THE EFFECT OF THROWING UNDER- AND OVER-WEIGHT BASEBALLS ON THE PITCHING MOTION

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ABSTRACT

The effects of pitching under- and over-weight balls on glenohumeral and elbow joint angles, pitch velocity, and pitch time were evaluated in Division I collegiate pitchers. Pitchers ($N = 6$) threw 3, 4, 5, 6, 7, 9, and 12 ounce balls from the mound to a regulation distance target. All pitches were compared to the 5 ounce control condition. Glenohumeral flexion ($p = .046$) and abduction ($p = .028$) significantly increased when pitching with the 12 ounce ball. Glenohumeral external rotation ($p = .043$) and pitch velocity ($p = .027$) significantly increased when pitching with the 3 ounce ball. Pitch velocity was significantly slower when pitching with the 7 ($p = .046$), 9 ($p = .027$), and 12 ($p = .028$) ounce balls. There are changes in the pitching motion when using alternate weight balls which alter movement patterns and pitching mechanics and may result in detrimental pitching performance.

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CHAPTER I

INTRODUCTION

In the 1970's, the Soviet Union began to use different weighted implements as part of training programs for Olympic athletes (Konstantinov, 1979; Vasiliev, 1983; Verkhoshansky & Tatyan, 1983). After this concept was spread to other countries and sports around the world, programs were developed specifically for baseball. These programs involve varying weighted balls ranging from 3 ounces to 21 ounces. While there has been some research on the use of weighted balls in baseball, most studies have focused on performance-based outcomes such as change in pitch velocity (Brose & Hanson, 1967; DeRenne, Buxton, Hetzler, & Ho, 1994; DeRenne, Ho, & Blitzblau, 1990; Van Huss, 1962) as opposed to pitching mechanics.

Research has shown that pitching velocity increases following a structured under- and over- weighted ball training program. Most of this research has been done with high school pitchers, but there are some data also demonstrating pitch velocity increases in elite pitchers (DeRenne et al., 1990; DeRenne et al., 1994; DeRenne, Tracy, & Dunn-Rankin, 1985). The short term effects of over-weight ball training has also been observed. Several researchers have examined the acute effect of warming-up with over-weight balls on velocity with varying outcomes. The results of these studies included an increase in velocity, no change in velocity, and results that were mixed (Matsuo, Escamilla, Fleisig, Barrentine, & Andrews, 2001; Straub, 1968; Van Huss, Albrecht, Nelson, & Hagerman, 1962). Similar studies have shown decreased velocity and altered timing in baseball hitting (Nakamoto, Ishii, Ikudome, & Ohta, 2012; Otsuji, Abe, & Kinoshita, 2002; Race, 1961; Southard & Groomer, 2003). Another performance-based variable that has been studied is the effect of training with weighted balls on pitching accuracy. Several studies have shown no significant change in pitching accuracy after a multi-week training program using weighted balls (Bagonzi, 1978; Brose & Hanson, 1967; Litwhiler & Hamm, 1973; Logan, McKinney, Rowe, & Lumpe, 1966; Straub, 1968). Further, all but one of these studies documented an increased pitch velocity after the training program (Straub, 1968).

There is a dearth of studies examining the impact of altered ball weight on pitching kinetic, kinematic, and temporal measures. Fleisig, Kingsley, et al., (2006) compared the effect of using a 4-oz ball to a standard 5-oz baseball in a youth sample. The lighter ball reduced the forces acting at the elbow and shoulder while not altering the timing of the throw. It could be postulated that the reduced force on the shoulder could lower the risk of shoulder injury. To date, there are a lack of studies examining changes in joint angles or “arm slot” while throwing under-and over-weight balls.

In summary, while it has been shown that under-and over-weighted ball training programs can increase pitching velocity, which may lead to an increase in performance, there is limited research on kinetic, kinematic, or temporal changes that occur during the throwing motion with under- and over-weighted balls. More research is needed in the area to examine these variables as under- and over-weight training programs become more popular.

Purpose of Study

The purpose of this study was to examine the effect of pitching under- and over-weight balls, ranging from 3 ounces to 12 ounces, with a fastball grip, on changes in joint angle at the shoulder and elbow joints, pitch velocity, and overall timing of the pitching motion in Division I collegiate pitchers.

Hypotheses

1. Peak glenohumeral joint angles when pitching with over-weight balls will be different than when pitching with a standard weight baseball.
2. Peak glenohumeral joint angles when pitching with under-weight balls will not be different than when pitching with a standard weight baseball.
3. Peak elbow flexion will be different when pitching with over-weight balls than when pitching with a standard weight baseball.
4. Peak elbow flexion will not be different when pitching with under-weight balls than when pitching with a standard weight baseball.
5. As the weight of the ball increases, there will be an increase in time from the onset of motion to ball release.
6. Pitch velocity will decrease as the weight of the ball increases.

Delimitations

1. The study was limited to one collegiate team in the Southeastern United States.
2. Participants were free from any shoulder or elbow injury in the past 6 months.
3. Participants were classified as throwing from a “three-quarter” or overhead arm slot.

4. Participants had been pitching for at least 4 years prior to the study and routinely used the overhead throwing motion in their sport.

Limitations

1. There was no method to assess whether each participant gave his maximal effort during each testing session.

Basic Assumptions

1. Participants were truthful regarding previous medical history.
2. Participants gave maximal effort during each training and measurement session.

Significance of Study

This study provided information on kinematic and temporal variables associated with pitching under- and over-weight baseballs. This research filled a void in the literature and allowed for future studies in the area.

