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THE VARIATION OF CENTER OF MASS EXCURSION
WITHIN AND BETWEEN INNINGS AND ITS
RELATIONSHIP TO PITCHED BALL
VELOCITY IN COLLEGIATE
SOFTBALL PLAYERS

An Abstract of a Thesis

Submitted

in Partial Fulfillment

of the Requirements for the Degree

Master of Arts

Leah Renee Embrey

University of Northern Iowa

May, 2015

ABSTRACT

The purpose of this study was to measure the changes to excursions of the COM with pitch count and innings pitched in a collegiate softball game. Additionally, the effect of excursion on pitched ball velocity was investigated.

Twenty-six collegiate pitchers were recorded using a high speed video camera. The first three fastballs and the last three fastballs in each inning were used to determine the COM position during the stride foot takeoff, the lead foot touchdown, and the release. Ball velocity was also calculated from the digitization of each video. MatLab and Excel were used to calculate the excursions between the start of the pitch to the lead foot land, the lead foot land and the release and the start of the pitch and the release.

The multivariate 2x5 Factorial MANOVA indicated that there was no significant interactions ($F(16,532)=0.133$, $p=0.809$) therefore main effects were investigated. There were no significant differences between the performance variables between the beginning and ending of the innings pitched ($F(4,130)=0.02$, $p=0.99$). Finally, there were no differences between innings ($F(16,532)=0.99$, $p=0.46$).

The lack of support was attributed to the complex nature of the pitch with a variety of variables contributing to the execution of the pitch. The small correlation found could possibly be an increase in the arm motion and be an example of one of the many compensating factors that allow a pitcher to maintain pitched ball velocity.

Future research for this topic should look at conducting the study during the spring season to reduce the variability of innings pitched, and research a younger

population of athletes with the idea that in younger players the changes may be more noticeable throughout a game due to lack of strength and lower skill level.

THE VARIATION OF CENTER OF MASS EXCURSION
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This Study by: Leah Embrey

Entitled: The Variation of Center of Mass Excursion within and Between Innings and its Relationship to Pitched Ball Velocity in Collegiate Softball Players

has been approved as meeting the thesis requirement for the
Degree of Master of Arts

Date Dr. Travis Ficklin, Chair, Thesis Committee

Date Dr. Robin Lund, Thesis Committee Member

Date Dr. Forest Dolgener, Thesis Committee Member

Date Dr. April Chatham-Carpenter, Interim Dean, Graduate College

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CHAPTER I

INTRODUCTION

Based on the defensive nature of softball, pitching is a dominant aspect of the game. Pitchers control the tempo and in many cases the outcome of the game. Axe, Windley and Snyder-Mackler (2002) noted that softball pitchers can average approximately 90 pitches per game. At the college level, one pitcher will generally throw a majority of the games in a season (Werner, Guido, McNeice, & Richardson, 2005). Werner et al. (2005) reported pitchers can throw between 1,200 -1,500 pitches in a three day period as compared to baseball only throwing 100 -150 pitches.

The initial styles of a pitch differ from athlete to athlete. However, even with the differences the fundamentals are the same. The underhand pitch can be split up into several distinct phases. The first phase is made up of the wind-up, in which the arm hyperextends past the body and initiates a rocking motion and ends with the arm perpendicular to the ground by the pitcher's side, in the six o'clock position as the stride foot toes-off (Barrentine, 1999; Barrentine, Fliesig, Whiteside, Escamilla & Andrews, 1998; Flyger, Button & Rishiraj, 2006). The second phase is initiated as the stride foot leaves the ground and ends as it touches the ground. Throughout the phase the trunk will rotate sideways facing third base as the arm extends over the pitchers head. The third phase begins as the foot makes contact with the ground and ends when the ball is released (Barrentine, 1999). The arm travels from above the head posteriorly from the 12 to 6 o'clock position as the hips forcefully close and the elbow begins to flex. The fourth and

final phase is described as the follow-through, which occurs at ball release until the arm comes to rest (Rojas et al., 2009).

As the body moves through the different phases of a pitch, momentum is transferred from the ground through the body to the final release of the ball. This notion is known as proximal-to-distal sequencing (Putnum, 1980). As the legs push off the ground during the first phase there is an initial ground reaction force (GRF) generated. During the stride phase, the initial momentum is transferred to the stride leg as it makes contact with the ground. This occurs in phase three of the pitch. As the stride foot lands, a braking impulse is generated against the ground to which the ground reacts with in an equal and opposite force (Oliver & Plummer, 2011). The force and momentum generated in the lower body moves through the segments of the kinetic chain. As each proximal segment decelerates, the distal segment accelerates until reaching the end of the arm when that momentum is transferred to the ball resulting in increased pitch velocity (Putnam, 1993). For the purpose of this study, the measurement of the second and third phase will be described as excursion zero (EXC_0), the second phase or stride length will be described as excursion one (EXC_1), and the third phase will be described as excursion two (EXC_2). It is feasible the excursion variables could vary within innings and between innings as a function of fatigue, furthermore this variable could affect pitched velocity. No other studies have look at this topic.

