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Relationships between throwing velocity and selected kinematics in youth baseball players

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RELATIONSHIPS BETWEEN THROWING
VELOCITY AND SELECTED KINEMATICS IN
YOUTH BASEBALL PLAYERS

A Thesis Presented To
Eastern Washington University
Cheney, Washington

In Partial Fulfillment of the Requirements
for the Degree
Master of Science in Physical Education

By
Nick Hedgecock
Spring 2018

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Abstract

Research investigating baseball position players has been limited primarily to pitchers. The current study examined several kinematic variables and their relationship with ball velocity in middle and high school-aged baseball players using two-dimensional (2D) motion analysis. The purpose of this study was to investigate these relationships using 2D motion analysis and compare these results to those reported in the literature using 3D analysis. Thirteen baseball players (15.31 ± 1.25 yrs., 72.29 ± 10.79 kg and 177.09 ± 5.59 cm tall) participated in the study. A video camera was used to record three throwing trials for each participant. Four reflective markers were placed on the participants to identify anatomical landmarks of interest on the players. Video trials were digitized in 2D using commercially available Dartfish software. Trunk side bend and knee flexion angle at foot contact, and trunk flexion, knee flexion, and knee extension velocity at ball release were calculated. Intra-rater reliability of ten re-digitized trials using Pearson's inter-item correlation was very high ($r = 0.99$, $p < 0.001$). Of the five kinematic variables analyzed, only trunk side-bend at foot contact achieved a significant correlation with ball velocity ($r = 0.527$, $p < 0.001$). 2D motion analysis may be a viable option for the analysis of throwing kinematics when expensive 3D systems are not available, however they are limited in the types of variables that can be related to ball velocity.

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Chapter 1: Introduction

For centuries, athletes have been pushing the limits of their physical abilities by any means necessary. They have vastly broadened the scope of training by using different elements and combining them into a polished body of work. This is seen through physical training, psychological training, nutritional interventions, and more recently, using video analysis. Position players in the game of baseball also seek new means to improve their performance. The combination of speed, agility and strength as well as the ability to generate a high ball velocity means a better chance to out-perform the competition.

Research investigating position players in baseball is limited in comparison to pitchers. While the majority of research conducted on pitchers tends to be regarding injury and the kinematics of pitching (Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999; Fleisig, 2010; Plummer, Oliver, Powers, & Michener, 2018; Solomito, Garibay, Woods, Öunpuu, & Nissen, 2015), some research has investigated the performance aspect and how pitchers can increase their ball velocity, among other things. Another reason that studies have focused on pitchers is due to the increase in participation rates in baseball, as well as the injury risks due to the overhead throwing motion. Compared to position players, pitchers make a greater number of throws which may increase their risk for injury. Catchers are studied even less, but their throwing mechanics have been evaluated (Fortenbaugh, Fleisig & Bolt, 2010; Oliver, Lohse & Gascon, 2015; Plummer & Oliver, 2013; Sakurai, Elliott & Grove, 1994). Unlike pitchers, catchers have no limitations to the number of throws they may make during a game. Catchers tend to make their throws from a squatted position, which differs from the position of a pitcher.

Additionally, the throws of catchers may or may not be maximal, depending on the specific play involved.

The throwing mechanics of position players have received much less research attention compared to pitchers and catchers. Because any given position player (short-stop, second baseman, right fielder, etc.) could be involved with any ball hit in play, they must be ready every single pitch. When a position player is involved in a defensive opportunity, they may not be in an ideal body position to deliver the baseball to their intended target. Position players must react to the ball in play and may move in a number of different directions. As a result of this, they must rely on a culmination of various physical factors (their strength and speed) along with skill and experience to deliver an accurate throw with velocity. Because position players may have to make many types of throws, it is necessary to identify one specific throw in order to investigate the kinematics involved in performing that throw. Position players are almost never in the exact same throwing position because they must react to the ball being put in play by the hitter. Position players may be moving laterally, in toward the plate, or away from the plate. It is also possible that position players may be making a throw while kneeling on the ground or jumping up in the air.

No matter which way position players move in order to field the ball, it is ideal that they gather their momentum as much as they can and direct it toward their intended target. Because of the wide variety of possible throws that could be completed by position players, the current study investigated the position player's throw as they would step toward the intended target, as if completing a routine play. The term *routine play* refers to an easier opportunity for the position player to receive the ball and complete a

successful throw without moving very far away from their starting position, resulting in an out. This places the position player moving forward to receive the ball, which allows them to set their bodies in an ideal position with their glove-hand side facing toward the intended target. As they complete the throw, their shoulders will square up to the target. By doing this, the position player first steps toward the target, and then throws the ball. Through the act of throwing, the position player releases the ball with their trunk flexing toward the intended target, which occurs in the sagittal plane.

Purpose of the Study

The purpose of this study was to determine angular kinematics of throws made by youth baseball position players, and to examine the correlations of these variables with ball velocity. Previous 3D analyses have examined the kinematics of pitchers, however these technologies are typically unavailable to the average youth baseball coach. We sought to determine if a 2D kinematic analysis could yield significant relationships with ball velocity, as have been reported using more complicated and expensive 3D analysis.

Null Hypothesis

H_0 : There will be no significant relationship between ball velocity and trunk side bending and knee flexion at foot contact, as well as trunk and knee flexion, and knee extension velocity at ball release.

Limitations

The youth participants in this study were recruited from one local area. Therefore, the results are limited to players of similar demographics as those studied here.

Video recordings for motion analysis were limited to a single camera, resulting in a 2D analysis of the throw. Multiple cameras and much more expensive hardware and software are necessary to accomplish 3D analyses.

Participants completed their throws in an indoor facility, which limited the generalizability of the results. While analyzing motion involved in a real-time game situation would have been ideal from the perspective of ecological validity, the controlled environment of an indoor facility offered greater repeatability of the throwing conditions.

Delimitations

The current study delimited the participant sample to youth players, thus the results cannot be extrapolated to younger or older players. Furthermore, position players were studied due to the limited research available in this population, with the majority of research conducted with pitchers and the overhead throwing motion.

An inexpensive 2D motion analysis was utilized which limited the types of kinematic variables examined. The current study investigated the throwing motion at foot contact and ball release. Because the participants stepped toward the target, they maintained a normal throwing motion. Foot contact allowed for frontal plane analysis of knee flexion and trunk side bend, whereas ball release allowed for sagittal plane analysis of trunk and knee flexion as well as knee extension velocity, both single planes of motion. With only one camera being used, this allows the researcher and future studies the ability to conduct more research due to the lower potential costs of equipment and motion analysis programs. This also represents the real-world setting of coaches analyzing their players and assessing performance with limited resources.

Assumptions

It was assumed that the participants did not take part in any strenuous activity which would alter the outcome of the data collection process. It was also assumed that the participants gave their maximum effort during data collection. Participants were also assumed to be free of any injury that would affect their ability to throw maximally. A Par-Q was completed prior to data collection to ensure the participant was cleared and able to participate in the study.

In regards to the physical set-up of the study, it was assumed that the radar gun would maintain high reliability throughout the data collection process as noted by the manufacturers website. Another assumption was that the marker placements did not shift over the bony landmarks during the act of throwing. It is known that there is error when placing reflective markers on the skin, as movement of the skin and soft tissue may not accurately represent the movement of the skeletal structure underneath (Akbarshahi et al. 2010; Reinschmidt, Van Den Bogert, Nigg, Lundberg, & Murphy, 1997). The reflective markers were placed on the participants once they completed their warm up, so as to limit any potential shifting during the data collection process.

Significance of Study

Baseball is a very popular sport played by youth across the world. However, very little is known about the biomechanics of the throwing motion in this population, in particular of position players. Understanding how the kinematics of the thrower's motion affects resulting ball velocity would help coaches focus training on specific movements involved in the throw. Although these variables have been evaluated in pitchers, as well

as adult players, it is not valid to assume the same relationships exist in youth position players. Youth coaches have limited to no access to expensive biomechanical analysis of their players. However, alternatives exist to these systems, which are within reach of the average baseball coach. Youth baseball coaches would benefit from knowing if meaningful information about the kinematics of their players' movements can be acquired using a single camera and a 2D analysis. If kinematics obtained in this manner can be related to ball velocity, then coaches can consider this type of system to assist them in improving throwing technique.