CHAPTER II

LITERATURE REVIEW

In this chapter, the complex forces and interactions that occur throughout the body during the baseball pitching motion will be examined. Success in baseball pitching requires velocity, accuracy, and consistency. In order to accomplish these components, pitchers must be able to generate maximal force and successfully transfer that force to a baseball during each pitch they throw. The principles and movement patterns that are utilized when pitching will be investigated to identify areas where detrimental changes can occur when throwing under- or over-weight balls. The chapter closes with an overall summary and review of the purpose of this study.

The Overhead Pitching Motion

The overhead pitch is a complex motion that relies on the effective transfer of force from proximal segments to distal segments (Bunn, 1972). Baseball pitchers utilize the summation of speed principle to complete one of the fastest motions in sports, reaching speeds of 7,430 degrees per second of internal rotation at the shoulder with a rotational torque of 68 Nm (Fleisig, Barrentine, Zheng, Escamilla, & Andrews, 1999). This motion is separated into three distinct phases defined as the cocking phase, acceleration phase, and deceleration phase (Tullos & King, 1973).

The first phase is the cocking phase. This phase begins with the wind-up, which is defined as the time between the initiation of motion to the moment the ball is removed from the glove or non-throwing hand (Tullos & King, 1973). The purpose of the wind-up is to develop rhythm and order to help achieve proper timing of subsequent movements (Pappas, Zawacki, & Sullivan, 1985). The cocking phase can be further subdivided into the early and late cocking phases. The early cocking phase begins once the ball is removed from the glove or non-throwing hand (Fleisig, Escamilla, Andrews, Matsuo, & Barrentine, 1996). After the ball is removed, several events occur simultaneously. The throwing arm is abducted, extended, and then internally rotated. This is one of two times in the pitching motion that the wrist is flexed, the other occurs just prior to ball release. The stride leg is flexed at the hip and knee, then moves forward towards the target and extends while the stance knee slightly bends, lowering the pitcher's center of gravity. The trunk rotates away from the target then begins to rotate toward the target. This movement allows for greater range of motion over which force can be generated by the trunk (Dillman, Fleisig, & Andrews, 1993; Pappas et al., 1985). As the trunk begins to turn, the arm moves from an internally rotated positon into external rotation. The late cocking phase begins once maximal external rotation is reached (Dillman et al., 1993; Fleisig et al., 1996). During the late cocking phase, the stride leg plants, the hips and trunk reach their peak velocity and then begin to slow, and the shoulder and arm begin to rotate towards the target (Pappas et al., 1985). At no point during the cocking phase does the ball move closer to the target. The entire cocking phase lasts about 1,500 ms which accounts for around 80% of the total pitching motion (Pappas et al., 1985). The goal of the cocking phase is to generate force with the legs and trunk while moving the upper extremity into a more advantageous position to receive the force generated by the lower extremities and generate additional force of its own.

The next phase is the acceleration phase, which begins once the ball starts to move towards the target (Pappas et al., 1985). The shoulder begins to internally rotate while the arm begins to horizontally adduct. The angular rotation of the shoulder during this phase can reach over 7,000 degrees per second in skilled pitchers (Fleisig et al., 1999). The elbow extends, although this motion is a result of the force passing though the arm, not due to triceps bachii contraction (Roberts, 1971). The wrist is flexed again and begins to pronate just prior to ball release, which aids in applying any desired spin on the ball, especially for breaking pitches like a slider or curveball. The trunk may continue to rotate, laterally flex, and forward flex (Tullos & King, 1973). This phase is the shortest, lasting about 50ms, or about 2% of the total pitching motion (Pappas et al., 1985). The purpose of this phase is to transfer energy into the upper extremity, allowing that segment to utilize its large range of motion to generate more force, and then transfer the force to the ball. The acceleration phase ends when the ball is released.

The final phase is the follow-though phase. The purpose of this phase is to decelerate the pitching limb and to allow the body to “catch-up” with the arm (Tullos & King, 1973). This is completed by activating the posterior shoulder girdle and biceps brachii while the arm is horizontally adducted, flexed at the elbow, internally rotated, and further pronated at the hand (Pappas et al., 1985). It is common to observe angular velocity deceleration values as high as 500,000 deg/sec. This phase ends when the stance leg makes contact with the ground and typically lasts about 350ms which is about 18% of the pitching motion (Pappas et al., 1985). From this positon, the pitcher either moves into a fielding stance or begins preparing to pitch again.

Within these phases, researchers have utilized 3D biomechanical motion capture systems to identify several key kinematic, kinetic, and temporal variables that greatly impact the velocity of a pitch. There is agreement among researchers that greater forward trunk tilt at ball release has the greatest impact on ball velocity (Dillman et al., 1993; Fleisig, 1994). During the cocking phase, the trunk generates the greatest total amount of force which is then transferred to distal segments. Pitchers who can better utilize their trunks tend to throw with more velocity (Solomito, Garibay, Woods, Ounpuu, & Nissen, 2015; Stodden, Fleisig, McLean, Lyman, & Andrews, 2001).

Several other variables have been identified as being associated with higher pitch velocities. Researchers agree that greater elbow flexion torque and greater maximum shoulder external rotation are associated with higher ball velocity. Each one of these variables places segments in ideal positons to either generate more force or to more efficiently transfer forces from proximal segments during the cocking and acceleration phases (Fleisig, Chu, Weber, & Andrews, 2009; Matsuo et al., 2001; Stodden, Fleisig, McLean, & Andrews, 2005; Werner, Suri, Guido, Meister, & Jones, 2008). Additionally, Matsuo et al. (2001) identified maximum shoulder internal rotational angular velocity and lead knee extension at ball release as significant variables between high and low velocity groups, both of which are in the acceleration phase. Werner et al. (2008) identified similar variables, but expanded some to maximum shoulder angular velocity rather than just internal rotation. Finally, Fleisig et al. (2009) identified two temporal parameters, increased time to max shoulder horizontal adduction and decreased time to max shoulder internal rotation, and two kinematic variables, decreased shoulder horizontal adduction at foot contact and decreased shoulder abduction during acceleration, as significant factors related to higher velocities among professional pitchers (Fleisig et al., 2009).