Statement of the Problem

The purpose of this study was to measure the changes to excursions of the COM with pitch count and innings pitched in a collegiate softball game. Additionally, the effect of excursion on pitched ball velocity was investigated.

Research Questions

1. How does the excursion of COM and pitched ball velocity change between the beginning and end of an inning?
2. How does the excursion of COM and pitched ball velocity vary across innings?
3. How does excursion of COM affect pitched ball velocity?

Hypotheses

It was hypothesized that the excursion of the COM would increase as pitch count rises from the beginning to the end of an inning, as well as across innings as the subjects experienced fatigue. The excursion was also hypothesized to be negatively related to the pitched ball velocity.

Significance of the Study

One variable related to success in pitching is the production of high ball velocity. The ability to brake is a key factor in how well momentum is transferred throughout a pitch. Momentum is transferred from the ground through the kinetic chain and ultimately to the ball resulting in max velocity. Although this study does not directly quantify the specific braking impulse, it is important to quantify how the braking impulse and excursion of COM does or does not change throughout a game. This will allow coaches

to identify key components within a pitch to improve the braking impulse and transfer of momentum resulting in pitch velocity.

Delimitations

The participants of this study included approximately 26 collegiate softball pitchers ranging from NJCAA to Division 1. Three to four participants were measured from each opposing team during four ten inning fall season games. Participants were filmed using a high speed video camera. The measurements were calculated using the first three fastballs and the last three fastballs of each participant in each inning played. The film data were digitized using MaxTraq as whole body segments.

Limitations

The limitations of this study came from uncontrollable aspects within the study design. The data were collected outside during collegiate softball games therefore weather may have played a factor in the data collection. The outcome of the game may have had a possible effect on the attitude and motivation of the specified pitcher which may have in turn effected the data collection. Having had multiple pitchers throughout the game may have been a limiting factor as the pitchers did not throw a full game thus skewing the data. The sample size was also a limit of this study due to the use of a convenience sample.

Assumptions

It was assumed the validity of the camera was high and recorded correctly. It was also assumed that the athletes gave their full participation during the game and had a high motivation to be successful.

Definition of Terms

1. Braking impulse can be defined as a force contributing to turn sharpness by causing deceleration in the initial movement direction (Houck, 2003 as cited in Jindrich, Besier & Lloyd, 2006).
2. Proximal-to-distal sequencing occurs as the energy starting in the proximal segment slows down as the momentum travels to the next segment thus increasing velocity. This process occurs from the large muscles and segments to the smaller segments (Putnam, 1993).
3. GRF is the reaction force supplied by the ground to the force the body exerts on the ground (Kwon, 1998).
4. EXC_0 is the horizontal distance the COM traveled between the start and release of a pitch.
5. EXC_1 is the horizontal distance the COM traveled between the start and the lead leg landing.
6. EXC_2 is the horizontal distance the COM traveled between lead leg landing and release.
7. Pitched ball velocity is the rate at which the ball changes position (Henderson, 2015).

CHAPTER II

REVIEW OF RELATED LITERATURE

The dominant position when on defense in softball is the pitcher. Every play begins with the ball inside the circle (Amateur Softball Association of America, 2014). During each pitch, the stride foot initiates a braking impulse that helps generate and transfer the momentum being produced from the ground through the body. An effective pitcher can generate large braking impulses allowing for a highly effective transfer of momentum through the body resulting in increased ball velocity. Naturally, as the game progresses more pitches will be thrown thus increasing the amount of braking impulse the lower legs will endure. As workload and time continue to increase, research has shown that an athlete can become fatigued (Nyland, Shapiro, Stine, Horn & Ireland, 1994). Based on this premise two questions were formed in the hopes to gain an insight into what happens to the excursion of COM during a game. The first question investigated the excursion of COM between the beginning and end of an inning. The second question looked into the relationship between excursion of COM and pitched ball velocity. This literature review will discuss in greater depth the components of this theory along with past and future research implications.

Phases of a Pitch

As previously mentioned, the softball pitch can be separated into four phases based on the movement of the total body (Barrentine, 1999; Barrentine et al., 1998; Flyger et al., 2006). Other researchers have separated the pitch into phases by arm position creating six or more phases (Rojas et al., 2009). The first phase of the pitch is

described as the wind up (Barrentine, 1999). The phase begins at the initial movement of the body until the non-stride foot leaves the mound. In a right handed player the non-stride foot is the right foot. The throwing arm initially travels away from the plate as the body travels towards the plate (Barrentine et al., 1998). During this phase, the pitcher creates a rocking motion, which begins the initial loading of the muscles in the shoulders and lower legs by stretching them to illicit a recoiling effect (Alexander & Haddow, 1982).

