by a score of "1" and a "no" was represented by a score of "0." Once all pitches had been qualitatively analyzed, a total score was received for each pitch from each rater, giving the pitcher a rater score out of 5 on the qualitative assessment sheet for each of their three pitches.

Statistical Analysis

Upon confirmation that assumptions (i.e., visual inspection of the normal P-P plot and a plot of the regression standard residual versus the regression standardized predicted values) were met a backward elimination multiple regression analysis was used to identify the variables that were predictive of ball velocity. Independent variables included in the model were PPAV, HTS, coordination, SL, and KE. The Variance Inflation Factor (VIF) was obtained to ensure there were no issues with multicollinearity among the predictor variables. Predictor variables were deemed significant at $p < 0.05$. This statistical analysis was performed using SPSS 24.0 (SPSS, Chicago, IL, USA).

For the statistical analysis of the QAPV data, Spearman rho correlation was used to examine the relationship between the total qualitative score out of 5 provided by the independent raters for each pitch and ordinal ball velocity determined for each pitch. Ordinal ball velocity was determined by finding the highest velocity value across all pitches analyzed from all pitchers, and deriving the percentile of each velocity value from that highest velocity. The level of significance for all statistical analysis was set at 0.05. This portion of the statistical analysis was performed in Microsoft Excel with the Real Statistics Resource Pack software ((Release 5.4.) Copyright (2013-2018) Charles Zaiontz. www.realstatistics.com).

Results

Kinematic Data

Means and standard deviations for the measured kinematic variables have been presented in Table 1. The stepwise multiple regression analysis produced a model summary indicating correlation values of R = 0.601 and $R^2 = 0.361$ (Table 2).

Table 1: Descriptive statistics for five quantitative variables and velocity

Variable	*Mean*	SD
PPAV (deg/sec)	696.82	82.05
KE (deg)	39.75	14.29
HTS (deg)	54.76	8.78
C (s)	0.07	0.04
SL (m)	1.56	0.09
Velocity (mph)	83.86	3.07

These low R and R^2 values indicate only a partial explanation of the observed variance in ball velocity. The final regression model indicated that PPAV, HTS, and KE were significant predictors of ball velocity (Figure 1, Figure 2, and Figure 3). Coordination and SL were not found to be significantly correlated to ball velocity (Table 2).

Table 2

Standardized partial regression coefficients (b), P values, and the variance inflation factors (VIF) obtained from the final backward multiple linear regression model.

Variable	*b*	P value	VIF
PPAV	.569	.000[a]	1.348
KE	.445	.002[a]	1.120
HTS	.491	.001[a]	1.284