The overall purpose of each of these three phases is to generate force, effectively transfer the force generated, and ultimately transfer that force to the ball which is thrown towards a desired target. Within these phases, there are specific movements and variables that contribute greatly to the generation of force. Maximizing these variables and effectively transferring the forces generated can only be accomplished through the effective coordination of each segment involved in the throwing motion.

Sequential Motion of Body Segments

Movements of the overhead pitching motion occur in a sequential pattern that allows for the generation, transfer, and summation of force. This theory was first credited to John Bunn who named it the summation of speed principle (Bunn, 1972). Bunn (1972) stated that in order to achieve maximum velocities, the movement must start with proximal segments and progress to more distal segments. He suggested that motion of a distal segment would begin when the more proximal segment reaches maximum speed, allowing for the distal segment to achieve an even greater speed. Bunn also observed that "jerky movements" were not as efficient as the "smooth rhythmic passing of speed" while pitching (Bunn, 1972). It should be noted that computer models investigating this principle were also being completed by Plagenhoef (1971) around the same time. Plagenhoef proposed that segments act in a proximal-to-distal sequence to allow for the summation of the speed for each segment, creating maximal velocity of the most distal segment. Additionally, it has been found that at peak efficiency, the distal segment begins to move forward as the movement of the proximal segment reaches its greatest angular velocity (Kreighbaum & Barthels, 1985).

This principle can only occur in a linked system that is synchronized. Further investigation has found that a proximal to distal sequence is more effective than the sequence observed in the principle of optimal coordination of partial momenta. This principle states that in order to maximize the speed of the distal segment in a linked system, the angular speeds of all segments must peak at the same time (Jöris, Van Muyen, Van Ingen Schenau, & Kemper, 1985). While this concept is occasionally seen in sport, most throwing movements do not follow this principle.

The pitching motion exhibits this proximal to distal sequence utilizing the phases previously explained. The movement begins when the lower extremity generates force and inertia. These forces are then transferred to the pelvis, torso, upper trunk, upper arm, forearm, and ending at the wrist and hand unit holding the ball (Atwater, 1979). At the initiation of movement, it is not uncommon for the most distal segments to move in the opposite direction compared to the rest of the chain. This movement assists in the generation of force by slowing the distal segment to a velocity close to zero, allowing for greater torque to be generated, and by putting soon to be contracted muscles in a slightly stretched positon, also allowing for greater concentric force output through the stretch shortening cycle (Chapman & Sanderson, 1990). Each proximal segment accelerates while the distal segment lags behind. Once peak velocity is reached, force is transferred to the distal segment and the proximal segment begins to decelerate (Putnam, 1993). As long as each distal segment's mass is less than the proximal segment's mass, the distal segment will move at a greater speed than its proximal neighbor. This process of proximal to distal acceleration will continue until the force is transferred to the ball (Southard, 1998). This complex transfer of force is the optimal method for throwing. It is considered a complex motion that is learned, refined, and mastered over time.

Motor Learning and Especial Skills

Several different motor program theories about how movements are learned or stored have been proposed and debated over the past century. Some of the original theories consisted of large global learning theories which focused on analyzing complex movements, but failed to explain how motor patterns were acquired (Hull, 1943). These ideas were replaced with Adam's closed-loop theory which proposed motor programs where governed by memory traces and perceptual traces (Adams, 1971). However, several flaws were found in this theory, especially regarding movement error corrections, fine tuning of learned skills, and the large storage requirements for each movement pattern (Schmidt, 1975). This theory was eventually replaced with Schmidt's schema theory for motor skill learning (Schmidt, 1975). Schema theory proposes that when learning a skill, a generalized motor program (GMP) is developed. The GMP consists of the broad concepts of the movement and relative components needed to complete a desired outcome. The theory explains that GMPs are created and stored as a way to limit storage requirements while still developing programs that can execute a vast array of motor skills. An example of a GMP is the overarm throwing motion, which could consist of throwing a football, baseball, or a water polo ball. While each example is a different action and sport, they all share similar underlying principles (Schmidt, 1975).

Generalized motor programs are stored with recall schemas, which are responsible for supplying the parameters needed to scale a GMP to accomplish a given task. Recall schemas are constantly being modified with practice and feedback, more specifically with external feedback about the results or success of the movement. Each time a motor program is run, feedback is used to slightly alter the recall schema parameters to reduce the error of the movement. The constant execution of movements and fine tuning of the recall schema are what result in better performance outcomes for the participant (Schmidt, 1975). It should be noted that most recently, dynamic systems theory has been created as an alternative to schema theory, but further research is needed on both theories (Newell, 1991).

While schema theory is intended to create broad motor programs that can be used for many different specific movements, Keetch, Schmidt, Lee, and Young (2005) hypothesized that there are some conditions that produce highly specific skills based off of constant practice in controlled conditions. Keetch et al. (2005) defined the term especial motor skill as “one that, as a result of massive amounts of practice, has a special status within a generalizable class of motor skills and that is distinguished by its enhanced performance capability relative to the other members of the same class” (Keetch, Schmidt, Lee, & Young, 2005, p. 976). Several researchers have provided evidence of this concept. Keetch et al. (2005) proposed that the free throw, a 15 foot shot that is taken with no defenders and in static conditions, would be an example of an especial motor skill. In three separate tests with male (*n* = 8) and female (*n* = 8) collegiate basketball players, the researchers showed that shooting accuracy decreased at any distance other than at the free throw line 15 feet from the basket. The researchers went on to show that a jump shot from the free throw line, rather than the typical standing free throw shot, also decreased accuracy. The researchers proposed that a free throw is an ideal example because it is a movement that is invariant across each attempt, making it close to being a closed skill. Some proposed explanations for the development of an especial motor skill are the creation of a separate GMP for the skill or an entirely new set of recall schema parameters for the movement. Due to the specificity of the movement, the practice time required to master the skill, the storage capacity required for the motor program or schemas, and the limited examples of these skills in sport, especial motor skills tend to be quite rare (Keetch et al., 2005).