The second phase, known as the stride phase, begins as the contralateral foot leaves the ground and ends when it makes contact with ground (Barrentine et al., 1998). The pitching arm travels from the 6 o'clock position to the 9 o'clock position as the body faces third base (Rojas et al., 2009). The non-stride foot creates a propulsive GRF causing the COM to translate towards the plate (Oliver & Plummer, 2011; Werner et al., 2005). When the lead foot makes contact with the ground, a braking impulse is created, stopping the forward momentum of the pitcher and translating it through the body (Werner, Jones, Guido, & Brunet, 2006).

The duration of when the stride foot makes contact till the release of the ball is classified as the delivery phase (Barrentine, 1999). The hips and torso forcefully rotate from the open position (facing third base) to a more closed position (facing home plate) and have been found to have high velocities of rotation. In one study, Werner et al. (2005) found the velocity of the upper trunk rotation during the delivery phase to be $901^{\circ}/s \pm 162^{\circ}/s$, while the velocity of the lower body rotation was $544^{\circ}/s \pm 20^{\circ}/s$. In the

same study it was found that the velocity of the arm rotation was also high reading at $1250^{\circ}/s \pm 111^{\circ}/s$.

The fourth and final phase is the follow-through which occurs at release until the arm stops moving. The arm decelerates throughout the phase and to facilitate with the deceleration Barrentine (1999), Barrentine et al. (1998), and Werner et al. (2006) found a second peak extension torque and a peak elbow compression force occur.

Characteristics of a Pitch

There are several ways that pitchers can beat their opponents, specifically through ball velocity and pitch movement. For the purpose of this study pitched ball velocity will be a key factor discussed. When pitchers are able to produce large ball velocities they tend to be more successful. Previous studies have gathered data for average ball velocities of all different ages and ability levels (Barrentine et al., 1998; Oliver, Dwelly, & Kwon, 2010; Werner et al., 2005). Guido, Werner, and Meister (2009) and Werner et al. (2005) conducted studies on youth pitchers ranging from 11-19 years old. They found the average ball velocity of that age range was 25 ± 1 m/s (55 ± 3 mph). Barrentine et al. (1998) and Werner et al. (2006) found the average velocity for elite pitchers ages 21 – 25, to be 25 ± 2 m/s and 27 ± 2 m/s (60 ± 5 mph) respectively. These studies show generous differences between ages and ability levels. One study conducted by Oliver and colleagues (2010) looked at the specific variances between ability levels and although they did not describe numerical values for pitch velocity, they did find a statistically significant difference between the novice, intermediate and advanced groups.

Performance Enhancements

The main objective when training any athlete is to increase their performance level for the specific sport they participate in. For pitchers, a main goal is to increase ball velocity at release. Several proposed methods to achieve this goal have been cited, the main method being strength and conditioning (Axe et al., 2002; Flyger et al., 2006; Oliver, 2011). Strength and conditioning programs generally focus to improve strength, velocity, power and agility in athletes (Nimphius, McGuigan & Newton, 2010).

Many studies have looked at strength training programs to increase pitch velocity for the upper body, such as a study done by Prokopy et al. (2008), which looked at the differences in throwing performance when open-kinetic chain resistance training (OKCRT) was used versus closed-kinetic chain resistance training (CKCRT). They found that the CKCRT significantly increased throwing velocity from 58.0 ± 3.7 mph to 60.0 ± 2.8 mph, whereas the OKCRT velocity was not significantly increased (58.7 ± 7.3 mph to 59.0 ± 7.1 mph) (Prokopy et al., 2008). The majority of studies have been conducted on strengthening the upper body, but there have been no other studies that have focused on lower body strength training in order to increase max pitching velocity.

To the author's knowledge there have not been any studies conducted on strength training of the lower extremities to increase pitching parameters. However, there have been studies that suggest the importance of lower body strength, specifically related to the GRFs produced by the lower body (Barrentine et al., 1998; MacWilliams, Chio, Perezeous, Chao & McFarland, 1998; Oliver & Plummer, 2011; Werner et al., 2005). The GRFs documented in the previously mentioned articles are looked at from the anterior-

posterior direction, medial direction and vertical direction. All components of the GRF play a part in the pitchers ability to generate force, however for the purpose of this study the main focus will be on the anterior-posterior force, otherwise known as the braking impulse.