Chapter 2: Review of Literature

The overhead throwing motion seen in the sport of baseball is an acquired skill which takes time to master. This study was concerned with position players and the ball velocity that they can generate as it relates to trunk flexion, trunk side bend, knee flexion and knee extension velocity. Position players are asked to perform the complex task of fielding a ball and positioning their bodies to make a successful throw to their desired target. While the position player may not always be able to direct their momentum toward the intended target, it is very important to understand the characteristics of the throwing motion under normal circumstances. Regarding this, there is limited research involving position players and the kinematic factors that directly relate to ball velocity. To more fully understand what goes on during the overhead throwing motion, it is necessary to understand various concepts that make up the throwing motion. This involves the throwing motion itself, the body as a kinetic chain, the muscles involved with throwing at the hip, trunk and knee, the summation of speed principle, ball velocity and motion analysis and how it is used to capture the throwing motion.

Throwing Motion

The baseball pitching motion is an incredibly complex movement that has been studied extensively by researchers (Chaudhari, McKenzie, Borchers & Best, 2011; Feltner, 1989; Fleisig et al., 1996; Fujii & Hubbard, 2002; Hurd & Kaufman, 2012; Keeley, Wicke, Alford & Oliver, 2010; Milewski, Öunpuu, Solomito, Westwell & Nissen, 2012; Oliver & Keeley, 2010a, 2010b; Oliver, Plummer & Henning, 2013; Seitz, Reinold, Schneider, Gill & Thigpen, 2012). Most of the previous studies examined overuse injuries resulting from the overhead throwing motion with the high number of

people participating in the sport. Other studies investigated how specific segments of the motion or kinetic chain may influence other segments.

The previous studies mentioned also show how video cameras and analysis programs have further dissected the pitching motion and have, in some ways, revolutionized coaching of baseball pitchers. Other players besides the pitcher must have excellent throwing biomechanics as well. When looking at position players separately from pitchers, it is apparent that there are similarities and differences between the two regarding the throwing motion. There are few studies that have investigated the throwing motion of the position player, and many studies that have done the same with the pitching motion. Because studies vary on the description and number of phases in the pitching motion, it has been up to the individual study to define their perception of the pitching motion. This is especially true when studies have investigated only the throwing shoulder and arm and not the whole motion. As an example, Table 1 shows a study conducted by Fleisig (2010) defining their perception of the pitching motion and possible outcomes.

Oliver and Keeley (2010b) defined the pitching motion in the following phases: the stride phase, arm-cocking phase, arm acceleration phase, and arm deceleration phase. Another study done by Oliver et al. (2013) described the pitching motion as being four events: lead foot contact, maximum external rotation (MER) at the shoulder, ball release and maximum shoulder internal rotation.

Table 1. Summary of proper and improper pitching mechanics

Phase / Event	Proper Mechanics	Pathomechanics → Consequences
Windup	Lift front leg.	
Maximum Knee Height 	Pitcher is balanced.	
Stride	Front leg goes down and forward. Arms separate, swing down, and up.	↓ push off rubber → ↓ ball velocity
Foot Contact 	Front foot is planted slightly to 3B side (for a right-handed pitcher). Front foot is pointed slightly inward. Shoulder is abducted approx. 90°, with approx. 60° of external rotation.	↓ stride length → ↓ ball velocity Front foot open (position or angle) → ↑ shoulder and elbow force Improper shoulder external rotation and shoulder abduction → ↑ shoulder and elbow kinetics Excessive shoulder external rotation → ↓ ball velocity ↓ shoulder horizontal abduction → ↓ ball velocity
Arm Cocking	Pelvis rotation, followed by upper trunk rotation. Shoulder externally rotates, and trunk arches.	Early pelvis rotation → ↓ ball velocity Late pelvis rotation → ↑ shoulder and elbow kinetics ↓ pelvis rotation velocity → ↓ ball velocity Poor timing between pelvis rotation and upper trunk rotation → ↓ ball velocity Poor timing between pelvis rotation and upper trunk rotation → ↑ shoulder internal rotation torque
Maximum External Rotation 	Shoulder external rotation is approx. 180°. Elbow flexion is approx. 90°	↓ shoulder external rotation → ↓ ball velocity Excessive shoulder horizontal adduction & elbow flexion → ↑ shoulder kinetics
Arm Acceleration	Elbow extends, followed by shoulder internal rotation. Front knee extends.	
Ball Release 	The throwing shoulder is abducted approx. 90°	↑ knee extension velocity → ↑ ball velocity Improper shoulder abduction → ↓ ball velocity Improper shoulder abduction → ↑ elbow varus torque ↓ forward trunk tilt → ↓ ball velocity
Arm Deceleration	Shoulder internally rotates and front knee extension continues. Trunk tilts forward.	
Maximum Internal Rotation 	Shoulder external rotation is approx 0°.	
Follow Through	Arm crosses in front of body. Trunk flexes forward.	

Feltner (1989) conducted a study in which the pitching motion was described first in general parts and then further defined. The pitching motion was defined by four

phases: windup phase, early preparatory phase, late preparatory phase, and the release phase. The windup phase consisted of the pitcher's first movement, and ended just before the lead foot contacted the ground. The early preparatory phase began with foot contact and ended just before 0° of internal/external rotation. Following 0° internal/external and ending just before MER is the late preparatory phase. Finally, the release phase consists of MER and ending at the instant of ball release.

Yet another definition of the pitching mechanics is seen in the study conducted by Stodden, Fleisig, McLean, Lyman, and Andrews (2001). This study defined the pitching motion as having three phases: Stride, arm cocking, and arm acceleration. The stride phase consisted of the pitcher's instant maximum knee height of the stride leg to the stride foot contact. The arm cocking phase consisted of the stride foot contact to the instant of MER. The final stage, arm acceleration was from MER to ball release.

In a study conducted by Stodden, Langendorfer, Fleisig and Andrews (2006), the throwing motion was assessed by the step and trunk action. The step was categorized by four levels: no-step, homolateral step, contralateral short step and contralateral long step. The trunk was categorized by three levels: no trunk action (forward or backward movement), upper trunk rotation or total trunk rotation and differentiated rotation. Differentiated trunk rotation involved the thrower twisting away from the intended target, then moving toward the target beginning trunk rotation.

The current study focused on the position player and the throwing motion associated with it. Unlike the pitching motion, the position player may be asked to perform a throwing motion in any direction or position. This is dependent on the direction of the ball when hit into play, and the momentum of the fielding player prior to

performing the throw. Ideally, the position player will direct their momentum toward their intended target as discussed earlier, which results in a relatively similar throwing pattern to the pitching motion.

In regard to the throwing motion for position players, the current study defined the throwing motion in the following steps: the preparatory phase, which included the stride leg as it moved forward into front foot contact and the throwing arm as it moved into MER, the throwing phase, which started from the instant after MER and lasted until ball release, and finally the follow-through phase, which included the moment after the ball was released to maximum shoulder internal rotation. Because the current study only used one camera, the video collected at front foot contact occurred in the frontal plane and ball release occurred in the sagittal plane.

The Body as a Kinetic Chain

The throwing motion of the position player can be categorized into similar movement patterns as has been done with pitchers. With the movement patterns categorized, it is important to note that the body can be seen as a kinetic chain, as seen in the study conducted by Oliver & Keeley (2010b). They stated that it has become common knowledge that the hip and torso play key roles in the transfer of energy from the lower body to the upper body. The importance of the kinetic chain as it applies to the throwing motion is seen in the sequential movement pattern that starts from the ground, or the thrower's feet, and ends at the top, or the thrower's arm and hand. The resulting sequential throwing movement pattern helps to generate ball velocity because the thrower uses their whole body to complete this complex task. The trunk segment acts as an energy transfer source from the lower body to the upper body. The throwing motion is a dynamic

activity that depends on the movement of many connected, but separate links of the body to generate force. The individual links include the lower leg, upper leg, hip, trunk, shoulder, upper arm and lower arm. To the investigator's knowledge, there has been no research which has examined the relationship between generated ball velocity and trunk flexion, trunk side bend, knee flexion or knee extension velocity in baseball position players.

In a study conducted by Wilk, Meister, Fleisig and Andrews (2000), they described the body as a kinetic chain as it pertains to the throwing athlete. According to them, before the ball is released, each segment prior is responsible for generating and building force that eventually is put forth into the ball. It was also noted that velocity of the ball should increase as the proper execution of the kinetic chain and efficiency of the throw is increased. This is because as a distal segment has achieved its maximum angular momentum, the next segment then begins to create its angular momentum, and so forth. This describes the *summation of speed principle*, which will be discussed later. With a failure in the kinetic chain, such as at the trunk level, there could be a decrease in the performance aspect of the overall movement, as well as an increased likelihood of injury (Oliver and Keeley, 2010b). This is important as it has also been noted that the trunk may contribute as much as 50% of the kinetic energy, which could impact a position player's ability to successfully execute a throw during a baseball game.