Keetch, Lee, and Schmid (2008) provided further evidence for especial motor skills by having female collegiate basketball players complete a 15 foot shot from different angles relative to the hoop. The typical free throw location at 90 degrees relative to the hoop produced the highest accuracy percentage. Breslin, Hodges, Kennedy, Hanlon, and Williams (2010) built on this research by having 10 collegiate basketball players and novice participants (*n* = 10) shoot free throws ranging from 11 to 19 feet using both a regular and an over-weight ball. As expected, there were no significant differences in accuracy at any distance or with the over-weight ball in the novice group because they would not have an especial motor skill for free throw shooting stored. The only condition the expert basketball players had significantly higher accuracy percentage was at 15 feet with the standard weight basketball. This supports the creation of especial motor skill because all other distance and the over-weight basketball are not part of the highly specific stored program (Breslin et al., 2010).

In the most recent study on especial motor skills, Breslin, Hodges, Steenson, and Williams, (2012) examined the creation of especial motor skill programs. Novice college students (*N* = 20) were put into 2 groups. One group completed 100 free throws from the free throw line at 15 feet each day for three consecutive days. The second groups completed 100 shots from variable locations on the basketball court each of three consecutive days. After a total of 300 shots, the group that only shot from the free throw line had a higher accuracy percentage than the variable location group. This shows that with a high volume of practice, especial motor skills can be developed (Breslin et al., 2012).

In the only study examining especial motor skills in a setting other than basketball, Simons, Wilson, Wilson, and Theall (2009) had collegiate baseball pitchers (*N* = 7) throw at a target from variable distances. Accuracy was significantly better at 60.5 feet from the target, which is the regulation distance from the pitchers rubber to home plate. Throwing from as little as one foot closer or one foot further resulted in significantly decreased performance (Simons et al., 2009).

An area for further research would be with under- and over-weight balls on pitching accuracy. This has not been examined in an acute capacity limited to the use of an especial motor skill. If the weight of a ball being pitched is different from a standard 5 ounce baseball, then the pitcher would no longer be using the especial motor skill, but rather returning to a less specific motor pattern used for throwing in variable conditions.

In a review of his schema theory, Schmidt (2003) acknowledged especial skills as a new emerging concept in motor learning that needs further investigation. During this reflection, Schmidt also acknowledged that changes in force production or loading pose problems to schema theory and need to be further researched. Changes in force production or loading are problematic because while the same motion is being completed, muscles must act in different ways to accomplish the same movement making relative force a new parameter (Schmidt, 2003). A theoretical example of this could be throwing weighted balls. The arm movement utilizes the same GMP as when throwing a regular baseball, but a different recall schema may need to be used because the anterior muscles need to be recruited differently to achieve acceleration of the arm. A similar idea could be applied to other segmental skills like hitting.

Kinesthetic Aftereffects

A kinesthetic aftereffect is defined as a perceived alteration in the shape, size, or weight of an external object. This may also be defined as the perceptual distortion of a body segment position, movement, or intensity of muscular contractions due to interaction with previous objects (Nakamoto et al., 2012). Kinesthetic aftereffects have been thoroughly explored in hitting. A parallel can be drawn between hitting and throwing because both movements utilize the summation of speed principle.

Early studies have shown that the duration of the kinesthetic aftereffect is directly related to how long a participant is exposed to an external stimulus. On average, it takes

90 seconds (Singer & Collins, 1972) to 120 seconds (Singer & Day, 1965) for the kinesthetic aftereffects to dissipate once a stimulus is removed. However, these time periods are related to simple controlled tasks, not sport-related events.

More recently, Nakamoto et al. (2012) studied the effect of warming-up with a weighted bat on the ability to adjust to varied simulated pitch speeds and locations. Due to the kinesthetic aftereffect, participants were not able to adapt to varied stimulated pitches as effectively as in control conditions. The researchers hypothesized that the kinesthetic aftereffect altered the motor pattern and in a ballistic activity like hitting, there was not enough time to correct the motor pattern, resulting in decreased hitting performance (Nakamoto et al., 2012). Schema theory helps to explain these results further. When a GMP and recall schema are run, no changes can be made in the motor pattern until feedback is gathered and processed. This requires a minimum of 200ms, which is the fastest reaction time, before any feedback can be gathered, processed, and alterations made (Schmidt, 1975). In a rapid task like hitting, which only takes about 160ms, no feedback can be provided. So, if the motor pattern is altered than performance will be negatively impacted.

Changes in performance only last as long as kinesthetic aftereffects are present. Once the sensation is gone, motor patterns and performance will return to baseline values. Otsuji et al. (2002) showed that after warming up with an over-weight bat, swing velocity decreased. However, velocity returned to control values after the second swing with a standard bat. This indicates that the kinesthetic aftereffects on performance had dissipated even though some participants reported feeling like the bat was lighter as late as the fifth swing. Interestingly, some reported the standard bat went from being lighter than normal to heavier than normal after the kinesthetic aftereffects dissipated (Otsuji et al., 2002). The results from Otsuji et al. (2002), as well as the results from Singer and Collins (1972) and Singer and Day (1965), must be considered for this study. Kinesthetic aftereffects must be controlled in order to ensure that any changes in mechanics, timing, or performance variables are due to alterations in ball weight, not kinesthetic aftereffects from prior conditions. Researchers have found that the aftereffects last for up to 2 minutes and can dissipate after 2 swings while hitting (Nakamoto et al., 2012; Singer & Collins, 1972; Singer & Day, 1965).