Braking impulse. Jindrich et al. (2006) described braking impulse as a force that decelerates the forward movement of the COM. The propulsive and braking impulses in the lower body have been researched in many instances during walking and running (Bishop, Brunt, Pathare, & Patel, 2003; Peterson, Kautz, & Neptune, 2001; Hase & Stein, 1998). Differences in these studies are related to the amount of force generated when stopping slowly versus stopping abruptly. Other studies have looked at the GRFs during turning and cutting maneuvers (Jindrich et al., 2006; Glaister, Orendurff, Schoen, Bernatz, & Klute, 2008). These studies examined the forces caused as the body attempts to travel in a new direction. From these articles, a base knowledge is obtained about how and why the braking force occurs in human movement. While these articles focus on the GRFs during walking and running, only a select few have looked at the GRFs during the softball pitch.

The studies conducted by Elliott, Grove, and Gibson (1988); Guido et al. (2009); Huang, Wang and Chien (2001); MacWilliams et al. (1998), and Oliver and Plummer (2011) are some of the few that have looked at the GRFs that occur in the lower extremities during a softball or baseball pitch. Elliott et al. (1988) recorded GRF data of each leg during a baseball pitch and related it to upper body movements for fastball and curveball. This study was only able to gather data from two force components, vertical

and horizontal due to the design of the study. MacWilliams et al. (1998) also studied the GRFs in baseball pitching, but measured both legs simultaneously during the pitch, which allowed the researcher to obtain data on all three force components.

Guido et al. (2009) collected data on the GRFs that occur in the legs and related them to pitch mechanics. They found the braking force was highest right after the stride foot made contact at 115 ± 46 % BW, quickly tapered to 0 at release and then became a driving force after release at 24 ± 27 % BW.

Oliver and Plummer (2011) examined the GRFs in the lower legs to describe the relationship between ground reaction forces and the kinematics and muscle activations during a pitch. The findings showed the braking forces in adolescent pitchers were 36 ± 10 % BW. The researchers also found that the gluteal muscles of the non-stride leg had high activation during the stride phase due to single-leg support.

Huang et al. (2001) quantitatively looked at the GRFs in both legs during a pitch. The findings showed the x and y force components were greater in softball than in baseball pitching (MacWilliams et al., 1998). Another difference they found in softball pitching versus baseball was two peak forces developed after the landing foot made contact with the ground. The first peak force ($F_x = 2.24 \pm 0.33$ % BW, $F_y = 3.49 \pm 0.21$ % BW) was greater than the second force in both F_x and F_y components ($F_x = 1.74 \pm 0.22$ % BW, $F_y = 2.46 \pm 0.20$ % BW). Huang et al. (2001) and MacWilliams et al. (1998) attributed the high GRFs to body stabilization and the mechanism of stopping the forward momentum in order to transfer the energy throughout the body.

Transfer of momentum. As the body moves through the pitching motion, force is generated from the ground up (Guido et al., 2009). During the stride phase, the non-stride leg generates a propulsive GRF, moving the body's COM forward (EXC_1). The stride leg is not in contact with the ground therefore the only force production comes from the non-stride leg (Oliver & Plummer, 2011). As the stride foot makes contact during the delivery phase, the force produced from the back leg is transferred to the stride leg resulting in a braking impulse (Werner et al., 2005). The braking impulse stops the forward progression of the COM and acts as the initial contributor in transferring the momentum through the body (MacWilliams et al., 1998). A greater braking impulse generated by the lower body is one factor involved in becoming more efficient in the excursion of COM.

The energy produced from the legs is the key contributor of pitch velocity. In order to produce high velocities, pitchers need to be able to efficiently transfer the momentum through the body (Putnam, 1993). In the literature, there have been a few researchers that have looked at the mechanism of the transfer of momentum, the most prominent studies were conducted by Putnam (1980 & 1993) and Alexander and Haddow (1982). In these three studies, the researcher described the process of how energy is transferred and the mechanism identified is known as proximal-to-distal sequencing (Putnam, 1993).

In the article written by Putnam (1993) describing the proximal-to-distal segmental movements, she attributed the major principle to Bunn's (1955) summation of velocity. The mechanism was defined as, each sequential segment will move continuously faster than the previous segment. Alexander and Haddow (1982) found the

same conclusion, as the velocity of the proximal segment slows down some momentum is transferred to the sequential distal segment. This results in an increase in angular velocity of the distal segment and therefore speeds the segment up (Alexander & Haddow, 1982; Putnam, 1993). They found that this process occurred continuously through ball release. Researchers attribute this process to increases in velocity and therefore increased success as a pitcher.

A supplementary action was found during the segmental interaction in the study done by Alexander and Haddow (1982), due to the nature of proximal-to-distal sequencing there is a lag in the distal segments, which creates a stretch reflex in the proximal segment muscles. This stretch increases potential energy in the agonist muscles and can therefore be transferred into larger segment velocities when those muscles are contracted (Alexander & Haddow, 1982).