Since research has shown the positives of the kinetic chain as it relates to performance and injury, it is logical to assume that if the hip and torso, the middle of the kinetic chain, also known as the lumbopelvic-hip complex (LPHC) as seen in the study conducted by Oliver et al. (2013) is not performing the way it should, that there may be

an increased risk of injury. While the focus of previous research has been on decreasing injury risks, the current study focused on the performance of the trunk as it relates to generated ball velocity because of the trunk's ability to contribute a large percentage of energy to the throwing motion.

Muscles Involved in the Overhead Throwing Motion

Because the overhead throwing motion involves the entire body, it can be assumed that all of the muscles in the human body are activated at one point or another throughout one completed throw. Because the current study investigated trunk side bend and knee flexion at foot contact and trunk flexion, knee flexion and knee extension velocity at ball release as it relates to generated ball velocity, this research focused on the muscles involved at the trunk and around the knee. More specifically, the current study looked at the LPHC musculature because of its importance in the transfer of energy from the lower half to the upper half of the kinetic chain and because it was the focus of the current study as it relates to generated ball velocity.

Before describing the current study's throwing motion and the muscles activated in each phase, it is necessary to note which movements are occurring at the hip/pelvis, and the trunk. The hip and pelvis will undergo external rotation, internal rotation, flexion and extension. The trunk will undergo flexion, extension, rotation as well as lateral flexion during the throw.

The following tables list the specific muscle groups that are involved with specific body segment movements (Reese, 2005). Although each muscle is listed for each specific action seen at the hip/pelvis and trunk and the knee, the current study was interested in

the correlation between trunk and knee movement at ball release and the generated ball velocity. Knowing which muscles control specific body actions may be key in terms of increasing the performance of baseball position players when looking at increasing strength and power to generate a higher ball velocity.

As mentioned earlier, the definition of the throwing phases has been up to each individual study. The current study used three categories (preparatory phase, throwing phase, and follow-through phase) which allowed the individual's hip and trunk action to be assigned to each subcategory listed next because of the LPHC's role in transferring momentum up the kinetic chain in the throwing motion. Table 2 describes the trunk actions and the muscles responsible for completing each action. Table 3 lists the hip actions and muscles associated with those actions. Lastly, Table 4 displays the knee actions and muscles associated with it.

For the throwing motion in this study, the participant began in a stance that was sideways (perpendicular) to the target. In the preparatory phase of the throw, they stepped toward the target. In this scenario, the plant leg underwent hip abduction, flexion, and external rotation, while the drive leg performed hip extension and internal rotation. At foot contact, the plant leg stops while the drive leg continues to see hip extension and hip internal rotation as the body accelerates toward the target. During this phase the arms separate and continue to abduct up to 90 degrees. The pelvis and lower trunk begins to rotate at this point. Toward the end of the preparatory phase the throwing arm begins to cock back into MER. At the same time, the plant leg begins to undergo knee extension, the pelvis and a greater portion of the trunk continues to rotate toward the target.

Table 2. Muscles involved in trunk actions

Trunk Rotation	
Muscle	Action
External Abdominal Oblique	Bilateral Action: Flexion of the vertebral column Unilateral Action: Lateral flexion and rotation of vertebral column toward the opposite side
Internal Abdominal Oblique	Bilateral Action: Flexion of the vertebral column Unilateral Action: Lateral flexion and rotation of vertebral column to the same side
Trunk Extension	
Muscle	Action
Iliocostalis Thoracis	Bilateral Action: Extension of the vertebral column Unilateral Action: Lateral flexion and rotation of vertebral column
Iliocostalis Lumborum	Bilateral Action: Extension of the vertebral column Unilateral Action: Lateral flexion and rotation of vertebral column, elevation of pelvis
Longissimus Thoracis	Bilateral Action: Extension of the vertebral column Unilateral Action: Lateral flexion of vertebral column
Spinalis Thoracis	Extension of the vertebral column
Multifidus	Bilateral Action: Extension of the vertebral column Unilateral Action: Lateral flexion of vertebral column and rotation to opposite side
Semispinalis	Bilateral Action: Extension of the vertebral column Unilateral Action: Rotation of vertebral column to the opposite side
Quadratus Lumborum	Bilateral Action: Extension of the lumbar spine Unilateral Action: Lateral flexion of lumbar spine, elevation of pelvis
Trunk Flexion	
Muscle	Action
Rectus Abdominis	Flexion of vertebral column

Table 3. Muscles involved in hip actions

Hip Flexion	
Muscle	Action
Iliacus	Flexion of the hip
Psoas Major	Bilateral Action: Flexion of trunk (while the thighs are fixed) Unilateral Action: Flexion of the hip
Hip Flexion, Abduction and External Rotation of the Hip	
Muscle	Action
Sartorius	Flexion, abduction and external rotation of the hip
Hip Extension	
Muscle	Action
Gluteus Maximus	Hip extension, external rotation of hip
Semitendinosus	Hip extension, flexion and internal rotation of knee
Semimembranosus	Hip extension, flexion and internal rotation of knee
Biceps Femoris	Hip extension, flexion and external rotation of knee
Hip Abduction	
Muscle	Action
Gluteus Medius	Hip abduction and internal rotation
Gluteus Minimus	Hip abduction and internal rotation
Hip Abduction with Flexion	
Muscle	Action
Tensor Fascia Lata	Hip abduction, hip flexion and internal rotation, extension of knee
Hip Adduction	
Muscle	Action
Adductor Magnus	Hip adduction
Adductor Longus	Hip adduction and flexion of hip
Adductor Brevis	Hip adduction, hip flexion and internal rotation
Pectineus	Hip adduction, hip flexion and internal rotation
Gracilis	Hip adduction, hip flexion and internal rotation
Hip Internal Rotation	
Muscle	Action
Tensor Fascia Lata	Hip abduction, hip flexion and internal rotation, extension of knee
Gluteus Minimus	Hip abduction and internal rotation
Gluteus Medius	Hip abduction and internal rotation
Hip External Rotation	
Muscle	Action
Piriformis	Hip external rotation, hip abduction (with hip flexed)
Gemellus Superior	Hip external rotation, hip abduction (with hip flexed)
Gemellus Inferior	Hip external rotation, hip abduction (with hip flexed)
Obturator Internus	Hip external rotation, hip abduction (with hip flexed)
Obturator Externus	Hip external rotation
Quadratus Femoris	Hip external rotation

Table 4. Muscles involved in knee actions

Knee Flexion	
Muscle	Action
Biceps Femoris	Hip extension, flexion and lateral rotation of the knee
Semitendinosus	Hip extension, flexion and medial rotation of the knee
Semimembranosus	Hip extension, flexion and medial rotation of the knee
Gastrocnemius	Flexion of the knee (when in a fixed position)
Knee Extension	
Muscle	Action
Rectus Femoris	Hip flexion, extension of the knee
Vastus Lateralis	Extension of the knee
Vastus Medialis	Extension of the knee
Vastus Intermedius	Extension of the knee

During the throwing phase, the throwing arm accelerates to the point of ball release, while the trunk continues to rotate toward the target. The pelvis rotates as well to face the intended target. The plant leg stabilizes the body. The drive leg hip extends as well as internally rotates in order to allow the pelvis to face the target. The trunk begins to move in flexion toward the target as the ball is released. Fleisig (2010) noted that if there was a decrease in trunk flexion, there was also a decrease in generated ball velocity in pitchers. This was the focal point of interest for the current study as the trunk may play an important role in generating ball velocity, as well as decreasing risks of injury.

Finally, the follow-through phase consists of the throwing arm internally rotating and decelerating. The trunk continues to move in flexion as the arm crosses down in front of the body. The knee of the plant leg will undergo extension as the momentum of the throw moves the body forward toward the intended throwing target.

Summation of Speed Principle

An important concept related to generated ball velocity in the game of baseball can be described by the summation of speed principle. Bunn (1972) states that “when the movement of several members of the body are involved in developing optimum speed, the speed of each successive member should be faster than that of its predecessor, should start at the moment of greatest velocity and of the preceding member, and be in the direction of the objective.” This helps us to understand the role of both the kinetic chain, or the position player’s body, and the ball velocity they can generate. Neal, Snyder and Kroonenberg (1991) also support the idea of generating velocity through the movement of the body as a kinetic chain, saying “when the intention of a movement is to generate maximum speed at the distal end of a kinematic linkage, for example, the action of throwing a ball, there may be a set order of body segment involvement to produce such an outcome.”

Ball Velocity

Ball velocity has been studied a lot over the years because of its importance in baseball. The ability for a baseball pitcher to generate high levels of ball velocity is imperative to their success by increasing their chances of limiting hitter success. The ability to make the ball move sharply and locate it is equally, if not more important to a pitcher’s success. Because of the distances that any given position player may have to throw, the ability to generate a high ball velocity is key to making a play.