Under- and Over-Weight Baseball Bats

A comparison can be drawn between pitching movements and striking movements used for hitting (Escamilla et al., 2009; Welch, Banks, Cook, & Draovitch, 1995). Both movements utilize the summation of speed and segmental timing for the transfer of force to the neighboring distal segment (Race, 1961). Similar to the phases of pitching, hitting has been divided into four phases. The phases are the waiting, preparative hitting, swing, and follow-through phases (Mason, 1987). The goal is to generate the maximal amount of force at each involved segment and transfer that force to the neighboring proximal segment. Ultimately, the last segment in the kinetic chain is the implement being thrown or swung (Race, 1961). In pitching, the goal is to throw a baseball at a high velocity, while in hitting, the goal is to swing the bat with maximal velocity.

There have been multiple studies on the effect of using a heavier bat during a warm-up routine on bat velocity, swing timing, and swing mechanics after return to a normal weight bat. Nakamoto et al., (2012) studied the kinesthetic aftereffects of warming up an over-weight bat. Collegiate baseball players (N = 8) completed three practice swings with an over-weight bat, then swung at a simulated pitch that varied in velocity. After warming up with the over-weight bat, the participants perceived the normal bat as lighter and felt they could swung faster due to kinesthetic aftereffects. After the warm-up, participants bat velocity was higher than during the control conditions. However, there were detrimental effects that occurred due to the kinesthetic aftereffects. When the velocity of the simulated pitch was altered, there was a larger absolute temporal error, which means that greater degrees of correction were required in an attempt to hit the ball. With an unexpected faster bat velocity, the hitter could not effectively adjust his swing pattern to the different velocity of the incoming pitch. This shows a negative influence in the movement timing correction process which is detrimental to performance (Nakamoto et al., 2012).

In a similar study, the effect of warming-up with an over-weight ball on electromyography activity of the right and left pectoralis major muscle, biceps brachii muscle, triceps brachii muscle, flexor carpi radialis muscle, and the extensor carpi ulnaris was investigated. Male collegiate baseball players (N = 7) completed a warm-up with a standard or over-weight bat then swung at a simulated pitch. There were no significant differences in muscle activity prior to ball contact, but both extensor carpi ulnaris muscles exhibited lower inhibition when the velocity of the simulated was altered. This suggests that warming-up with an over-weight bat decreases the ability to adjust in variable situations and limits the ability stop a swing. This is especially detrimental when trying to complete a “check swing” (Ohta, Ishii, Ikudome, & Nakamoto, 2014).

As previously discussed, Otsuji et al. (2002) also studied the effect of using an over-weight bat. Participants (*N* = 8) completed three sets of 15 swings. The first five swings were with a normal weight bat (920 grams), followed by 5 swings with an 800g weight added to the same bat, then five more swings at the normal bat weight. This was completed three times. Participants reported the normal weight bat felt lighter and that they swung faster after using the over-weight bat. However, the first swing after using the over-weight bat had a significantly lower velocity. This indicates that the motor patterns were altered by the use of an over-weight bat. Swing velocity returned to normal on the second swing showing that the kinesthetic after effects may not last long (Otsuji et al., 2002).

Several researchers have concurrently investigated the influence of under- and over-weight bats. Southard and Groomer (2003) examined the effect of warming-up with under-, normal, and over-weight bats. Participants (*N* = 10) completed three different test conditions, one with a standard 34 ounce bat, one with a 56 ounce over-weight bat, and one with a 12 ounce under-weight bat. Warming-up with an over-weight bat significantly reduced bat velocity. The over-weight bat condition also altered joint velocities and swing pattern. Part of the alteration in swing pattern was a decrease in segmental timing which resulted in negative effects on the sequential coordination of motion. These changes are considered detrimental to performance (Southard & Groomer, 2003)

Montoya, Brown, Coburn, and Zinder (2009) studied the bat velocity of recreational baseball players (N = 19) as they warmed-up with an under-, standard, or over-weight bat. Participants then rested for 30 seconds and swung the standard bat while bat velocity was measured. Both during the warm-up and after the warm-up, the bat velocity for the under-weight bat and standard bat were significantly faster than the over-weight bat. It should be noted that warming up with the under-weight bat produced the greatest increase in bat velocity post warm-up (Montoya et al., 2009).

Overall, this research indicates that the use of an over-weight bat can be detrimental to hitting performance. There is evidence to show that over-weight bats can alter segmental timing, swing velocity, and the mechanics of a swing. Based on the similarity between the hitting and throwing motions, similar changes could be seen with pitching.

Under- and Over-Weight Baseball Training

There is record of athletes and coaches utilizing resistance training to increase athletic performance dating as far back as Ancient Greece and the first Olympics. Olympic track and field athletes and coaches from the Soviet Union are commonly cited as the first to use weighted, sport-specific implements to train (Konstantinov, 1979; Vasiliev, 1983; Verkhoshansky & Tatyan, 1983). The use of these training implements in baseball has generated an abundance of anecdotal results and assessments, but the research literature is lacking in the area.