Researchers have proved time and again that segmental interaction occurs during a pitch. In order to increase the efficiency to transfer momentum, muscle activation patterns during a pitch need to be understood. Previous studies conducted by Oliver (2011); Oliver and Plummer (2011); Oliver, Plummer and Keeley (2011); and Rojas et al. (2009) have identified specific muscle activation in the upper and lower body during pitch and have attributed them to the enhancement of transfer of momentum efficiency.

As previous studies have stated, there is a high importance for a strong lower body. Along with generating power from the ground, the core muscles need to be developed as well to maintain a rigid system to enhance the transfer of momentum from the proximal lower body to the distal upper body (Oliver & Plummer, 2011). An article

written by Kibler, Press and Sciascia (2006) looked at the definition of core stability, as well as its role in athletic function. They generally defined core stability as, “the ability to control the position and motion of the trunk over the pelvis and leg to allow optimum production, transfer and control of force and motion to the terminal segment in integrated kinetic chain activities” (Kibler et al., 2006, p. 190). Core stability within pitching acts as a stabilizer during the stride phase when the body is on single-leg support (Oliver & Plummer, 2011). Core stability is essential to connect the lower body to the upper body through the kinetic chain (Oliver et al., 2010). As the stability increases, it allows for greater muscle activation and trunk rotation during throwing motions (Kibler et al., 2006). The findings of Kibler et al. (2006) found that approximately 50 percent of the energy and force produced in throwing motions come from the hip and trunk area.

As mentioned previously, the trunk and lower body greatly contribute to throwing ability. Studies have looked at the large peak ground reaction forces the lower body generates, in both propulsive and braking directions. While these forces are generally positive influences, they can have a negative effect on performance in the case of injury.

Performance Detriments

It is well known that an injury to an athlete can have a detrimental effect on performance. Depending on the seriousness of the injury, the time an athlete may have to sit out of competition varies from mild, missing one or two days to severe, sitting out weeks even months (Hill, Humphries, Weidner & Newton, 2004). In softball, as in any other sport there are common injuries that occur due to the nature of the sport. Numerous studies have been published looking at the injuries in overhand throwing in baseball,

however there have been only a number of studies that have looked at the injuries associated with pitching (Hill et al., 2004).

The studies that have been conducted on pitching injuries can be separated into two focus groups: upper extremity injuries and lower extremity injuries. Upper body injuries tend to be more prevalent than lower body injuries, but both can have a significant impact on a pitcher's performance. A study conducted by Loosli et al. (1992) attempted to quantify the number of injuries underhand pitchers experience during a season (as cited in Barrentine et al., 1998). Of the 24 pitchers that participated, 20 participants experienced an injury and 26 injuries were observed overall. The study found that eighty two percent of all time-loss injuries occurred in the upper body and almost half of those injuries occurred in the shoulder and elbow (Loosli et al., 1992, as cited in Hill et al. 2004).

In a descriptive study conducted by Shanley, Micherner, Ellenbecker and Rauh (2012) upper extremity injury data were collected from high school pitchers throughout a 10-week season. In the results of their study, only two participants encountered an injury. They discussed this as a limitation of the study; however even with the small sample size they were able to specify pitch counts that may have led to possible overuse injuries (Shanley et al., 2012). The two athletes that became injured pitched on average approximately 1200 pitches per season, while the other pitchers threw approximately 660 pitches per season. These findings were similar to the results found by Loosli et al. (1992).

Several studies have been able to identify common injuries that occur in the upper extremity. Barrentine (1999) found high instances of injuries related to tendinitis, rotator

cuff and tendon strain and damage to the ulnar nerve. The specific causes of these injuries are still unknown, however Werner et al. (2006) and Hill et al. (2004) eluded that they may result from overuse and instability in the shoulder.

A possible mechanism of injury in the shoulders due to instability could be the result of high compressive forces that resist the shoulder from distraction. These forces have been found to be $80\% \text{ BW} \pm 22\% \text{ BW}$ in a study by Werner et al. (2006). Similar findings have been found in elite baseball pitchers (Flyger et al., 2006). By knowing the high forces the upper extremities generate, it is not surprising that injuries are caused from overuse. Pitching counts have been documented between 1200-1500 pitches per season in high school and the same amount of pitches in a weekend for collegiate pitchers (Shanley et al., 2012; Werner et al., 2006).

While upper body injuries do have a great effect on the overall performance of a pitcher, lower body injuries are more likely to cause problems generating power for the pitch. Throughout the literature there have only been a few studies conducted that focus on injuries to the lower extremities. In the study done by Hill et al. (2004), of the injured participants 30 injuries were associated with the lower trunk and extremities. Of those 30, 16 were injuries to the lower back and 4 were of the pelvis/hip region. Hill et al. (2004) attributed the cause of the injuries to overuse of the muscles within those regions.