Chaudhari et al. (2011) points out that poor LPHC and torso control can lead to less energy transfer, which can lead to a decreased ball velocity. While these authors were studying baseball pitchers, the same argument can be made for position players

because of the similar throwing motion. When position players are not able to direct their momentum toward the intended target, they may have a lower generated ball velocity.

A 3D study conducted by Stodden, Fleisig, McLean and Andrews (2005) found that ball velocity generated by pitchers (average age of 20.9 ± 2.1 years) had a mean of 35.2 m/s ($\pm 1.6 \text{ m/s}$) with a mean trunk flexion of 32° ($\pm 9^\circ$). They noted however that as pitchers increased their trunk flexion values, their velocities increased. This is a key finding that leads researchers to believe the same to be true for position players.

In the 3D study completed by Kageyama et al. (2014), they also found that pitchers were able to generate a higher ball velocity through trunk flexion. This study split 30 male collegiate baseball pitchers into two groups, a high-velocity group (HG) and low-velocity group (LG). The researchers found that pitchers in the HG had a significantly higher forward trunk flexion value ($28.4^\circ \pm 6.9^\circ$) than the LG ($19.4^\circ \pm 7.8^\circ$). It was also noted that pitchers in the HG had significantly higher stride knee extension maximum angular velocity $267.2^\circ/\text{s}$ (± 98.6) than the LG $163.6^\circ/\text{s}$ (± 129.2), as well as at MER $-192.6^\circ/\text{s}$ (± 137.3) versus $-33.6^\circ/\text{s}$ (± 123.7) and also at release (REL) the HG $-204.8^\circ/\text{s}$ (± 100.0) exhibited significantly greater values than the LG $-87.1^\circ/\text{s}$ (± 101.0). The researchers noted that the pitchers who were able to generate a higher ball velocity may have been able to do so by increasing trunk forward motion and rotation as a result of extending the stride leg knee during the arm acceleration phase. The researchers concluded that the HG were able to exhibit greater knee extension of the stride leg in order to increase trunk rotation and flexion during the throwing movement, and that stabilizing of the lower limbs plays an important role in generating a high ball velocity.

Research performed by Matsuo, Escamilla, Fleisig, Barrentine and Andrews (2001) noted that pitchers who were able to generate a higher ball velocity demonstrated greater forward trunk tilt than pitchers who had lower generated ball velocities. The HG $243^{\circ}/s (\pm 149)$ was also observed to have greater knee extension angular velocity at the instant of ball release as compared to LG $124^{\circ}/s (\pm 141)$. An interesting finding in this study was the fact that seventy percent of the HG showed knee extension movement of the lead leg during the approach to ball release, whereas the LG exhibited different movement types involving more knee flexion and less knee extension.

Yamada et al. (2013) conducted a study that investigated youth baseball pitchers (mean age 16.2 ± 0.7 years) and their ability to generate ball velocity with respect to segmental muscle volume. In this study, the authors found that trunk muscle volume was not correlated with ball velocity. The findings of this study conflict with the previous study mentioned above, but it must be taken into account the methods by which each study was performed.

Although the reported trunk and knee values of the studies mentioned above are interesting, these are not realistic numbers to compare position players to. This is because that while the throwing motions of pitchers and position players are similar, position players don't throw from an elevated starting point. Another difference is the fact that pitchers start from a set starting position for every throw, whereas the position player may be forced to throw to their target while moving in a number of different directions.

This is where there is a lack of research regarding position players and their ability to generate ball velocity, specifically looking at trunk flexion, knee flexion and knee extension velocity. These values have been researched extensively with pitchers

using 3D motion analysis, so the current study sought to use 2D motion analysis in order to investigate their relationship with generated ball velocity in baseball position players.

Motion Analysis

In order for researchers to examine the throwing motion, a way of slowing down the motion has been imperative. For years the throwing motion has been examined through the use of video recording and then analyzing the captured video. Early researchers utilized two-dimensional (2D) video in order to examine the throwing motion. Some reasons for capturing video motion was to determine joint angles, torque and angular velocities. More recently, scientists have turned to three-dimensional (3D) video as it gives a multi-planar look at the pitching motion and has been labeled as the gold standard for movement analysis.

A key step before gathering data is to determine what is being studied and how to mark the subject (reflective markers or other methods). For 3D analysis, researchers (Feltner, 1989; Feltner & Nelson, 1996; Fleisig et al., 1996; Fujii & Hubbard, 2002; Hurd & Kaufman, 2012) used anywhere from two cameras up to ten or more. The cameras used in previous studies captured video at sampling rates between 60 Hz and 500 Hz. The captured videos were then imported into various software programs in order to analyze the pitching motion. Other software programs have been used such as Visual3D (C-Motion Inc., Germantown, MD) in the study by Hurd & Kaufman (2012), Peak Performance Analysis in the study done by Feltner & Nelson (1996), and Motion Analysis ExpertVision 3D in the study done by Stodden, Fleisig, McLean, and Andrews (2005).

While 2D analysis have been conducted in many sports, its uses have been limited. because of its nature. With the multi-planar movements of the throwing motion, this quickly brings to the forefront a major flaw with 2D analysis. 2D analysis may be justified in single-plane movements, such as a countermovement jump. In the current study, 2D analysis was performed on the throwing motion at front foot contact to analyze trunk-side bend and knee flexion as well as the moment of ball release in order to analyze trunk flexion, knee flexion and knee extension velocity which occurs in the sagittal plane.

Intra-rater reliability has been researched utilizing 2D analysis. Norris and Olson (2011) reported high intraclass correlation coefficients > 0.98 , as well as a high correlation between Dartfish and goniometric measurements (Pearson's $r > 0.95$) in sagittal plane angles at the hip and knee joint during a lifting task. Associations between 2D and 3D analysis has also been researched, as seen in the study conducted by Mostaed, Werner, and Barrios (2018). It was noted that 2D movement significantly correlated with 3D movement ($r = 0.47-0.57$) with hip adduction and hip internal rotation with a lateral step-down test. Maykut, Taylor-Haas, Paterno, DiCesare, and Ford (2015) agreed that 2D analysis demonstrates high intra-rater reliability values across several variables when they examined collegiate cross-country runners on a treadmill from the frontal plane. Peak hip adduction angle ($r = 0.951 - 0.963$), contralateral pelvic drop ($r = 0.958 - 0.966$), and the peak knee abduction angle ($r = 0.955 - 0.976$) all showed high intra-rater reliability. There were also moderate correlations between 2D and 3D measurements with peak hip adduction angle on the left leg ($r = 0.539, p = 0.007$), peak hip adduction on the left leg ($r = 0.623, p = 0.001$) and the peak knee abduction angle on the left leg ($r = 0.541, p = 0.006$).

One method of analyzing 2D movement is through the software program, Dartfish. Founded in 1998, Dartfish has been utilized in many settings in professional athletics such as: the Olympics, FIFA World Cup, MLB, Taekwondo World Federation, and the PGA. Research articles utilizing Dartfish with sport include: water polo (Napolitano, Tursi & Raiola, 2013), track (Andrews, Goosey-Tolfrey & Bressan, 2009; Ilie, 2010; Ilie, 2012), rugby (Kraak, Malan & Van Den Berg, 2011), swimming (“Don’t Overlook,” 2005), and soccer (Padulo, D’Ottavio, Pizzolato, Smith & Annino, 2012). Currently to the researcher’s knowledge there have not been any studies conducted using Dartfish with baseball.

While the use of 3D and 2D have been well reported, 3D analysis programs have been used primarily when looking at joint angular velocities and analysis of the human movement from multiple planes. 2D analysis programs has been used on the other hand as tools to analyze team formations (Kraak et al., 2011; Padulo et al., 2012), and single plane human movements such as from the sagittal view (Andrews et al., 2009).

3D versus 2D procedures differ significantly in terms of cost. Optitrack (2018) helps researchers build their own 3D motion analysis set-up. An 8-camera set that captures video at 240 frames per second with all the necessary cables and computer cards costs \$24,490.00 before taxes. Operating a 2D motion analysis system requires only one camera, which range in price, but a Sony – Handycam was priced at \$179.99 at Best Buy (2018). Furthermore, a decrease in cost may lead to an increased number of operating analysis sites, which could reach a higher number of baseball players. Finally, with a higher number of analysis sites reaching out to more baseball players, an increase in performance regarding ball velocity generated by position players could be possible with

an increased focus on the baseball throwing motion. Portability is also increased when only using one camera, instead of setting up multiple cameras in any given location.