a = partial regression coefficient is statistically significant at $p < 0.05$

Figure 2. Partial Regression Plot for PPAV

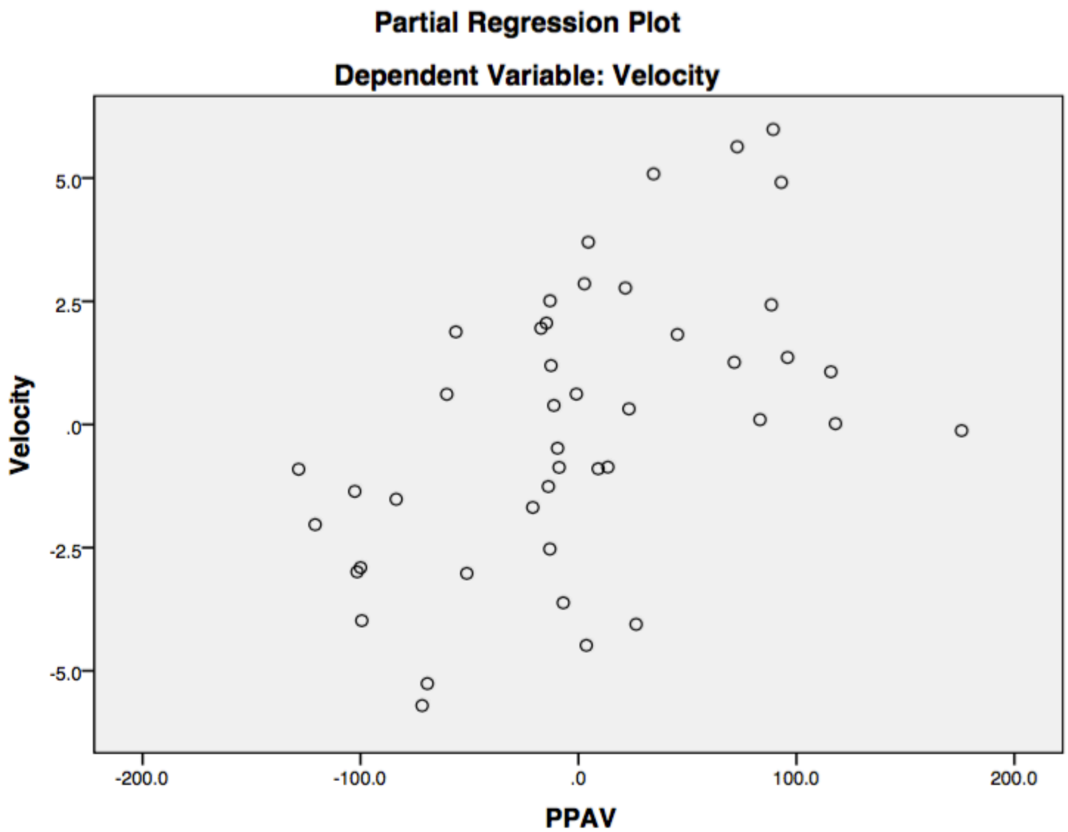


Figure 3. Partial Regression Plot for HTS

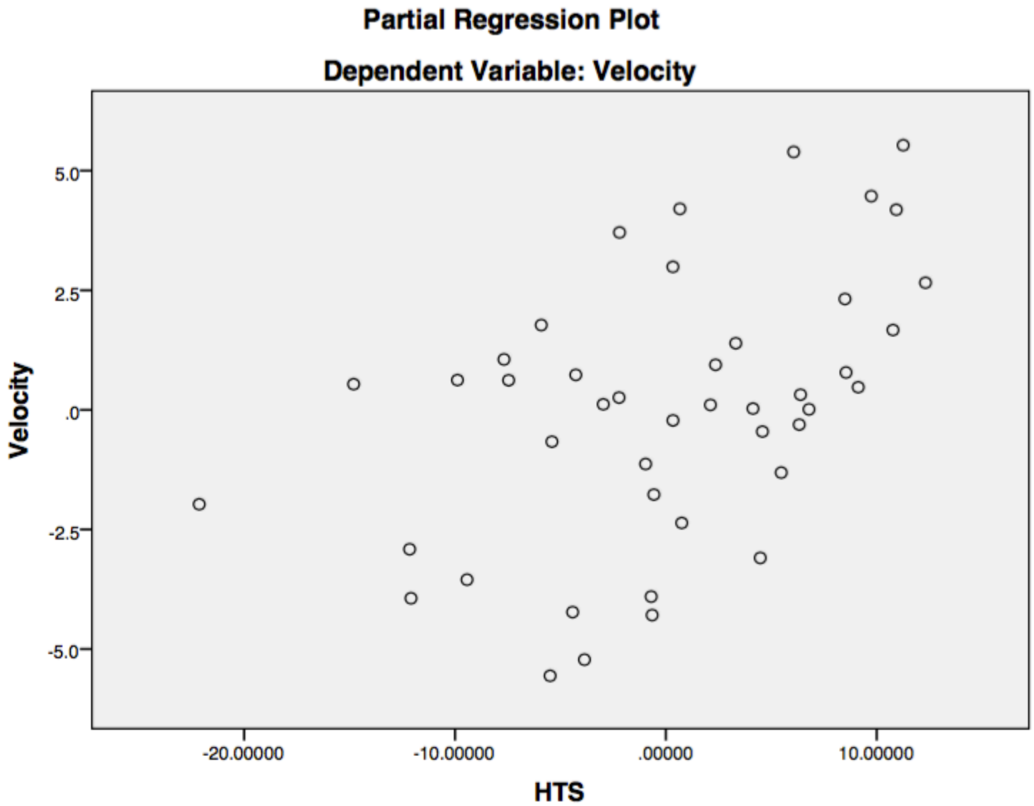
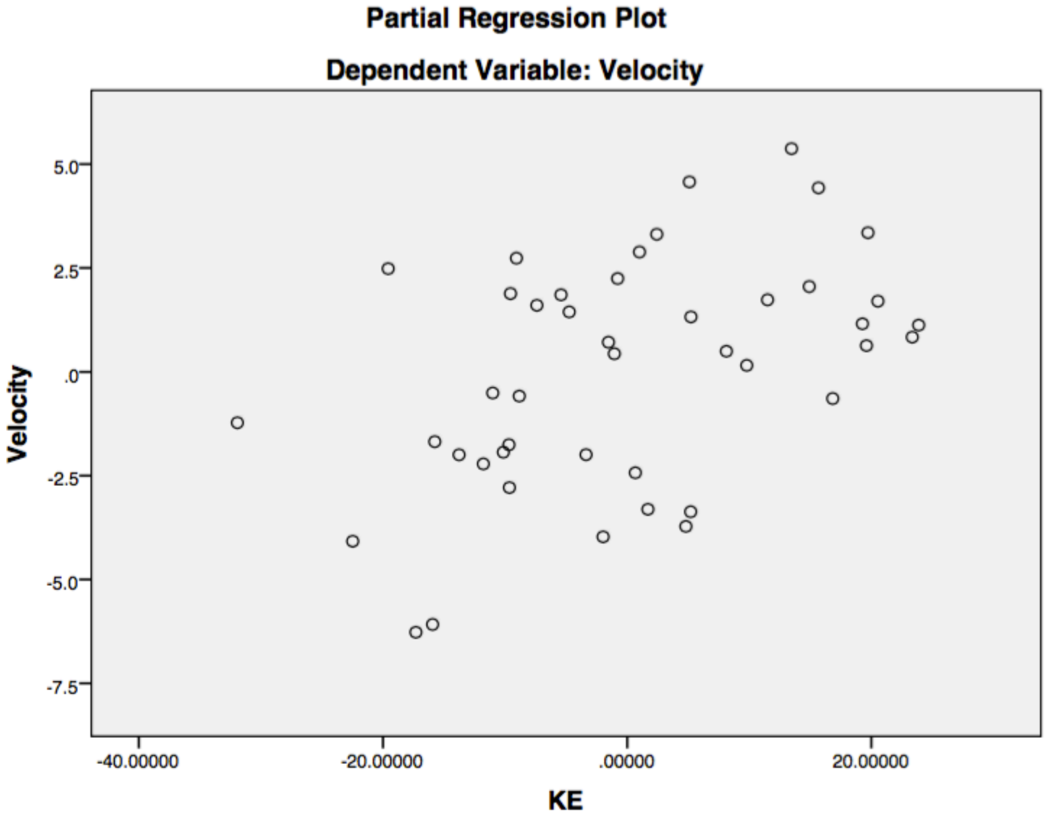


Figure 4. Partial Regression Plot for KE


Partial Regression Plot
Dependent Variable: Velocity
5.0
2.5
.0
-2.5
-5.0
-7.5
Velocity
-40.00000
-20.00000
.00000
20.00000
KE

QAPV

The Spearman Rho correlation analysis of the association between QAPV rater scores and ball velocity was not significant ($r_s = 0.167$; $p = 0.272$). The velocity, average QAPV rating, and ordinal velocity of each pitch used to complete the Spearman test have been provided (Appendix B). In addition, the individual rater values for each landmark for each pitch have been given (Appendix C).

Discussion

Of the five quantitative variables analyzed in this study, three were found to be statistically significant predictors of ball velocity: PPAV, HTS, KE. The regression model including these three variables together explain 36% of the ball velocity variance. The first of these three variables, PPAV, being predictive of ball velocity means the greater peak velocity with which the pelvis rotated through the propulsive phase of the pitching motion, the greater the ball velocity. This finding is consistent with that of Escamilla et al. (2002), who analyzed differences between high and low velocity pitchers. They found that pitchers with higher ball velocity exhibited a significantly greater peak pelvis angular velocity than lower velocity pitchers. One important difference between the work of Escamilla et al. (2002) and the present work is that they measured pelvis velocity during the arm cocking phase, whereas in the present study peak pelvis rotational velocity was identified during the propulsive phase of the pitching motion. The difference in the two methods of analysis is notable as it indicates that the rotational velocity of the pelvis is important throughout the entire force producing period of the motion (i.e., the propulsive phase), not just during one phase (e.g., the arm cocking phase).