General overuse based on amount of pitches thrown, as previously mentioned, have been shown to be a common mechanism for injuries related to the lower body, however other factors have been noted to have as big of an impact on performance. For

example, ground reaction forces produced as the body goes through the pitching motion have been found to be greater than the pitcher's body weight (Werner et al., 2005).

The high ground reaction forces leads to an increased amount of stress on the lower body. The braking impulse imparted on the stride leg during the delivery phase was found to be $36\% \pm 10\%$ BW in a study conducted by Oliver and Plummer (2011) and $115\% \pm 46\%$ BW from Guido et al. (2009). These forces are similar and in some cases higher than the braking impulse in an overhand pitch (Werner et al., 2005).

The vertical component of the ground reaction force is generally higher than the anterior-posterior forces as shown in studies conducted by Guido et al. (2009), Oliver and Plummer, (2011), and Werner et al. (2005). They found the vertical components to be 139% BW, 139% BW and $179 \pm 38\%$ BW, respectively. These values were similar to the values MacWilliams et al. (1998) found in baseball pitching at 150% BW. As a result of the high forces above body, the vertical component is also seen as a contributing factor to injuries of the lower body.

During the pitch, the rotational velocities and torques of the trunk have also been shown to play a part in lower extremity injuries. Werner et al. (2005) found the peak pelvis rotation velocity in youth pitchers to be $544 \pm 139^\circ/\text{s}$. Werner et al. (2006) determined that the average hip rotation of Olympic softball pitchers traveled from an angle of $70^\circ \pm 17^\circ$ when the arm was directly above the head, to a closed position of $52^\circ \pm 18^\circ$ at release. This rotation occurred in approximately 150 milliseconds causing an increased rotational velocity of $616 \pm 165^\circ/\text{s}$ (Werner et al., 2006).

The specific mechanisms of different types of injuries to the lower body have not yet been fully discovered (Hill et al., 2004). Researchers have attributed some injuries to overuse and a result of the high forces placed on the body, however none have looked at other possible mechanisms such as fatigue (Barrentine et al., 1998).

Research Implications

Possible implications from the current research study are related to a wide variety of professionals. As understanding of what happens to the excursion of COM throughout a pitch increases, professionals in the realm of softball will be able to gain a better perspective on how to train, coach and rehabilitate athletes. Coaches will have an increased knowledge of the actions that occur in the lower body during pitching therefore adjust training protocols to enhance the pitcher's ability. Clinicians will benefit from the new knowledge this study will bring to the forefront allowing them to better prevent and rehabilitate injuries caused by high ground reaction forces. Strength and conditioning specialists can use the knowledge to create more specific training regiments to strengthen the trunk and lower body based on the peak forces that are endured by the body. Lastly, the results from the current study may bring up new questions for future research while increasing the base knowledge in the present literature about ground reaction forces in softball pitching.

CHAPTER III

METHODOLOGY

As stated previously, in order to achieve the greatest ball velocity a pitcher needs to be highly efficient in transferring momentum from the ground through the kinetic chain (Barrentine et al., 1998). As a pitcher progresses through the pitch, the stride foot lands causing the transfer of momentum. The ability to keep this leg firm allows the momentum to be transferred efficiently through proximal (lower body) to distal (upper body) segments (Guido et al., 2009). It has not been previously studied whether or not the ability to transfer momentum changes from inning to inning, therefore the problem is to determine the excursion of the COM between the beginning and end of each inning.

Research Design

The research design is descriptive in nature. The study was conducted by observing a pitcher's tendencies throughout the duration of a softball game. No variables were controlled during each game. The results of the measurements were quantitative based and resulted in specific calculations to determine the distance a pitcher's COM travels from pitch to pitch throughout the game.

Research Participants

The participants were chosen based on a convenience sample from National Junior College Athletic Association (NJCAA), National Association of Intercollegiate Athletics (NAIA), and Division 1 collegiate softball pitchers during the fall season. Twenty-six pitchers were observed during four ten inning games, with approximately

three to four pitchers throwing from each team per game. The age of the participants ranged from 18-24 years and included both right and left-handed pitchers.

Instrumentation

The data collected includes video data of each pitch in every inning. Each pitch was videotaped using a high speed camera filming at 300 Hz and was analyzed using MaxTraq software. The whole body was digitized to calculate the location of the COM at key instants defining the excursion. Ball speed at release was also calculated.

Procedures for Collecting Data

IRB approval as well as informed consent forms from participants were not needed for this study as the games were public events. It was assumed the participants were motivated to perform maximally.