Because there is a lack of research regarding position players in baseball in general, more research needs to be done. Specifically to the current study, more research needs to be done regarding the performance of position players and their ability to generate ball velocity. If trunk flexion, trunk side bending, knee flexion and knee extension velocity is correlated to generated ball velocity, then more research is warranted involving the lower extremity, pelvis, and torso in order to more fully understand what is happening during the throwing motion as it pertains to position players. Therefore, the purpose of this study was to look at trunk flexion, trunk side bend, knee flexion and knee extension velocity at ball release with regards to generated ball velocity in middle and high school-aged male baseball position players. This will allow us to determine if there are correlations between these values and ball velocity, and in turn, lead to more research regarding improving the performance characteristics of position players in baseball.

Chapter 3: Methods

The purpose of this study was to determine the correlation between trunk flexion, trunk side bend, knee flexion and knee extension velocity with ball velocity in middle and high school-aged baseball position players. The values reported by the 2D motion analysis system Dartfish will be cross-referenced with other studies that have used 3D methods.

Participants

Thirteen middle and high school-aged male baseball players were recruited from the Spokane, Washington area. A flier was created and given to local baseball coaches, both at the school and club level. Participants were also informed by word-of-mouth and social media (Instagram and Facebook). An informed assent was completed by each participant, as well as a parental consent in the case of minors. Each participant was asked to fill out the PAR-Q as seen in Jamnik, Gledhill and Shepard (2007) before the study was conducted. An exclusion question regarding any prior injury relating to baseball within the last six months was also completed by each participant.

Equipment

Each participant was instructed to bring their own glove. Each participant was also informed beforehand to wear dark, tight-fitting clothing so the palpating of bony landmarks was more successful, which made the application of markers easier. The darker clothing also allowed for easier and more accurate video analysis. Baseballs (A1030, Wilson) were supplied to each participant. A pop-up net was set up 45 feet away from the participant starting point. White tape was applied to the ground from the

participant's starting point in a straight line to the middle of the net. Additional white lines were applied to the ground, each five inches away from the original line. The result was a ten-inch throwing lane for the participants to stride in as they completed their throws. This was to help each participant to stride on line toward the target, to decrease the variances in possible throwing techniques. A Detecto scale (Detecto, Webb City, MO) was used to collect the height and weight of each participant.

A radar gun (Stalker Pro II, Stalker Radar) was used to record ball velocity for each throwing trial. The Stalker Pro II has an accuracy of +/- 0.1 mph and acquires targets in 10 ms as noted by the manufacturer Stalker Radar (2015).

2D Equipment. One camera, a JVC Everio, was used and placed so that the middle of the camera lens was aimed at the hip of the lead leg of the subject. The camera was set up seventeen feet away from the participants starting point and leveled with a bubble level. The camera recorded video at 30 frames per second, with the shutter speed at 1/60 of a second. The camera was calibrated by recording video of a meter stick. Two external light sources were used, both aimed toward the participant's starting point. The computer software program that was used for the analysis was Dartfish 10 (*myDartfish Live S*).

Procedures

The study was conducted in an indoor facility in Spokane, Washington. Participants first completed the required paperwork, which was collected by the researcher. Each participant was given an identification number for data collection purposes. Then height and weight were then collected, as well as age, hand dominance,

years of playing experience and whether or not they were injury free in the last six months. Then each participant completed a general warm up consisting of jumping rope for five minutes. After jumping rope, each participant completed a dynamic warm up which included ten meters each of forward walking lunges, backward walking lunges, walking side lunges to the right and left. Participants then performed high knee skips down and back, high knee runs down and back. Lastly, before playing catch, each participant completed five small, medium and large arm circles, both forward and backward, then five prayer stretches. Each participant was instructed to warm up as they normally would before a game so that they felt like they could make a throw as if in a game-like situation.

At the conclusion of their warm up, each participant was fitted with reflective markers. Markers were placed on the lateral malleolus, the lateral femoral epicondyle and the lateral greater trochanter of the lead leg. A marker was also placed on the lateral tip of the acromion of their glove side. After the application of the markers, the participants began their testing. All participants were instructed to throw as hard as they could while only taking one step toward the pop-up net. Each participant completed three throws. Because each throw was at maximal effort, a rest period of thirty seconds was given between each throw.

Intra-rater reliability was conducted to assess the reliability of the current researcher's ability to digitize angles reliably. Ten trials were randomly selected to be re-digitized which yielded 40 values. The re-digitized trials data was compared with the original 40 values of the same trials using Pearson's inter-item correlation coefficient. A paired t-test was generated to determine if there was any significance.

Data Collection

Descriptive data collected included age, weight, height, hand dominance, years of experience and injury status. Each participant completed three throws, of which throw number and velocity was recorded on an excel spreadsheet. All completed throws from each participant was analyzed.

Dartfish was used to analyze trunk side bend and knee flexion at foot contact, trunk flexion, knee flexion and knee extension velocity at the moment of ball release of each throw for each participant. Trunk flexion, trunk side bend and knee flexion for the current study was defined as seen in the study conducted by Kageyama et al. (2014). Trunk side bending was analyzed at front foot contact and is depicted in Figure 1. The trunk side bending angle was defined as the angle created from the vertical line perpendicular to the ground through the greater trochanter to the acromion process of the glove hand side of the participant. Trunk flexion at ball release is pictured in Figure 2. It was defined as the angle created by the vertical line going through the greater trochanter and the line created from the greater trochanter through the acromion process.

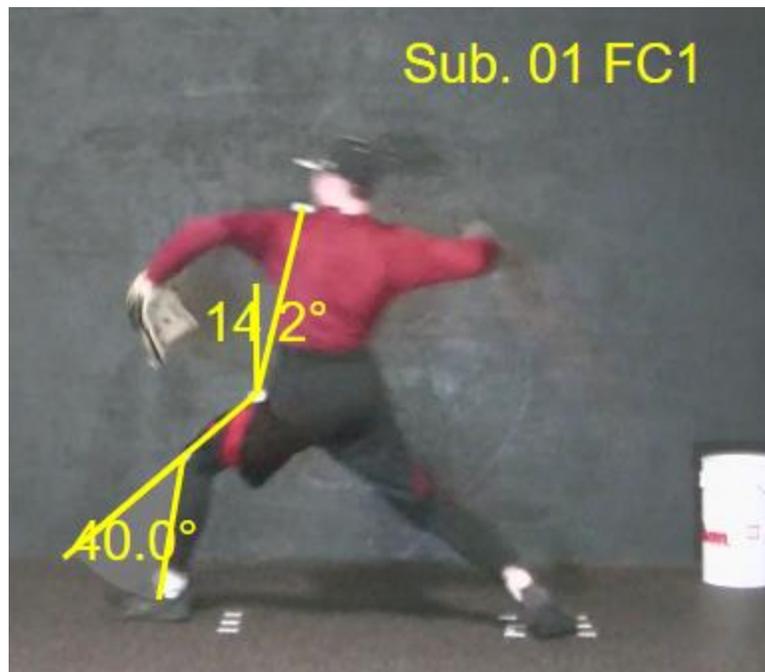


Figure 1. Video analysis at foot contact. FC = Foot contact

Lead knee flexion at the point of foot contact and at the point of ball release was also analyzed and can be seen in Figure 1 and Figure 2. Knee flexion was defined as the angle created by extending a line from the greater trochanter through the lateral femoral epicondyle and the line from the lateral femoral epicondyle through the lateral malleolus.

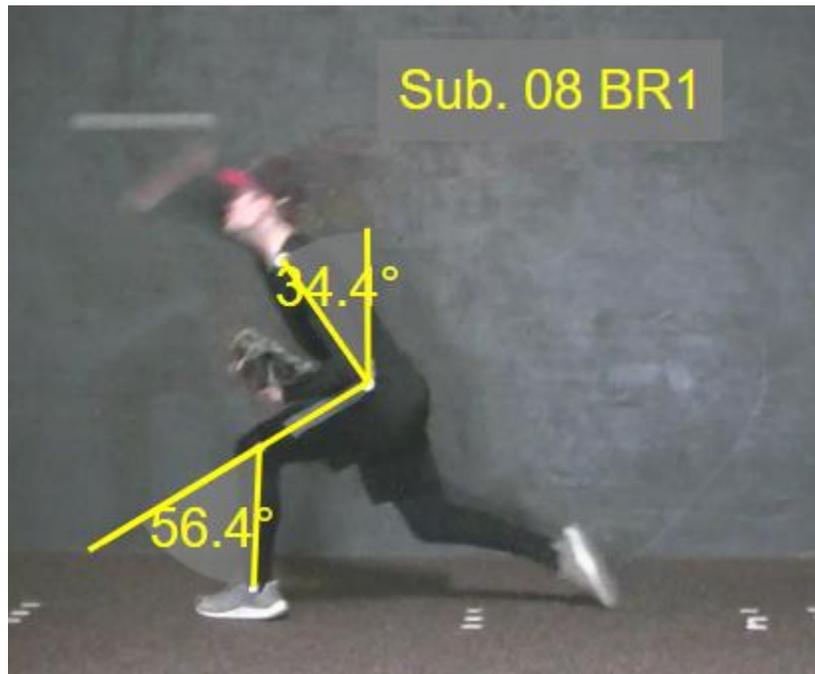


Figure 2. Video analysis at ball release. BR = Ball Release

Lastly, knee extension velocity was calculated using the following formula: $\omega = \Delta\theta / \Delta t$. Specifically, the angular position of the knee one frame before ball release was subtracted from the angular position one frame after ball release, and this difference was divided by elapsed time (0.066 sec) based on the frame rate of the camera.