Other methods have also been used to address the contribution of the lower body to the pitching motion. For example, Macwilliams et al. (1998) determined that peak ground reaction forces of both legs during the pitching motion correlated with wrist velocity. Specifically, they found greater wrist velocities were directly related to greater push-off anterior-posterior shear forces and greater landing anterior-posterior shear, vertical, and resultant forces. Though this correlation existed when the data were analyzed as a group, the researchers also reported some individualized discrepancies within the group correlation. For example, a couple of subjects displayed higher forces yet lower wrist velocities. This anomaly was explained as these specific subjects potentially "overthrowing". This overthrowing is also evident in the current study which may be due to a break in the kinetic chain between lower and upper extremity. Further study is needed to examine the relationship between push-off force, pelvis rotational velocity, and ball velocity to develop a better understanding of the link between lower body power and ball velocity.

If pelvis angular velocity is in fact one of the key factors in differentiating between low and high velocity pitching, then it is important to reevaluate the method of analyzing the pitching motion. Dillman et al. (1993), previously broke down the pitching motion into six phases for the purpose of analysis; a model of analysis that has been used extensively throughout the literature. However, if pelvis rotational velocity is as important as we hypothesize then perhaps a simpler model of pitching phases could be used. A more direct approach to the analysis of pitching would be to simply consider two phases, a linear phase and a rotational phase. The linear phase of the motion would occur from the top of the leg lift (Image 3) to the moment of front foot strike (Image 4), and the rotational phase would occur from the moment of front foot strike (Image 4) to the moment of ball release (Image 5).

Image 3: Start of Linear Phase (i.e., Top of Leg Lift)

Image 4: End of Linear Phase/Beginning of Rotational Phase (i.e., Front Foot Strike)

Image 5: End of Rotational Phase (i.e. Ball Release)

The identification of these two phases, specifically the transition between these two phases, would help to emphasize the importance of pelvis angular velocity as an indicator of ball velocity. That is, pelvic angular velocity is the means by which the velocity produced by the lower body during the linear phase is eventually transferred to the upper body during the rotational phase. The PPAV variable may allow for a way to measure this violent change from the proposed linear phase to the rotational phase, and thus a way to identify possible areas for performance enhancement in a pitcher. This is encouraging for coaches and athletes alike because pelvic angular velocity is a kinematic movement that can be isolated and potentially trained specifically in a strength and plyometric training program.

The second of the three quantitative variables found to be a predictor of ball velocity was HTS. This finding confirms the canon of literature supporting HTS as one of the most reliable kinematic indicators of ball velocity in pitching. For example, Fleisig et al. (1999) determined that greater HTS was related to greater pitch velocity. Thus, one of the goals of the present work was achieved by confirming the relevance of HTS with regards to hip velocity.

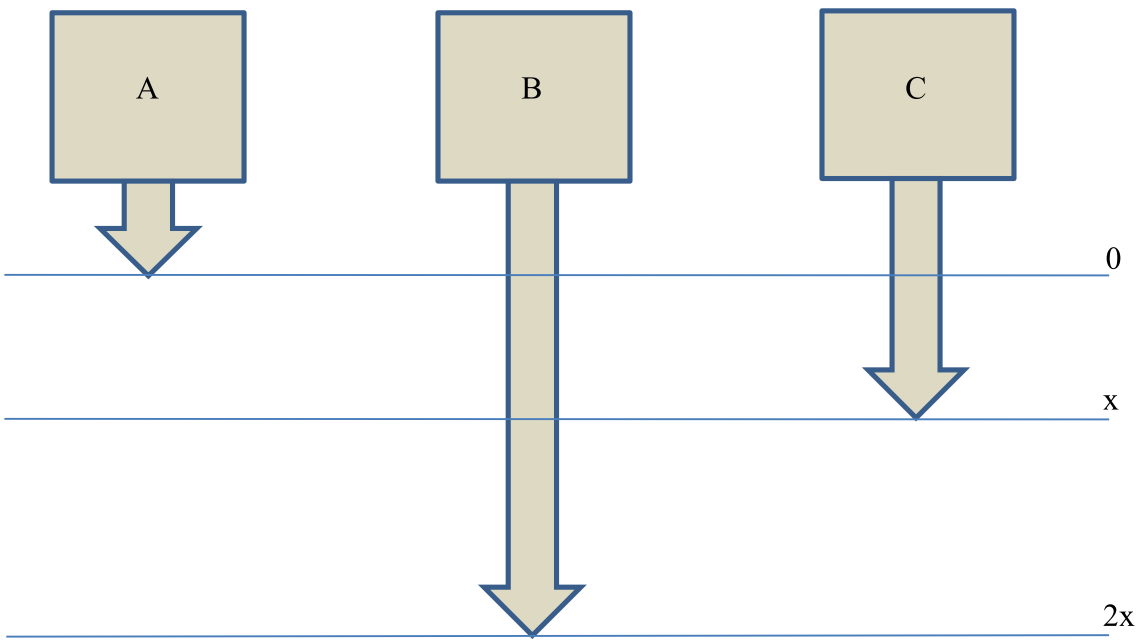
Traditionally, greater HTS as a maximal value measured between the top of the leg lift and the moment of ball release, has been interpreted as a direct indicator of pitch velocity (Robb et al. 2010). The present results confirm previous findings; however, it is important to consider how exactly HTS might lead to greater ball velocity. Perhaps maximal HTS is an indicator of the transfer of energy (i.e., velocity) from the lower body to the upper body. If PPAV is the bridge by which produced kinetic energy is ultimately transferred from the lower body to the upper body, then HTS is the storage location for this energy. Rather than being just a statistical indication of velocity, HTS may instead be an indication of the potential for an occurrence of a transfer of energy from the lower to upper body.