Prior to the start of the game the camera was set up with the optical axis of the camera perpendicular to the vertical plane containing the line from the center of the rubber's front edge to the apex of home plate. The camera was placed approximately 30 meters from the pitching mound in order to minimize perspective error. Calibration of the camera occurred at the completion of the game using a two by six board with a two by two inch white rectangle on either end separated by a known calibration distance. The inner edge of the white line was parallel with the rubber's front vertical edge and perpendicular to the horizontal plane of the front edge of the rubber. It was positioned in the center of the mound and pointed directly at the plate.

Just prior to the pitcher's initial movement of the pitch, the researcher clicked the "Record" button on the video camera. Once the ball had been released the researcher clicked "Record" again to end the trial. This process was repeated for each pitch throughout the game.

Following data collection, 21 body landmarks were digitized, and the body COM was calculated from video using a previously employed method (Ficklin, Lund, & Schipper, 2014). The horizontal location of the COM was measured at the instant the stride foot left the ground, when the stride foot touched down, and at the release of the ball for the first three fastballs and the last three fastballs in each inning per player. Additionally, the ball's position was measured for the first ten frames following release, from which the ball's release velocity was calculated.

Data Analysis

The data collected from the games were used to calculate the excursion of the COM. Descriptive statistics were collected (mean \pm SD) for all performance variables. A multivariate 2x5 Factorial MANOVA was used to determine if there was a difference in the performance variables, EXC₀, EXC₁, EXC₂ and velocity, between the beginning and end of the innings as well as across all innings pitched. Pearson moment correlations were used to examine the relationships between the performance variables. The level of significance was set at $p < 0.05$ for all inferential statistics.

CHAPTER IV

RESULTS

The descriptive statistics of all performance variables during the beginning and ending of each inning can be found in Tables 1-5. The results of the Pearson product moment correlations can be found in Table 6. The multivariate 2x5 Factorial MANOVA indicated that there was no significant interactions ($F(16,532)=0.133$, $p=0.809$) therefore main effects were investigated. There were no significant differences between the performance variables between the beginning and ending of the innings pitched ($F(4,130)=0.02$, $p=0.99$). Finally, there were no differences between innings ($F(16,532)=0.99$, $p=0.46$).

Table 1

Means and Standard Deviations of COM Location at the Beginning and End of Inning 1

| Variable | BEGINNING | | ENDING | |
|----------------------|-----------|------|--------|------|
| | Mean | SD | Mean | SD |
| EXC ₀ (m) | 1.01 | 0.09 | 1.01 | 0.08 |
| EXC ₁ (m) | 1.22 | 0.11 | 1.22 | 0.09 |
| EXC ₂ (m) | 0.19 | 0.04 | 0.18 | 0.04 |
| Velocity (m/s) | 26.78 | 1.81 | 26.37 | 1.33 |

Table 2
Means and Standard Deviations of COM Location at the Beginning and End of Inning 2

| Variable | BEGINNING | | ENDING | |
|----------------------|-----------|------|--------|------|
| | Mean | SD | Mean | SD |
| EXC ₀ (m) | 1.00 | 0.07 | 1.02 | 0.08 |
| EXC ₁ (m) | 1.22 | 0.09 | 1.23 | 0.09 |
| EXC ₂ (m) | 0.19 | 0.04 | 0.18 | 0.04 |
| Velocity (m/s) | 26.71 | 1.47 | 26.27 | 1.58 |

Table 3
Means and Standard Deviations of COM Location at the Beginning and End of Inning 3

| Variable | BEGINNING | | ENDING | |
|----------------------|-----------|------|--------|------|
| | Mean | SD | Mean | SD |
| EXC ₀ (m) | 1.03 | 0.09 | 1.03 | 0.09 |
| EXC ₁ (m) | 1.25 | 0.12 | 1.25 | 0.10 |
| EXC ₂ (m) | 0.20 | 0.04 | 0.20 | 0.03 |
| Velocity (m/s) | 26.73 | 1.07 | 26.92 | 1.77 |

Table 4
Means and Standard Deviations of COM Location at the Beginning and End of Inning 4

| Variable | BEGINNING | | ENDING | |
|----------------------|-----------|------|--------|------|
| | Mean | SD | Mean | SD |
| EXC ₀ (m) | 1.07 | 0.08 | 1.05 | 0.10 |
| EXC ₁ (m) | 1.30 | 0.13 | 1.28 | 0.15 |
| EXC ₂ (m) | 0.21 | 0.03 | 0.20 | 0.01 |
| Velocity (m/s) | 25.91 | 1.27 | 26.10 | 1.28 |

Table 5
Means and Standard Deviations of COM Location at the Beginning and End of Inning 5

| Variable | BEGINNING | | ENDING | |
|----------------------|-----------|------|--------|------|
| | Mean | SD | Mean | SD |
| EXC ₀ (m) | 0.97 | 0.12 | 0.99 | 0.12 |
| EXC ₁ (m) | 1.18 | 0.16 | 1.18 | 0.16 |
| EXC ₂ (m) | 0.19 | 0.01 | 0.20 | 0.01 |
| Velocity (m/s) | 27.29 | 1.36 | 27.76 | 1.37 |