Statistics

All statistical analyses were conducted using SPSS version 24 (IBM Corp., Armonk, NY). Descriptive statistics were calculated, and intra-rater reliability determined by Cronbach's alpha and t-test. Pearson's Product Moment Correlation was used to

assess relationships between participant kinematics and ball velocity. Specifically, ball velocity was correlated with the following: trunk side bend at foot contact, knee flexion at foot contact, trunk flexion at ball release, knee flexion at ball release and knee extension velocity at ball release. An alpha level $p < 0.05$ was used to determine statistical significance, and to decrease the chance of committing Type I errors.

Chapter 4: Results

Participants

Thirteen male baseball position players (twelve right-handed, one left-handed) were recruited for this study. The average age was 15.31 (± 1.25), average weight 72.29 kg (± 10.79), average height 177.09 cm (± 5.59), and they achieved a mean ball velocity of 64.95 mph (± 4.07). Each subject completed three trials. For this study, each trial was treated as an independent subject to increase the statistical power as each trial was an independent throwing event. Table 5 shows the descriptive statistics for each measured variable.

Table 5

Kinematic Descriptive Statistics ($n = 39$)

	M	SD
Ball Velocity (mph)	64.95	4.07
Foot Contact Trunk Side Bend	12.75°	6.82°
Foot Contact Knee Flexion	37.76°	12.40°
Ball Release Trunk Flexion	21.73°	11.74°
Ball Release Knee Flexion	40.85°	18.41°
Ball Release Knee Extension Velocity (°/s)	154.93	68.95

Note. mph = miles per hour.

Reliability

To assess intra-rater reliability in digitizing, ten trials were randomly selected and re-digitized by the investigator, yielding a total of 40 values. The re-digitized angular position data were then compared to the original values of the same throwing trials. Pearson's inter-item correlation coefficient ($r = 0.99$, $p < 0.001$) indicated extremely high reliability between the data. Paired t-test results further supported that no significant differences existed between the re-digitized ($27.92^\circ \pm 16.10^\circ$) and original ($27.71^\circ \pm 16.09^\circ$) values ($t_{(39)} = 0.99$, $p = 0.061$).

Correlation

All collected data passed assumptions of normality with $p > .05$ except for knee angle at foot contact ($p = 0.002$). There were four outliers associated with this variable. There are several ways to deal statistically with correlation analyses of outlying data. One method is to run the Pearson correlation both with, and without the outlying data points, and compare the results. This is the method chosen for the current study. Table 6 shows the Pearson correlation values resulting from the entire data set. A second Pearson analysis was then conducted with the outliers removed. This analysis confirmed that no significant relationship between ball velocity and foot contact knee angle existed ($r = -0.045$ at $p = 0.798$). We therefore retained the outlying data points as there was minimal difference.

Table 6

Pearson's Product Moment Correlations (n=39)

Ball Velocity Correlated to	<i>r</i>	<i>p</i>
Foot Contact Trunk Angle	0.527*	0.001
Foot Contact Knee Angle	0.180	0.272
Ball Release Trunk Angle	0.113	0.494
Ball Release Knee Angle	0.107	0.515
Ball Release Knee Angular Velocity	-0.147	0.372

Note. * = Significant correlation.

Only the correlation between ball velocity and trunk angle at foot contact was statistically significant. The scatterplot of this bivariate relationship is shown in Figure 3.

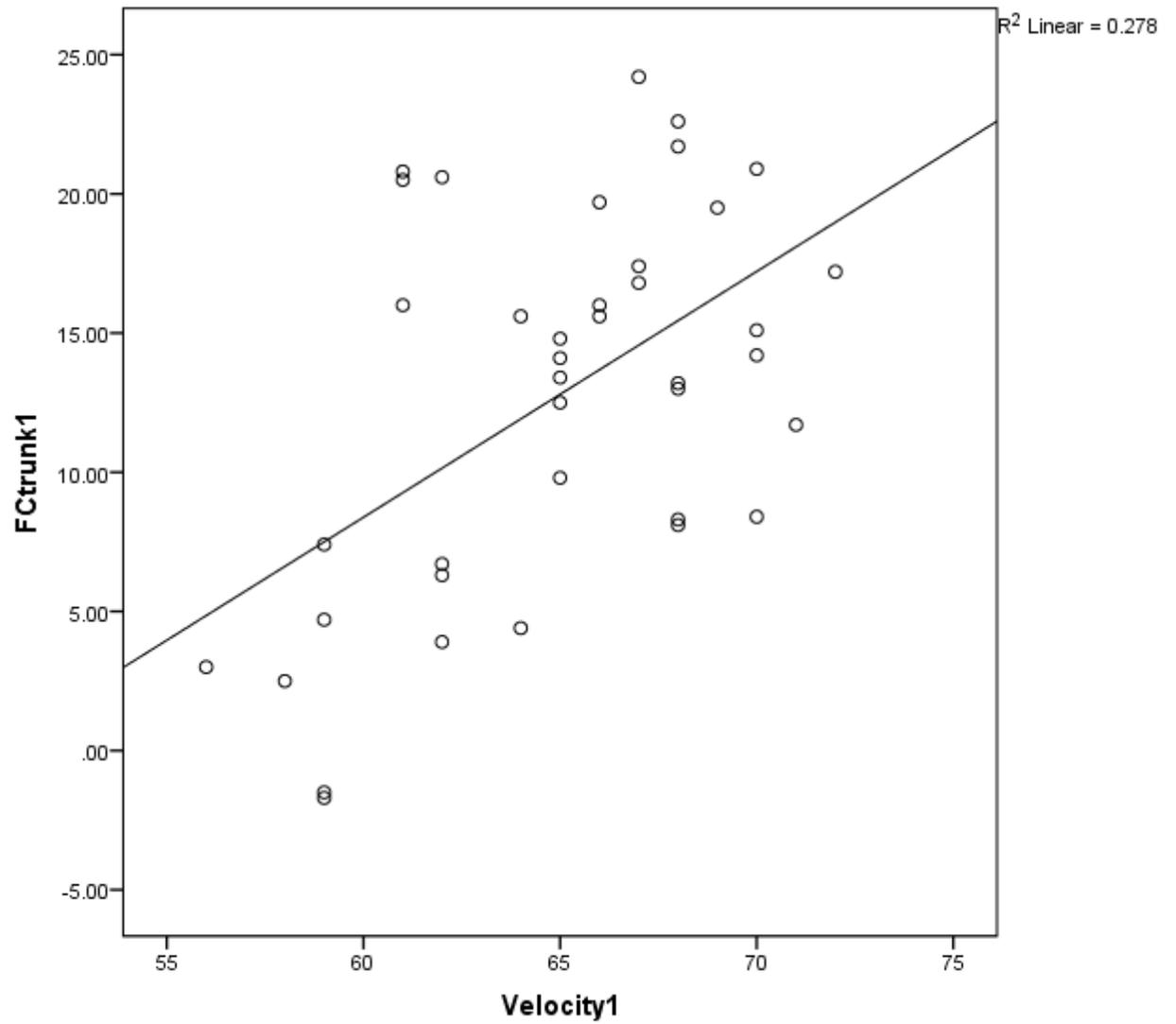


Figure 3. Correlation of ball velocity and foot contact trunk angle.
FCtrunk1 = Foot contact trunk angle.

Chapter 5: Discussion

With most of the research conducted utilizing baseball pitchers, it is evident that more research needs to occur with baseball position players. Research in this area is extremely limited, especially including middle and high school-aged baseball players. While 3D motion analysis provides the gold standard method for assessing throwing mechanics, its expense and expertise requirements are far out of reach of youth baseball coaches. For these coaches, user-friendly 2D motion analysis programs can be utilized at minimal expense. However, the efficacy of 2D analysis in determining kinematic variables and their relationship to ball velocity has not been investigated. Therefore, the current study sought to determine if 2D analysis would yield significant relationships previously found with 3D methods.