In order to further understand HTS, it is important to consider its contribution as a potential energy mechanism, and that the conservation of this energy is important in creating ball velocity. The idea of a transfer of energy in the pitching motion has been addressed before but not in the exact manner discussed herein. For example, Seroyer et al. (2010) used the term “transfer of energy” in their review of the kinematics and kinetics of baseball pitching. They cited previous kinematic research to describe a transfer of energy from proximal to distal in the participating body segments in the pitching motion, and described this link of parts as the “kinetic chain”. In their discussion of energy, the authors emphasized the importance of keeping the center of gravity over the back leg during the windup phase, stride length, and rotation of the upper torso and shoulder during the arm cocking and acceleration phase. However, this “analysis” included no actual measurement of potential or kinetic energy.

On the other hand, Naito, Takagi, and Maruyama (2011), attempted to determine how mechanical work and energy are produced in the pitching motion. They concluded the trunk flexors and rotators were perhaps the most important source of velocity that eventually contributes to acceleration of the throwing arm. This is important when thinking about HTS as the link between pelvic velocity and upper body velocity. If the velocity created by the lower body is not transferred to the upper body sufficiently, then trunk rotation and flexion will not occur at an optimal magnitude, and according to Naito et al. (2011), this will limit the overall output that can be achieved. This supports the proposed hypothesis of viewing the pitching motion as two phases, linear followed by rotational. It also provides a glimpse of the effects of properly stored, conserved, and efficiently converted potential energy, represented by HTS. Further analysis of the idea of transfer of energy in pitching may be needed in pitching research going forward, as it seems these aspects are important and highly applicable.

In order to visualize this, it may be helpful to imagine energy within the throwing motion as a spring (Figure 5).

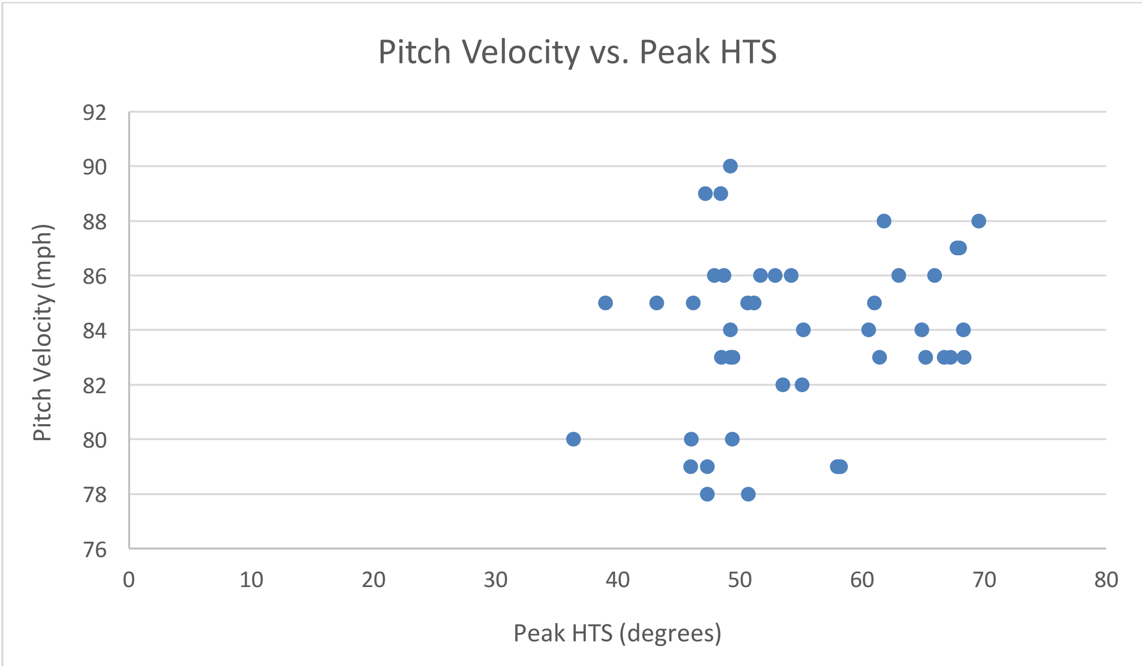
Figure 5: Visual representation of deformation of a spring (Barker 2018). Three scenarios are depicted: one of zero deformation (A), maximal deformation (B), and minimal deformation (C). These depictions symbolize possible executions of HTS at the moment of front foot strike in pitching.



The spring represents the energy created by the lower body and is then transferred through pelvic and trunk rotation to the upper body. The energy stored in the deformation of "the spring" is analogous to the HTS achieved during the pitch, specifically HTS at the time of front foot strike. Figure 5 depicts three scenarios for a spring: one of zero deformation (A), maximal deformation (B), and minimal deformation (C). These scenarios correlate to zero, maximal, and minimal HTS in the pitching motion, respectively. If the spring is stretched to maximal length, then it possesses a higher amount of instantaneous potential energy than that of a lesser stretched spring. But if this maximal stretch isn't maintained to the point in time where the spring is going to be released (front foot strike in pitching), then it loses that previously achieved instantaneous potential energy and only cashes in on the energy it possesses at that specific point in time. This is similar to the pitching motion with respect to HTS and the rotational phase. HTS can increase in value before the moment of front foot strike, but if that amount of HTS is not maintained up to and beyond the moment of front foot strike then its potential to contribute to the delivery of rotational energy goes away. In this case, the spring is essentially being stretched maximally, and then returned halfway back to its starting position before its energy can be utilized. This analogy for HTS helps support the idea that maximal HTS may not be the ideal measurement for indicating velocity, but that HTS at or after the moment of front foot strike may be more beneficial. It could at least help explain a deficiency in velocity if an athlete seems to be achieving a magnitude of HTS that would otherwise seem adequate for a higher velocity output. Based on previous and current findings pitchers should strive to maximize thoracic and pelvic flexibility and utilize neuromuscular training to elicit proper muscle signaling for greater HTS.

Despite the fact that maximal HTS was a significant predictor of pitch velocity it is important to note that this relationship was not evident in all of the observed pitches (Figure 6).

Figure 6: Pitch Velocity vs Peak HTS for all pitches



For some pitches, greater maximal HTS was not directly related to greater ball velocity. There are instances of inadequate HTS resulting in higher velocity, and vice versa. Therefore, it is possible that maximal HTS may not be as important as HTS at the moment of front foot strike. If the conversion of linear energy to rotational energy cannot occur until the front foot has made contact with the ground, and HTS is the storage location for this energy, then the linear energy available to be converted is indicated by HTS at front foot strike. If the HTS at front foot strike is less than maximal HTS, then the pitcher is wasting the HTS they achieved prior to this moment. The current analysis does not prove this hypothesis, thus future researchers should continue to explore the importance of maximal HTS and its timing.