DeRenne has published multiple studies on the topic of under- and over-weight ball training. DeRenne et al., (1985) studied the effect of under- and over- weight balls on throwing velocity. One group only used over-weight balls (*n* = 5) and another group used both under- and over-weight balls (*n* = 5). It should be noted that there was no control group for this study. The program was completed for 10 weeks with three training sessions per week. In the over-weight group, the participants threw a 5.25 ounce baseball for the first 2 weeks and then ball weight was increased by .25 ounces every 2 weeks. Sessions were timed with 15 minutes for warm-up, 15 minutes of long toss, 10-15 minutes of throwing to a catcher at 50% to 75%, and a 20-25 minutes 100 % bullpen session once per week. Participants in the other group warmed up with a regulation baseball, then did 10 to 15 minutes of long toss with an under-weight ball. The group started with a 4.75 ounce ball and then ball weight was decreased by .25 ounces every 2 weeks. Once per week, a 100% bullpen was thrown. The first 10 to 15 minutes was with an under-weight ball and the next 10 to 15 minutes was with a normal weight baseball. While not the strongest research design because there was no control group, the results showed an increase of 3 mph for the under-weight group and a 1.5 mph increase for the over-weight group compared to pre-program values. The authors theorized that with an over-weight ball, throwers had to slightly change their motions to more of a “shot put” throw which does not effectively transfer force and eliminates the summation of speed principle and could be detrimental to the pitching movement pattern (DeRenne et al., 1985).

DeRenne et al., (1990) used a similar study design, but included a control group. The participants (*N* = 30) were divided into under-weight, control, and over-weight throwing groups. Training was completed three times per week for 10 weeks. All groups completed a 10 minute warm-up with a normal 5 ounce baseball then completed a 10 minute throwing session with the prescribed ball. Each session totaled 50 throws, with the under- and over- weight groups each completing 20 throws with the prescribed ball and 30 with standard baseballs. The control group completed 50 throws with a standard baseball. After 10 weeks, the over-weight ball group increased throwing velocity by 3.75 mph and the under-weight group increased throwing velocity by 4.72 mph compared to baseline values while the control ground showed no significant change (DeRenne et al., 1990). This study shows that equal gains can be made with under- and over-weight throwing programs. It can be theorized that in the under-weight ball group they are throwing at a higher velocity along the force velocity curve due to the lower load. The over-weight group would be operating at a slower velocity but experiencing some overall strength increases.

In another study completed by DeRenne et al., (1994), the effect of under- and over-weight implement training on pitch velocity for a large group of high and collegiate school athletes (N = 225) was examined. Participants were separated into 3 groups, one with under-, normal, and over-weight balls, one with normal and over-weight balls, and a control group with only normal weight baseballs. Each group completed a prescribed training plan that consisted of three sessions for 10 weeks. Each group began with 54 throws per session and increased by six throws every 2 weeks. Group 1 threw 4, 5, and 6 ounce balls in a designated sequence each week. Group 2 threw a 5 and a 6 ounce ball for the first half then switched to 4 and 5 ounce balls for the second half of the study. Group 3 was the control group which threw only standard 5 ounce baseballs. After 10 weeks, groups 1 and 2 showed significant improvement in pitch velocity although the actual magnitude of change was not provided (DeRenne et al., 1994). This study further shows that increases in pitch velocity can be achieved with under- and over-weight balls.

Several other researchers have studied the effect of throwing over-weight balls on other variables. Litwhiler and Hamm (1973) completed a 12 week training program with three training sessions per week. Each session consisted of a sequence of 15 over-weight ball throws, 20 standard baseball throws, 10 over-weight ball throws, and finished with 10 standard baseball throws. Collegiate pitchers (*N* = 5) used balls starting at 7 ounces and slowly progressed to heavier weights ending at 12 ounces. In addition to pitch velocity, which increased by 5 m/s from baseline measurements, they measured pitch accuracy. There was no significant change in accuracy with a standard baseball after a 12 week over-weight ball training program (Litwhiler & Hamm, 1973). This study is one of the first to examine the effect of over-weight ball training on pitch velocity. Participants also utilized substantially heavier over-weight balls during their training program compared to more recent studies. Where similar pitch velocity gains using balls that were 20% under-weight rather than balls that were 240% over-weight like this study were achieved.

Morimoto, Ito, Kawamura, and Muraki (2003) completed a similar study with collegiate pitchers (*N* = 8). Instead of completing a training program, participants completed a single prescribed session in which they threw a ball that was 10% under or over the weight of a standard baseball. The sessions consisted of throwing an under-weight, normal weight, over-weight ball, or a combination of the three for 6 to 18 pitches depending on if they were throwing under- or over-weight balls in addition to a standard baseball. After the prescribed number of throws, a standard baseball was thrown and velocity and accuracy were measured. There was an increase in velocity immediately after throwing for three of the test conditions, all of which finished with throwing under-weight balls, and there was no effect on accuracy. The researchers found that throwing an under-weight ball always resulted in a higher pitch velocity. Throwing with a higher speed activated the neuromuscular system which affected subsequent pitches (Morimoto et al., 2003). These results may indicate that there is a form of kinesthetic aftereffect after throwing under-weight balls that can alter pitch velocity. Therefore, the aftereffects must be controlled in the current study.

Neal, Snyder, and Kroonenberg (1991) published a study in which changes in segmental velocities for collegiate volunteers (*N* = 12) were analyzed. Each participant threw three different weighted balls, relative to their anthropometric measurements, for distance, and were recorded with high speed cameras. As the weight progressed, differences in skill level on technique, throwing styles, and the effect of the weighted balls became apparent. More specifically, skilled throwers showed fewer alterations in technique as the weight of the ball increased compared to non-skilled throwers. This finding has two implications. The first being that there could be a motor learning component that takes over once a skill is learned and the second that there seems to be a critical value that changes movement patterns between participants. When that value is reached, throwers find a new movement pattern to complete the task. This new movement pattern no longer utilized the summation of speed principle, but instead was more like a shot put throw. Based on these findings, over-weight balls can alter segmental timing, resulting in the loss of the summation of speed principle during throwing motions (Neal et al., 1991).