Dartfish

Dartfish was reliable for the researcher to digitize the angles exhibited by the participants of this study with a high intra-rater reliability score. Maykut et al. (2015) also found that Dartfish allowed for high intra-rater reliability across all variables from the frontal plane with runners on a treadmill that correlated with 3D measurements. In other studies, Dartfish was a valid and reliable means of analyzing 2D and 3D movement. Mostaed, Werner, and Barrios (2018) discussed that 2D movement was associated with 3D movement in their study of a lateral step-down exercise off a four-inch box with patients who had reconstructive anterior cruciate ligament (ACL) surgeries. However, when a six-inch box was used, only two variables correlated with 3D measurements. With more range of motion occurring, as well as movement in other planes of motion occurring, 2D measurements are more likely to produce erroneous data. Future

researchers must decide if the movements taking place in their study happen primarily in a single-plane or if other factors may be involved before making a decision on 2D or 3D analysis.

Current data. The current study's data were analyzed in 2D motion, whereas all other data mentioned in the following paragraphs were analyzed in 3D motion. The current study is not looking to correlate the data found in this study with other studies, but only looking to discuss its findings.

The only significant correlation found in the current study was between ball velocity and the trunk side-bending angle at foot contact. The current study's trunk side-bend angle is different than the angles seen in other studies because the trunk is captured bending laterally, and not at a flexed position as seen in other studies with the thrower at MER at foot contact. When the thrower is at MER, the trunk has rotated toward the throwing target, which occurs closer to ball release than at initial foot contact. Solomito, Garibay, Woods, Õunpuu, and Nissen (2015) was the only study found that mentioned lateral trunk bending at foot contact in the frontal plane. In this study, it was found that at foot contact, pitchers had a nearly neutral trunk or a slightly leaning trunk toward the throwing arm at $3^\circ (\pm 7)$. At ball release, they noted that for every 10° degree of lateral trunk lean away from the pitching arm led to a higher ball velocity of 0.4 m/s at $p = .023$.

To the researcher's knowledge, there is no other literature that has examined lateral trunk bend at the moment of foot contact. Further research investigating lateral trunk bending at the moment of initial foot contact is warranted. Because the current study utilized 2D analysis, Dartfish was unable to determine any lateral trunk bending at ball release. The importance of the trunk side-bending angle may be significant for

position players due to the flat ground they throw on. Without the aid of the mound to help generate more momentum into the throw, the trunk side-bending action may be a way for the position player to create an advantage in the trunk.

At foot contact, the knee flexion angle was $37.76^\circ (\pm 12.40)$. Fleisig's (2010) study of pitchers exhibited a knee flexion angle of $45^\circ (\pm 9)$ at foot contact. Fleisig, Barrentine, Zheng, Escamilla, and Andrews (1999) reported knee flexion values of $43^\circ (\pm 12)$ for 10-15 year old pitchers and $50^\circ (\pm 9)$ for 15-20 year old pitchers. While the population age matches the current study's participant age, a big difference between the two is the use of pitchers throwing from a mound versus position players throwing from a flat surface. There are typically two throwing motions the pitcher will use, a wind-up, or the stretch, a shortened variation with runners on base. When pitchers throw from their wind-up position (usually with their chest facing home plate), they will take as much time as they need to make a near-maximal effort throw. When runners are on base, pitchers will start from a sideways position, with their chest either facing first or third base. Regardless of their starting positions, pitchers are taught to bring their lead leg knee upward to gather their momentum and to alternatively drive off the rubber with their drive leg. Because pitchers start at an elevated position, they are able to generate more momentum moving downhill than position players are. Pitchers throwing from a mound also exhibit notable differences in the kinematics of the lower body as opposed to pitchers throwing from flat ground, as seen in Nissen, Solomito, Garibay, Öunpuu, and Westwell (2013).

At ball release, the trunk flexion angle for the current study was $21.73^\circ (\pm 11.74)$. Knee flexion values were $40.85^\circ (\pm 18.41)$. Fleisig (2010) reported ball release trunk

flexion at $36^\circ (\pm 7)$ and knee flexion at $35^\circ (\pm 12)$. They noted that a decrease in trunk flexion showed a resulting decrease in ball velocity. Fleisig et al. (1999) reported ball release trunk flexion values of $32^\circ (\pm 9)$ for 10-15 year olds and $31^\circ (\pm 9)$ for 15-20 year old pitchers, while knee flexion values were $36^\circ (\pm 11)$ and $43^\circ (\pm 13)$ respectively. Milewski et al. (2012) reported knee flexion values at ball release of $41^\circ (\pm 16)$. The current study's ball release trunk flexion values were less than other reported values, due to pitchers generating more momentum and throwing downhill, rather than from taking one step and throwing from a flat surface.

Knee extension velocity at ball release for the current study was $154.93^\circ/\text{s} (\pm 68.95)$. Matsuo et al. (2001) reported knee extension velocities at ball release to be $243^\circ/\text{s} (\pm 149)$ in the high velocity group and $124^\circ (\pm 141)$ in the low velocity group of collegiate pitchers. Milewski et al. (2012) discussed that their subjects exhibited knee extension velocity at ball release to be $176^\circ/\text{s} (\pm 143)$ in adolescent pitchers with an average age of 12.4 years (range 10 – 15). The greater knee velocities found by Matsuo et al. (2001) and Milewski et al. (2012) are likely due to their use of pitchers as study participants, versus position players as in this investigation and the differences in starting positions, momentum generated and throwing mechanics.

Ball velocity for the current study was $64.95 \text{ mph} (\pm 4.07)$. This converts to $29.04 \text{ m/s} (\pm 1.82)$, for ease of discussing other studies reported ball velocity values. Fleisig et al. (1999) reported their youth sample had a ball velocity of $28 \text{ m/s} (\pm 1)$ and $33 (\pm 2)$ for the high school sample. The current study's ball velocity sits between the two groups, but the nature of how pitchers and position players each complete their throw is different.

Coaches should consider capturing video from camera angles that will give them the information they are looking for. If coaches capture video as seen in the current study, they may miss seeing the throwing arm and where it is positioned. The frontal plane would be recommended for viewing the throwing arm to determine upper arm horizontal abduction as well as elbow flexion. A general rule of thumb is that baseball players should aim to throw with their upper arm abducted to 90° so as to limit increased forces on the throwing shoulder and elbow.

Limitations

The current researcher has decades of experience in baseball, both as a position player and as a pitcher. Having played at the collegiate level and coached at the high school level, it was apparent through analyzing the video that the participants exhibited different throwing techniques, some which were less efficient as others. The participants were given a command to throw as hard as they could, but it is impossible to tell if they were indeed giving their max effort on each trial. Years of experience with each participant varied as well, with some having three years of playing experience versus eleven years.

Whether or not the participants adhered to the request of the researcher to abstain from anything strenuous the day before that could have altered their performance was uncontrollable. Each participant went through the same warm-up procedure before playing catch. Each participant was given ample time to play catch, but there was no restricted time limit before they began their throwing trials. Some participants began their throwing trials sooner than others, which may have affected the data collected.

The resulting data could have been influenced due to the sample size. Future studies involving position players should look at larger sample sizes to see if there are throwing patterns that yield higher generated ball velocity especially when involving correlational statistics. The current study originally planned to include thirty participants but was unable to reach that number. Some of the reasons for this was a limited window for data collection, as well as a lack of the researcher's ability to effectively recruit participants. Specifically, a strategic relationship was unable to reach out to their database of baseball players in a timely manner for the researcher. Another reason that the sample size was not met was that data collection occurred during the spring baseball season for middle and high school baseball players. It is possible that there was an unwillingness to participate during the season even after the researcher reassured that there would be no negative effects on the participants well-being and ability to continue to participate in their season. A larger sample size increases the statistical power, which affects the probability of committing a Type II error. A larger sample size also increases the stability of the data, reducing the effect any outliers may have on correlations.

Another limitation involves the camera used. Capturing video at 30 frames per second involving movement patterns such as overhead throwing involves a lot of moving parts and develops quickly. A standard camera such as the one used in this study is not the best but was available to the researcher due to budget limitations and convenience. Using a camera that has a higher frame rate is necessary to capture a movement like throwing a baseball so analyzing participants at the moment of foot contact and at ball release is more accurate. Other studies cited throughout this paper have used cameras that capture video anywhere from 200 hz to 500 hz. Frames per second refer to the number of

frames that occur in one elapsed second, which is synonymous with hertz (relates to the refreshing rate of frames that occur in one elapsed second). Therefore, it was known to the researcher that there was less precision that was going to occur during data collection and analysis with using a camcorder that recorded video at 30 frames per second.