Table 6
Correlations between Three COM Positions and Pitch Velocity

| Variable | 1 | 2 | 3 |
|--------------------|--------|--------|------|
| 1 EXC ₀ | - | | |
| 2 EXC ₁ | 0.84** | - | |
| 3 EXC ₂ | 0.08 | -0.01 | - |
| 4 Velocity | -0.05 | -0.17* | 0.03 |

Note: **. Correlation is significant at the .01 level (2-tailed). *. Correlation is significant at the 0.05 level (2-tailed). N= 143

CHAPTER V

DISCUSSION

As stated earlier, the amount of ball velocity a pitcher is able to produce theoretically depends on how effectively momentum can be transferred from the initial movement to release. The ability to transfer momentum comes from proximal to distal sequencing starting from the ground and ultimately transferring the built up momentum into the ball at release (Putnam, 1993). Because the success of a pitcher depends heavily on this sequencing, two questions were formed in the hopes of gaining more insight into what occurs to the location of the COM during a pitch. The first question investigated the change of excursion of the COM change between the beginning and ending of innings pitched. The second question examined the effect of excursion of COM on pitched ball velocity.

It was found that there was no significant change in any of the performance variables between the beginning and end of the innings pitched. When interpreting the results several indicators came to light as to why the results did not support the hypothesis. The majority of them relate to the variability and lack of control due to in-game data.

First, not all subjects pitched the same amount of innings. Only three subjects pitched five innings and all others pitched between one and four innings. This discrepancy resulted in various degrees of fatigue among the subjects. In short, under the conditions that occurred in this study, the ability to maintain similar excursions during an inning and throughout a game appears to be maintained. It is also possible that the

subjects may have not given maximal effort every pitch of each inning. If some of the subjects were able to achieve their desired velocities through greater mechanical efficiency of technique, this may have also caused variations in fatigue among the sample. The most logical explanation is that the windmill pitching motion is a complex motor pattern involving a variety of variables that are interrelated with one another. A change in any one variable resulting in a potential change in performance could be compensated for via an adjustment in some other variables.

It is also plausible that the results of this study did not support the initial hypothesis due to the season in which the study was conducted. The fall games are set up differently than the regular spring season, as a result more pitchers see game time, but each play a smaller number of innings. The nature of the fall games is seen as a limiting factor by increasing the variability of innings played among subjects.

The results of this study also suggest that variations in braking ability do not directly affect pitched ball velocity. The theoretical transfer of momentum in regards to pitched ball velocity has been established in the literature but concept is not supported by this study. The previous argument regarding the complexity of the movement is potentially the strongest explanation for the lack of an effect. That is, small changes in excursion are compensated for by the subject in other ways. Interestingly, there was weak but significant negative relationship between EXC_1 (stride length) and pitched ball velocity. This could be a result of an increased arm velocity to make up for a decrease in the time it took to perform the previous drive phase. It would be interesting to calculate

arm velocity during each pitch to determine if this is an example of how subjects may compensate to maintain pitched ball velocity.

Future Research

This subject matter is one of importance to head coaches, strength coaches and athletic trainers and should be researched in the future. With more information, coaches will be able to identify what components of the body are affected as the innings increase. Strength coaches and athletic trainers will be able to detect deficiencies within the athlete during a pitch leading to more specified workouts and injury prevent. This knowledge will allow those individuals to help increase athlete success while decreasing their chance of injury as the season progresses.

From this study it is questioned whether or not a more controlled testing design would yield different results. Instead of collecting data during a game, testing the athletes one at a time in a controlled environment such as practice may show different information. There would be less variability between pitches and innings and can be timed to ensure consistency.

A second option for future research is completing this study on a younger population. The preface being a possible change in athletes that aren't at the same level physically and mentally as collegiate players. With younger players the changes may be more noticeable throughout a game due to lack of strength and lower skill level. They may have a lower exhaustion threshold leading to greater changes in braking ability.

Summary

The results of this study found no correlation in the excursion of COM between the beginning and the end of each inning. No differences were found across innings either. The determining factor why there was no evidence to support the hypothesis cannot be narrowed to one characteristic but rather due to the complex nature of the pitch and the multitude of variables related to one another. There was a small but significant relationship between EXC_1 and pitch ball speed possibly due to a higher generation of velocity in the upper body as a compensation factor. The results may have shown a different outcome if the study was conducted in the spring season due to type of game and season. It would be beneficial to replicate this study in the future using a more controlled environment and on a younger population to determine a possible effect on the excursion of COM in an inning and pitched ball velocity.

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