Some of the documented changes in pitch velocity with under-weight balls can be traced back to the velocity of the arm while throwing. Hill (1938) is credited with first publishing the force-velocity curve. This is a hyperbolic shaped curve that illustrates as velocity decreases, force increases in concentric contractions. This concept has been observed with overhead throwing in experienced hand ball players (N = 7). Participants threw handballs ranging from 0.2kg to 0.8kg. As expected, there was a negative linear relationship between ball velocity and ball weight with concentric contractions. The kinematics of each throw were recorded with a 3D motion capture system and compared to baseline measurements. There was a positive liner relationship between total throw time and ball weight. It was also observed that the proximal to distal segment timing pattern was lost as the weight of the ball increased. This resulted in elbow extension preceding shoulder internal rotation and the wrist reaching peak angular velocity prior to the elbow (Van Den Tillaar & Ettema, 2004). This change in the movement pattern reveals that there may be a threshold where the summation of speed principle is lost resulting in negative performance outcomes.

Based on the literature, both under- and over-weight ball training programs are effective at increasing throwing velocity. Further, the evidence shows that under-weight ball training may be more effective at increasing velocity. Neal et al. (1991) revealed that although velocity may increase, movement patterns could be negatively altered. Fleisig et al. (2006) published a study on the effect of pitching an under-weight ball (4 ounces) on kinematic and kinetic variables in youth pitchers. The rationale behind this study was that there has been an increase in the number of serious injuries in youth baseball (Fleisig et al., 2006). They hypothesized that if youth baseball players pitched with a lower weight ball, there would be less force exerted on the structures in the arm. A 3D biomechanical motion capture system recorded youth pitchers (*N* = 34) throwing 4 and 5 ounce balls. There were no changes in arm position while pitching but there were significantly higher pitch and arm velocities, significantly less elbow and shoulder internal rotation torque, and 68% of the participants reported that the 4 ounce ball felt better while pitching compared to the standard 5 ounce baseball (Fleisig et al., 2006). A lighter ball may be able to help reduce pitching injuries in youth athletes due to the lower toque on the arm. Although many studies have used performance measures for variables, this is one of the first to use biomechanical analysis as a variable.

Based on the literature, under- and over-weight ball training has been shown to be effective at increasing pitch velocity. It has also been shown that when pitching with under-weight balls, there is less force stressing the arm, potentially making under-weight balls safer. Further research is need examining the effects of throwing under- and over-weight balls on biomechanical variables.

Overall Summary

Baseball pitching is a complex, whole body motion. There are many small mechanical variables that, when synchronized, lead to better performance outcomes such as higher velocity, ball control, and pitch consistency. Each body segment must generate force and then transfer that force to the neighboring proximal segment to achieve maximal velocity. Additionally, pitchers develop and utilize highly refined motor programs to complete the desired skill. Alterations in the segmental timing or deviations from the learned especial motor skill may lead to decreased performance.

To date, there has not been any research using motion capture technology to evaluate the baseball pitching motion while throwing under- and over-weight balls. Further, most of the previous research has been completed with balls 20% lighter or heavier than a standard baseball. Most pitchers utilize balls that that range from 40% lighter to 240% heavier than the weight of a standard baseball. While there is evidence that under- and over-weight ball training can increase velocity, further research utilizing new technology and the newer ball weights is needed. Therefore, the purpose of this study was to examine the effects pitching with under- and over-weight balls on the joint angles at the shoulder and elbow, pitch velocity, and total pitch time of collegiate pitchers.

CHAPTER III

METHODS

Participants

Participant were current Division I collegiate baseball pitchers (N = 6) with a minimum of 4 years of pitching experience. Participants were recruited on a voluntary basis with no compensation offered. To be included, the pitchers had to throw from the "over-top" or "3/4"arm slot, and list pitching as their primary position. All participants were cleared by their team physician to participate in regular physical training. Athletes with a history of musculoskeletal injury that had caused them to stop throwing within the past 6 months were excluded from participation.

Instrumentation

Height, body mass, and arm length. Participant's height and body mass were measured prior to testing for demographic purposes. Height was measured to the nearest 0.5 cm using a stadiometer (Seca Stadiometer – Hanover, MD). Body mass was measured in kilograms on a digital scale (Seca 869, Chino, CA) to the nearest 0.1 kg. The length of the radius, defined as the length between the radial styloid process and the radial head, was measured to the nearest 0.5 cm using a cloth tape measure. Additionally, the length of the humerus, defined as the length between the lateral epicondyle and the greater trochanter, was measured to the nearest 0.5 cm. The midpoint of the radius and humerus was marked at this time for later use. All measurements were taken with shoes off, while wearing gym shorts, gym shirt, and with empty pockets.

Health history form. Participants also filled out a health history questionnaire (American Academy of Family Physicians Preparticipation Evaluation History Form). This was used to screen for any orthopedic injuries in the past 6 months that would disqualify them from participating in this study.

Weighted balls. Balls that were under-weight (4 oz), standard weight (5 oz), and over-weight (7, 9, and 12 oz), manufactured by Champion Sports (Marlboro, NJ), and an under-weight 3 oz ball, manufactured by Markwort Sporting Goods (St. Louis, MO), were used during the study. Each ball was regulation size (9.25 in). The weight of each ball was blinded to the participants.

Motion capture system. A Noraxon myoMotion (Noraxon U.S.A. Inc., Scottsdale, AZ) system was used to assess peak glenohumeral flexion, peak glenohumeral abduction, and peak elbow flexion. Total pitch time was determined by measuring the elapsed time between when the ball was removed from glove to the time the ball was released, also known as the cocking and acceleration phases.