The third variable found to be a significant predictor of ball velocity was KE specifically greater extension in the lead knee at the moment of ball release was associated with greater ball velocity. Werner et al. (2008) found similar results with a greater knee extension angle at the moment of ball release being directly related to ball velocity. Because of the relationship between knee extension and ball velocity at the moment of ball release, the spring analogy and visualization of the transfer of energy through the throwing motion can be continued to help explain the importance of knee extension. If PPAV is the initial transfer from linear kinetic energy to rotational kinetic energy, and HTS represents the storage this energy, then KE at ball release is the final delivery of energy to the ball. The greater KE that can be achieved, the greater the efficiency of the final transfer of energy and the greater the velocity of the ball. Conversely, if a lower KE is observed (i.e., too much flexion remains in the lead knee), this may indicate the knee is still extending at the moment of a ball release and thus is not fully ready to transfer energy into ball release. This idea that KE needs to be maximized by the time the ball is released reinforces the idea that the timing of this measurement is essential. If the knee extends to an adequate amount but it is after the ball has left the hand of the pitcher, then the opportunity to transfer energy to the ball has already occurred. Furthermore, lead KE is likely a highly trainable kinematic action due to its nature as a simple single joint movement in the sagittal plane. Knee extension is a primary component of many complex strength movements and can also be isolated fairly easily in single leg exercises. With this in mind, focus on this movement can be easily incorporated into the workouts and training schedules of pitchers who need to improve this aspect of the pitching motion.

Neither coordination nor SL were found to be significant predictors of ball velocity. In the present study, coordination was defined as the difference in time between front foot strike and PPAV. Similarly, Matsuo et al. (2001) did not find a significant relationship between front foot strike timing and ball velocity, though the study examined the time gap between front foot strike and ball release rather than front foot strike and PPAV as was presently investigated. However, Matsuo et al. (2001) did find a correlation between ball velocity and a more sequential coordination pattern in the upper body (i.e., timing of maximal shoulder internal rotation and elbow extension). Based on the previously discussed hypothesis regarding the transfer of energy, the timing of the different kinematic events in the pitching motion seem to be of high importance, so continued measurement of temporal aspects could prove valuable. The parameters used in measuring coordination with respect to the lower body need to be perfected in order to find a reliable temporal measure that is useful in predicting ball velocity.

SL has been measured in research involving pitching but was not found to be a significant predictor of ball velocity in this study. Ramsey et al. (2014) found SL to be an indicator of a greater amount of anterior momentum and thus inferred that a greater SL would create greater ball velocity. However, similar to this study, they did not find SL to be directly related to ball velocity. This fact coupled with the findings of this study point towards the conclusion that SL is not necessarily a direct indication of ball velocity but rather a measure of lower body power output. Moreover, the size of the pitcher was not accounted for in this study or by Ramsey et al. (2014). Perhaps relative SL should be utilized in future study to better understand the importance, or lack thereof, of SL in contributing to ball velocity.

In conclusion, we found three of the five measured kinematic variables to be significant predictors of ball velocity in pitching. These three variables included: PPAV, HTS, and KE. It is important to acknowledge that the regression analysis of these five quantitative variables did involve a considerable amount of variance unexplained by the variables selected (i.e., 64%). This unexplained variance means there are likely other important variables that we did not measure that could better predict ball velocity. Further research in this field should aim to confirm the significant predictors of ball velocity described in this study and determine other important predictors of ball velocity.

Qualitative Aspect

In the qualitative aspect of this study, the QAPV was found to be ineffective in predicting pitch velocity ($p = 0.27$). The goal of this analysis was to improve upon the measuring conditions and camera quality of Nicholls et al. (2007), to develop an effective tool for qualitatively analyzing the pitching motion. Despite limiting the number of qualitative variables analyzed and improving the frame rate of the camera used, the present tool proved to be ineffective. While the effectiveness of each of the 5 landmarks included in the QAPV were not individually analyzed, several of the landmarks used in the QAPV tool seem to be related to quantitative variables found to be significant predictors of ball velocity such as landmarks 4 and 5, rotation of the hips and extension of the front knee. Therefore, these two landmarks should be included for future iterations of QAPV.

When trying to understand why the QAPV was ineffective, it is important to understand its design and the attempts that were made to connect qualitative assessment with previously confirmed quantitative findings. The aim of this portion of the study was to improve the methodology of Nicholls et. al., (2007) by reducing the number of landmarks used for analysis and to try to address the aspects that seemed most relevant in terms of high ball velocity. The landmarks selected for the QAPV were chosen in an attempt to find a visual relationship to some of the previously discussed quantitative variables found to be relevant in existing pitching research, as well as the kinematic measures of our study. Landmarks 1, 2 and 3 involving lean and evaluating the position of the drive leg attempted to establish a link with the anterior-posterior shear force found in the research of Macwilliams et al., (1998) and SL measured in the present study. Landmark 4 involving evaluation of the timing of hip rotation attempted to establish a link with the timing measurements of Matsuo et. al., (2001) and HTS, coordination, and PPAV in the present study. This landmark was chosen in an attempt to link the QAPV with the measured kinematic variables coordination, HTS, and PPAV. Landmark 5 describing extension of the lead knee attempted to establish a link with the lead knee angle findings of Werner et. al., (2008) where greater knee extension correlated to greater ball velocity. Despite the care taken to choose visual landmarks that would seemingly correlate to previously confirmed quantitative findings, the QAPV was still ineffective. This may also be explained by the fact that only three of the five measured kinematic variables in the present study were found to be significant predictors of ball velocity. Furthermore, these 3 variables explained a relatively small portion of variance in ball velocity. A future study to identify the correct combination of variables that can predict greater variance within ball velocity, potentially using factor analysis, could be beneficial. With this in mind future versions of the QAPV should continue to be developed by linking visual landmarks with specific quantitative variables, but analysis of different landmarks may be more fruitful.