Coaches who want to analyze their player's throwing mechanics should look into purchasing a camcorder that records video closer to 200 hz to increase the precision of their analyses. However, coaches should refer to manufacturer websites, as department stores such as Best Buy don't typically list the video recording rate on the basic camcorders, which are priced around \$200.

The reflective markers being applied to each participant was another limitation. Application was done by the same researcher throughout data collection, and to the researcher's knowledge, the markers were placed as accurately as possible over the clothing that was being worn, using the same procedure to assess the bony landmark each time. The limiting factor was the reflective markers being placed on clothing, rather than skin. Participants all wore dark-tight fitting clothing. Some participants wore leggings, and some wore shorts. In the case of those who wore shorts, one reflective marker was placed directly on the skin over the bony landmark. The limiting factor relates to the movement of the markers, as some of the movement may have been due to the clothing moving than the movement of the bony landmark. Reinschmidt et al. (1997) noted that passive markers have error associated with bony landmarks due to the skin and soft tissue shifting during movement, stating specifically that there was up to a 21% error with knee flexion and extension. The reported errors increased further with adduction/abduction and with rotational movement. The amount of error would further increase with the reflective

marker being placed on clothing over a bony landmark. Future studies should ask participants if they would consent to throwing with no shirt on in order to decrease the amount of error with digitizing. Coaches should also be aware of the potential for error when digitizing angles and should advise their players to throw with tight-fitting clothing for better analysis of throwing mechanics.

The radar gun was unable to pick up the ball velocity a few times, which could have been due to the set-up of the target, or the lighting. At times, other participants were completing their warm-up procedure, which took place behind the net. Future studies should limit the amount of movement occurring in the direction of the throw, to decrease the chances of not picking up the ball velocity. When the radar gun was unable to detect the velocity of the ball, the participant was given the full rest period, and another throwing trial was completed.

Generated ball velocity by position players with a one-step throw toward a target does not represent the majority of throws they may make during a game. However, for the current study, it was necessary to define a common throwing technique to collect data that might represent similarly the sample population in other studies. Position players typically will field a ground ball while moving, thus allowing for more momentum as they prepare to make a throw toward their intended target. However, with adding momentum toward their throwing target, it is possible that position players may exhibit different throwing mechanics. One example would be that position players typically field a ground ball from a slightly squatted position and maintain that position through their throw. The current study had the participants start from a standing position, instead of fielding a ground ball.

Conclusion

This study was able to demonstrate that greater trunk side-bending at foot contact was related to faster ball velocity. Coaches should be able to evaluate this angle in their players using a simple, inexpensive 2D analysis program, and create specific training aimed at improving trunk side-bending at foot contact. Though correlations between 2D and 3D analysis were not conducted in the current study, there are associations between the two with single-plane movement. Coaches should also capture video from multiple camera angles while players complete their throws. Further research needs to be done regarding position players, specifically of middle and high school age.

Appendix A

RESEARCH ASSENT FORM

Title of Research: Youth and Adolescent Baseball Position Players and Throwing Velocity

Principal Investigator: Nick Hedgecock, Masters of Exercise Science student, (509) 850-7249

Responsible Project Investigator: Dr. McNeal, PhD in Exercise and Sport Science, (509) 359-2872

I want to tell you about a research study we are doing. A research study is a way to learn information about something. We would like to find out more about middle school and high school baseball position players and their ability to throw a baseball hard. We are looking at the throwing mechanics and the throwing velocity. You are being asked to join the study because you represent the research study's needs.

If you agree to join this study, you will be asked to come to an indoor facility for one day (it should take about 30 minutes to one hour to complete the testing). When you come, your height and weight will be measured. Then You will begin to warm up, which also includes playing catch. We will apply some reflective markers on your body to help us better understand how you throw the baseball. When you are ready, you will be instructed to throw as hard as you can into a net while we record your throwing motion with a video camera. When you're done throwing, you will have plenty of time to cool down and stretch. After this, you will receive a free coupon!

As with any athlete playing in a sport, there are always chances that someone can get hurt. We do not anticipate you getting hurt because of this study. You will be asked a few questions to make sure that you are healthy and have no injuries. You will be given ample time to warm up and are able to stop at any point during the testing if you start to feel pain or discomfort.

I do not know if you will be helped by being in this study. I may learn something that will help other baseball players learn how to throw the ball harder someday because of this research study.

You do not have to join this study. It is up to you. You can say okay now, and you can change your mind later. All you have to do is tell me. No one will be mad at you if you change your mind.

Anything we learn about you from this study will be kept as secret as possible.

Before you say yes to be in this study, we will answer any questions you have.

If you want to be in this study, please sign your name. You will get a copy of this form to keep for yourself.

This study has been explained to me and I am willing to be in it.

Child's Name (printed) and Signature	Date
--------------------------------------	------

Check which applies below *[to be completed by the person administering the assent]*.

- The child is capable of reading and understanding the assent form and has signed above as documentation of assent to take part in this study.

- The child is not capable of reading the assent form, but the information was verbally explained to him/her. The child signed above as documentation of assent to take part in this study.

Name (printed) and Signature of Person Obtaining Consent	Date
--	------

Appendix B

Consent Form

Youth and Adolescent Baseball Players and Throwing Velocity

Nick Hedgecock, Masters of Exercise Science student, EWU PEHR; Dr. Jeni McNeal

Purpose and Benefits

This research study involves middle and high school baseball position players. These players will be warming up in an indoor facility and completing three full effort throws into a net. The things learned from this study could potentially help coaches on how to evaluate and coach their players better, as well as to increase the position player's ability to throw the baseball harder toward their target.

Procedures

Each participant will be asked to show up once at an indoor facility to complete the testing. Every participant who agrees to take part in this research study will be informed on what to bring to the facility (dark, tight-fitting clothing and a glove). If a participant forgets to bring tight-fitting clothing, the researcher will have extras available. Each participant will be measured and weighed and will be instructed to complete a warm up. At the conclusion of the warm up, which includes playing catch, the participants will be fitted with reflective markers that will help the collection of the throwing mechanics. Each participant will then be instructed on where to stand, and how many times they will throw at full effort in order for the throwing motion to be captured by a video camera. At the end of the testing, each participant has completed their portion of the research study and can leave when they are ready. The estimated time for each participant to complete the testing is 30 minutes to 1 hour.

Risk, Stress or Discomfort

Any time that athletes participate in a sport, whether it be in a game or practice, there is risk of injury. It is anticipated that the risk of injury for this event is minimal. Each athlete will be screened beforehand to make sure there are no prior injuries. Each participant for this study will be given ample time to warm up, and will have enough rest time between maximal effort throws to recover. If at any time a participant feels uncomfortable or begins to feel pain, they are able to withdraw prior to finishing the test. Each participant will also be given ample time to properly stretch and cool down when the testing is completed.

Other Information

The identity of the participants for this study will remain anonymous. Each participant is free to withdraw at any time without penalty. Each participant will receive a coupon for free strength and conditioning services for their time and participation in this research study. The coupon is good for three (3) free small group sessions. These sessions are good for one calendar year. If participants end up withdrawing from the research study at any time, they will still receive a full coupon for their consideration in participating.

Date

Participant Statement

"The study described above has been explained to me, and I voluntarily consent to participate in this study. I have had an opportunity to ask questions. I understand that by signing this form I am not waiving my legal rights. I understand that I will receive a signed copy of this form.

Signature of Subject

Date

[as appropriate]

Signature of Parent/Legal Guardian

Date

[for adult who is unable to provide
consent]

Signature of Subject Advocate

Date

If you have any concerns about your rights as a participant in this research or any complaints you wish to make, you may contact Ruth Galm, Human Protections Administrator, at (509) 359-7971 or rgalm@ewu.edu.

Appendix C

Physical Activity Readiness
Questionnaire - PAR-Q
(revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
<input type="checkbox"/>	<input type="checkbox"/>	1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?
<input type="checkbox"/>	<input type="checkbox"/>	2. Do you feel pain in your chest when you do physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	3. In the past month, have you had chest pain when you were not doing physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	4. Do you lose your balance because of dizziness or do you ever lose consciousness?
<input type="checkbox"/>	<input type="checkbox"/>	5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?
<input type="checkbox"/>	<input type="checkbox"/>	6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?
<input type="checkbox"/>	<input type="checkbox"/>	7. Do you know of any other reason why you should not do physical activity?

If
you
answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active — begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal — this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever — wait until you feel better; or
- if you are or may be pregnant — talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME _____

SIGNATURE _____

DATE _____

SIGNATURE OF PARENT
or GUARDIAN (for participants under the age of majority) _____

WITNESS _____

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.



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