Another reason for the failure of the QAPV might be that the provided descriptions of the landmarks may not have been in depth enough to allow for a complete understanding on the part of the raters. It would be useful to debrief with the raters to develop a better understanding of whether this was in fact an issue. Third, the raters were relatively homogenous in their experiences involving baseball, their baseball environments, and their places of employment. The three raters all have significant baseball experience, but all work at CSU, Chico, and all share similar opinions on the movement of pitching and baseball in general. A more diverse group of raters, or in fact a larger group of raters may have produced a more reliable test for the effectiveness of the QAPV. Finally, a fourth potential reason could be the homogeneity of the participants. The range of velocity found in the participant pool was 79-90 mph, only an 11 mph range. While this range is quite large when analyzing pitchers within high levels of competition, the QAPV tool or similar future tools may have more effectiveness among a larger range of velocities or across more levels of pitchers.

Limitations

The present study was not without limitations. One limitation of the study is the generalizability of the findings. This limitation comes into play due to the small, homogenous sample used for this research. Although there was a relatively wide spread of ball velocities within the group and significant correlations were discovered, these findings may not prove true in another group of pitchers. Another limitation is the fact that the research was conducted indoors on a turf mound, despite our best attempts to replicate a typical pitching environment these are not the same conditions under which pitching is performed during competition. Thus, the laboratory environment may have altered the mechanics of the pitchers or potentially limited their ability to perform at their highest output. A third limitation is the homogeneity of the qualitative raters, which may have affected the effectiveness of the QAPV tool. Despite these limitations, the findings of this research and the hypotheses developed from analyzing these findings, offer important insights into the lens with which pitching mechanics are analyzed and how that lens can be adjusted to look for the aspects of pitching that are related to ball velocity.

Conclusions

The first goal of this study was to confirm previous quantitative findings in pitching research. Of the five quantitative variables measured (i.e., PPAV, HTS, KE, coordination, and SL) only three were confirmed to be significant predictors of ball velocity (i.e., PPAV, HTS, KE). The present results help to narrow the focus of variables that should be quantitatively analyzed in baseball pitching research. Moving forward, rather than attempting to document and observe every mechanical aspect of the pitching motion, we can begin to focus on the few quantitative aspects that appear to be most closely related to the production of greater ball velocity and develop tools to modify the pitching motion in order to maximize these important kinematic variables. The present findings are the first step in addressing one of the original goals of this study of bridging the gap between observing high velocity pitching and using these observations to attempt to create high velocity pitching.

The second goal of this study was to test the effectiveness of a qualitative tool for evaluating the pitching motion outside a motion analysis lab. The QAPV tool was found to be ineffective as a whole but perhaps has pieces that were on the right track and their value should be examined in future work. Based on the present findings the landmarks in the QAPV need to be revisited, revised, and retested, so that it may become an effective tool for qualitatively analyzing the pitching motion.

Appendix A

Qualitative Assessment of Pitching Velocity (QAPV)

Instructions:

- Review each of the pitches using the video provided
- For each pitch score the 5 qualitative landmarks
- Score each qualitative landmark as:
  - 1 = Performs correctly
  - 0 = does not perform correctly

Qualitative Landmarks	Pitch 1	Pitch 2	Pitch 3
1) The pitcher has started to lean towards the plate at the top of the leg lift (Lead hip inside the rubber)			
2) The lead hip reaches the 0.9 m line on the distance gauge before the lead knee crosses the lead hip.			
3) At the moment the front knee crosses the lead hip, the angle between the ground and the tibia of the drive leg is close to 45 degrees			
4) At the moment of front foot contact, the drive hip appears to rotating towards home plate.			
5) The lead knee is extended at the moment of ball release.			
Total Per Pitch			

Appendix B

This table depicts the following:

- Every pitch analyzed labeled by subject number and pitch number
- Radar gun velocity of each pitch in mph
- Average rating across raters from the QAPV
- Ordinal velocity in mph calculated in order to perform statistical analysis of the QAPV

Average Ratings, Actual Ball Velocity, and Ordinal Velocity

Subject/ Pitch	Velocity (mph)	Rate	Ordinal V (mph)
S01 P1	90	3.00	97.78
S01 P2	89	3.00	95.56
S01 P3	89	3.00	95.56
S02 P1	82	3.00	24.44
S02 P2	82	3.33	24.44
S02 P3	80	3.33	20
S03 P1	88	2.33	91.11
S03 P2	86	2.00	82.22
S03 P3	86	1.67	82.22
S04 P1	84	2.67	53.33
S04 P2	83	3.00	42.22
S04 P3	83	2.67	42.22
S05 P1	79	1.67	13.33
S05 P2	79	1.33	13.33
S05 P3	78	2.33	0
S06 P1	84	2.33	53.33
S06 P2	83	1.67	42.22
S06 P3	83	2.33	42.22
S07 P1	85	2.67	66.67
S07 P2	84	2.67	53.33
S07 P3	83	2.67	42.22
S08 P1	86	1.67	82.22
S08 P2	85	2.00	66.67
S08 P3	85	1.67	66.67
S09 P1	83	3.33	42.22
S09 P2	83	3.33	42.22
S09 P3	83	3.33	42.22

S10 P1	85	1.67	66.67
S10 P2	84	2.50	53.33
S10 P3	84	1.67	53.33
S11 P1	88	2.67	91.11
S11 P2	87	2.67	86.67
S11 P3	87	2.67	86.67
S12 P1	86	1.67	82.22
S12 P2	85	1.67	66.67
S12 P3	85	1.33	66.67
S13 P1	86	2.67	82.22
S13 P2	86	3.00	82.22
S13 P3	86	3.00	82.22
S14 P1	79	1.67	13.33
S14 P2	79	1.67	13.33
S14 P3	79	2.00	13.33
S15 P1	80	1.67	20
S15 P2	80	2.00	20
S15 P3	79	2.00	13.33

Appendix C

Individual Pitch Ratings for All Raters

	Rater 1				Rater 2				Rater 3		
S01											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	1	1		1	1	1
2	0	0	0		0	0	0		0	0	0
3	0	0	0		0	0	0		0	0	0
4	1	1	1		1	1	1		1	1	1
5	1	1	1		1	1	1		1	1	1
Totals	3	3	3		3	3	3		3	3	3
S02											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	1	1		1	1	1
2	0	0	0		1	1	1		1	1	1
3	0	0	0		1	1	1		0	1	0
4	0	0	0		0	0	1		0	0	0
5	1	1	1		1	1	1		1	1	1
Totals	2	2	2		4	4	5		3	4	3
S03											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		0	0	0		0	0	0
2	0	0	0		0	0	0		0	0	0
3	0	0	0		1	0	0		0	0	0
4	1	1	1		1	1	1		1	1	1
5	1	1	1		0	0	0		1	1	0
Totals	3	3	3		2	1	1		2	2	1
S04											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		0	1	0		1	1	1
2	0	0	0		0	0	0		0	0	0
3	1	1	1		1	1	1		1	1	1
4	1	1	1		1	1	1		1	1	1

5	0	0	0		0	0	0		0	0	0
Totals	3	3	3		2	3	2		3	3	3
S05											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	0	0	0		0	0	0		0	0	0
2	0	0	1		1	1	1		0	0	0
3	0	0	1		0	0	1		1	0	0
4	0	0	0		0	0	0		0	0	0
5	1	1	1		1	1	1		1	1	1
Totals	1	1	3		2	2	3		2	1	1
S06											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	0	1		1	0	1
2	0	0	0		0	0	0		0	0	0
3	0	0	0		0	0	0		0	0	0
4	0	0	0		1	1	1		0	0	0
5	1	1	1		1	1	1		1	1	1
Totals	2	2	2		3	2	3		2	1	2
S07											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	1	1		1	1	1
2	0	0	0		0	0	0		0	0	0
3	0	0	0		0	0	0		0	0	0
4	1	1	1		1	1	1		1	1	1
5	1	1	1		1	1	1		0	0	0
Totals	3	3	3		3	3	3		2	2	2
S08											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	0	1		1	1	1
2	0	0	0		0	0	0		0	0	0
3	0	0	0		0	0	0		0	1	1
4	0	0	0		1	0	0		0	0	0
5	1	1	1		0	0	0		0	0	0
Totals	2	2	2		2	0	1		1	2	2

S09											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	1	1		1	1	1
2	0	0	0		0	0	0		0	0	0
3	0	0	0		0	0	0		1	1	1
4	1	1	1		1	1	1		1	1	1
5	1	1	1		1	1	1		1	1	1
Totals	3	3	3		3	3	3		4	4	4
S10											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		0	0	1		0	0	0
2	1	1	0		1	1	1		0	0	0
3	0	0	0		0	0	0		0	0	0
4	0	0	0		0	0	0		1	1	1
5	1	1	1		0	0	0		0	0	0
Totals	3	3	2		1	1	2		1	1	1
S11											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	1	1		0	0	0
2	0	0	0		0	0	0		0	0	0
3	0	0	0		1	1	1		0	0	0
4	1	1	1		0	0	0		1	1	1
5	1	1	1		1	1	1		1	1	1
Totals	3	3	3		3	3	3		2	2	2
S12											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	1	1		1	1	1
2	0	0	0		0	0	0		0	0	0
3	0	0	0		1	1	0		1	1	1
4	0	0	0		0	0	0		0	0	0
5	0	1	0		0	0	0		0	0	0
Totals	1	2	1		2	2	1		2	2	2
S13											

Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	1	1		1	1	1
2	0	0	0		0	0	0		0	1	1
3	0	0	0		0	0	0		0	0	0
4	1	1	1		1	1	1		0	0	0
5	1	1	1		1	1	1		1	1	1
Totals	3	3	3		3	3	3		2	3	3
S14											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	1	1		1	1	1
2	0	0	0		0	0	0		0	0	0
3	0	0	0		0	0	0		0	0	0
4	1	1	1		0	0	0		0	0	0
5	0	0	1		1	1	1		0	0	0
Totals	2	2	3		2	2	2		1	1	1
S15											
Landmark	Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3		Pitch 1	Pitch 2	Pitch 3
1	1	1	1		1	1	1		1	1	1
2	0	0	0		0	0	0		0	0	0
3	0	0	0		0	0	0		0	0	0
4	0	0	0		0	0	0		0	0	0
5	1	1	1		1	1	1		0	1	1
Totals	2	2	2		2	2	2		1	2	2

Appendix D

Informed Consent Form

Informed Consent

Invitation to Participate

My name is Luke Barker. As a master's student in the Kinesiology department at CSU Chico I am required to complete a master's thesis which involves the development of a research project. You are being invited to participate in this project because you have collegiate experience in baseball pitching. The purpose of this study is to examine the kinematics of baseball pitching and use this information to formulate a qualitative assessment strategy that coaches can use in an applied setting.

Requirements of Participation

Participation in this study will consist of a one-day commitment totaling approximately 1 hour of lab time. You will be equipped with a full-body set of adhesive reflective markers for use in the motion analysis lab. These reflective markers will be applied directly to your clothing by the researcher. In order minimize measurement error, you will be required to wear tight fitting spandex short and low cut athletic footwear. After completing a provided warm-up, you will be asked to perform multiple trials of baseball pitching for recording with both 3-D motion analysis cameras and a GoPro Hero3+ video camera. After the researcher has collected the data, the participants will be free to go and have no other commitment to the study. Data recorded from both of these instruments will be stored and subsequently analyzed by the researcher, with the identity of the subject being kept anonymous during the analysis. In order to preserve anonymity, participants will be assigned a participant number that they will be referred to during data collection and data analysis. Names and personal information outside of height, weight, sex, and age will be not be recorded or kept.

Risks and Safeguards

While very minimal, muscle and joint injury risk consistent with performing the act of pitching will be associated with participation in this study. In order to minimize this risk you will be given adequate time to warm-up, including time to stretch, run and lightly throw. It is unlikely that you will be get injured during your participation in this study; however, in case of an unanticipated injury, emergency personnel will be contacted. Neither the researchers, nor CSU, Chico is responsible for any injury that may occur during the course of your participation in this study.

Benefits

The benefits of participating in this study involve furthering the field of pitching biomechanics and also the possibility that participants may learn something about improving their own performance through participation of this study. The qualitative aspect of the study will also help coaches identify qualitative landmarks in a pitcher more effectively and therefore help them become a more efficient and successful pitching coach.

Voluntary Participation

Involvement and participation in this research study is completely voluntary and at any time in the process of the study a participant may withdraw their participation with no personal consequences. Please feel free to contact any of the researchers if you have any questions, comments, or concerns about this research project. Having read the information above and had a chance to ask any questions, please sign below if you would like to participate in this research. A copy of this form will be given to you for future reference.

Contact Information

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Participant Printed Name: ____

Participant Signature: ____

Researcher Signature: ____

REFERENCES

Coaching Association of Canada (CAC). (2011). *My First Pitch.* Retrieved from https://cdn2.sportngin.com/attachments/document/0072/2615/myfirstpitchbooklet.pdf

Davis, R. B., Ounpuu, S., Tyburski, D., & Gage, J. R. (1991). A gait analysis data collection and reduction technique. *Human Movement Science*, *10*, 575–587.

De Leva, P. (1996). Adjustments to Zatsiorksy-Seluyanov's segment inertia parameters. *Journal of Biomechanics, 9*, 1223-30.

Dillman, C. J., Fleisig, G. S., & Andrews, J. R. (1993). Biomechanics of pitching with emphasis upon shoulder kinematics. *Journal of Orthopedic & Sports Physical Therapy, 18*(2), 402-408.

Dun, S. D., Fleisig, G. S., Loftice, J., Kingsley, D., & Andrews, J.R. (2007). The relationship between age and baseball pitching kinematics in professional baseball pitchers. *Journal of Biomechanics, 40*, 265-270.

Ellis, S. (2015). *The ultimate guide to advanced pitching*. Wellesley, MA: The Complete Pitcher Inc.

Escamilla, R. F., Fleisig, G. S., Barrentine, S. W., Andrews, J. R., & Moorman, C. (2002). Kinematic and kinetic comparisons between American and Korean professional baseball pitchers. *Sports Biomechanics, 1*(2), 213-228.

Fleisig, G. S., Andrews, J. R., Dillman, C. J., & Escamilla, R. F. (1995). Kinetics of baseball pitching with implications about injury mechanisms. *American Journal of Sports*

Medicine, 23 (2), 233-239.

Fleisig, G. S., Barrentine, S. W., Zheng, N., Escamilla, R. F., & Andrews, J. R. (1999). Kinematic and kinetic comparison of baseball pitching among various levels of development. *Journal of Biomechanics, 32*, 1371-1375.

Gotch, N. (2012, October 20). *The only pitching mechanics guide you'll ever need*.

House, T., Heil, G., & Johnson, S. (2006). *The art and science of pitching.* Monterey, CA: Coaches Choice.

House, T., Rosenthal, J., & Ryan, N. (1991) *Nolan Ryan's pitcher's bible: the ultimate guide to power, precision, and long-term performance*. Simon & Schuster/Fireside: New York, NY.

Johnson, D. (2013). *The Complete Guide to Pitching.* Champaign, IL: Human Kinetics.

Keller, D. (2001) *Survival guide for coaching youth baseball.* Champaign, IL: Human Kinetics.

Mache, M. (2005). *The use of biomechanical feedback to improve vertical jump performance.* Unpublished master's thesis, California State University, Chico.

Macwilliams, B. A., Choi, T., Perezous, M. K., Chao, E. Y., & McFarland, E. G.(1998). Characteristic ground-reaction forces in baseball pitching. *American Journal of Sports Medicine, 26(*1), 66-71.

Matsuo, T., Escamilla, R. F., Fleisig, G. S., Barrentine, S. W., & Andrews, J. R. (2001). Comparison of kinematic and temporal parameters between different pitch velocity groups. *Journal of Applied Biomechanics*, *17*, 1-13.

Naito, K., Takagi, H., Maruyama, T. (2011). Mechanical work, efficiency, and energy redistribution mechanisms, in baseball pitching. Sports Technology, *4*(1-2), 48-64.

Nicholls, R., Fleisig, G., Elliott, B., Lyman, S., & Osinksi, E. (2007). Accuracy of qualitative analysis for assessment of skilled baseball pitching technique. *Sport Biomechanics, 2*(2), 213-226. doi:10.1080/14763140308522819

Oyama, S. (2012). Baseball pitching kinematics, joint loads, and injury prevention. *Journal of Sport and Health Science, 1*, 80-91.

Ramsey, D. K., Crotin, R. L., &White, S. (2014) Effect of stride length on overarm throwing delivery: A linear momentum response. *Human Movement Science*, *38*, 185-196.

Robb, A. J., Fleisig, G., Wilk, K., Macrina, L., Bolt, B., & Pajaczkowski, J. (2010). Passive ranges of motion of the hips and their relationship with pitching biomechanics and ball velocity in professional baseball pitchers. *American Journal of Sports Medicine, 38*(12), 2487-2493. doi:10.1177/0363546510375535

Russell, D. (2013). *Pitching Mechanics Explained, A Parent's Guide.* Chicago, IL: Price World Publishing.

Seidel, G. K., Marchinda, D. M., Dijkers, M., Soutas-Little, R. W. (1995). Hip joint center location from palpable bony landmarks–a cadaver study. *Journal of Biomechanics*, *28*(8), 995–998.

Seroyer, S. T., Nho, S. J., Bach, B. R., Bush-Joseph, C. A., Nicholson, G. P., & Romeo, A. A. (2010). The kinetic chain in overhand pitching: Its potential role for performance enhancement and injury prevention. *Sports Health*, *2*(2), 135-46.

Ulrich, D. (2000). *The test of gross motor development*. Austin, TX: Prod-Ed.

Urbin, M.A., Fleisig, G. S., Abebe, A., & Andrews, J.R. (2012). Associations between timing in the baseball pitch and shoulder kinetics, elbow kinetics, and ball speed. *American Journal of Sports Medicine, 41*(2), 336-342. doi: 10.1177/0363546512467952

Werner, S.L., Suri, M., Guido Jr, J. A., Meister K., & Jones D. G. (2008). Relationships between ball velocity and throwing mechanics in collegiate baseball pitchers. *Journal of Shoulder and Elbow Surgery, 6*, 905-8. doi:10.1016/j.jse.2008.04.002

Youth Pitcher. (n.d.) *Youth Pitching Guide – All You Need to Know.* Retrieved from http://squiddly.bandl.com/cdwnlds/BaseBall/youth_pitching_guide_21603.pdf