Pitch velocity. Pitch velocity was measured with a Stalker Pro II radar gun (Stalker Radar, Plano, TX). The radar gun was set to measure peak velocity, also known as release velocity, during each pitch.

Procedures

Study approval was obtained from the Institutional Review Board (IRB) at the university (see Appendix A). Participants were recruited from the varsity baseball team of a university in the Southeastern United States. The baseball coaches were informed of the nature of the study and agreed to allow the student-athletes to volunteer for the study. All testing took place in the bullpen at the university baseball field. First, participants read and signed the consent form and then completed the health history questionnaire. Height, body mass, radius length, and humerus length were then measured. Each site that a sensor was placed on was identified, marked, and if the participant had excess body hair, the area was shaved.

Prior to throwing, participants were given unlimited amount of time to complete their normal warm-up as if they were preparing to pitch in a game. Once they reported being ready, the areas where the sensors for the Noraxon myoMotion system were going to be placed were prepared. Participants removed their shirt and each area was also cleaned with isopropyl alcohol 70% prep pads, then an adhesive spray was applied directly to the skin. A total of six sensors were applied bilaterally on the midpoint of each humerus, bilaterally on the midpoint of each ulna, at the T1 spinous process, and the T10 spinous process. The T1 spinous process was found by palpating the superior angle of the scapula and the T2 spinous process parallel to that angle, then by moving superiorly one spinous process to T1. The T10 spinous process was found by palpating the inferior angle of the scapular and the T7 spinous process parallel to that angle, then by moving inferiorly three spinous processes to T10. (Starkey, Brown, & Ryan, 2010). The sensors on the throwing arm were secured using the provided Velcro wraps and a fabric based cohesive athletic tape. The T1 and T10 sensors were attached directly to the body utilizing double sided tape and Omniflex dressing retention tape. All data were recorded and analyzed using the Noraxon myoMotion software. A standing calibration file was collected prior to each pitching session. This enabled the joint centers for the upper extremities to be determined. For this calibration trial, each pitcher was asked to stand erect with his arms held straight by his sides and his palms facing forward for 20 secs.

Pitching trials took place from a standard pitching mound with a height of 10 inches and set 60 feet 6 inches from home plate. Each trial consisted of 5 maximal effort throws at a stationary pad with a simulated strike zone (The Pitching Pad, Bishop Family Enterprises, San Antonio, TX). Each outcome variable was determined from the average of the last three pitches for each condition, to account for any lingering kinesthetic aftereffects (Otsuji et al., 2002). Participants were instructed to complete all throws using a fastball grip and to throw at the center of the simulated strike zone. Participants were instructed to throw at maximal effort while still retaining accuracy. Trials were with 3 oz, 4 oz, 5 oz, 7 oz, 9 oz, and 12 oz balls. The first trial was with a standard 5 oz baseball to establish a baseline. The under- and over-weight balls were then thrown in a randomly assigned order and participants had a 3 minute rest period between each test condition (Nakamoto et al., 2012; Singer & Collins, 1972; Singer & Day, 1965).

Data Analyses

Descriptive characteristics (means and standard deviations) were calculated for all data collected on the control weight, under-weight, and over-weight conditions for each participant. Six Wilcoxon Signed Ranks Tests and effect size were completed to examine the difference in glenohumeral and elbow joint angles, total pitch time, and pitch velocity across ball weight. An alpha of .05 was set prior to data collection. Data were analyzed using Statistical Package for Social Sciences (SPSS) Version 23.

CHAPTER IV

RESULTS

Collegiate baseball pitchers (*N* = 6, *M* age = 21.1 years ± 1.5 years) volunteered to participate in this study. All pitchers were right arm dominant. Demographic characteristics of the sample are found in Table 1. Differences in joint angles across the different ball weights are depicted in Table 2. There were significant increases in glenohumeral flexion (*Mdn* = 104.74°) and glenohumeral abduction (*Mdn* = 109.53°) while pitching with the 12 ounce ball compared to the control 5 ounce baseball (*Mdn* = 101.25°, *Mdn* = 101.85°). Both of these results had a moderate effect size (Cohen, 1988). There were also significant increases to glenohumeral external rotation during the pitching motion with the 3 ounce ball (*Mdn* = 159.65°) in comparison to the 5 ounce baseball (*Mdn* = 150.60°), which also had a moderate effect size.

Differences in velocity and total pitch time across the different ball weights are depicted in Table 3. Pitch velocity for the 3 ounce ball (*Mdn* = 87.17 mph) was significantly faster while the pitch velocity for the 7 (*Mdn* = 76.00 mph), 9 (*Mdn* = 70.67 mph), and 12 ounce balls (*Mdn* = 66.17 mph) were all significantly slower compared to the control condition (*Mdn* = 81.67 mph), with moderate effect sizes. There were no changes in total pitch time.

Table 1

Descriptive Statistics of the Sample (N = 6)

	Mean	*SD*
Height (cm)	180.4	6.0
Body mass (kg)	87.0	8.1
Humerus (cm)	31.8	1.6
Radius (cm)	26.2	1.5

Note. Humerus is the length between the lateral epicondyle and the greater tuberosity. Radius is the length between the radial styloid process and the radial head.

Table 2

Wilcoxon Signed Ranks Test for Difference in Joint Angle by Ball Weight

Ball weight (ounces)	*M*	*SD*	*N*	*Z*	Asymp. Sig.(two tailed)	ES
Glenohumeral flexion						
3	108.43	10.97	5	-1.483	0.138	0.42
4	109.75	11.92	6	-0.734	0.463	0.21
5	104.67	12.45	6			
7	109.51	11.39	6	-1.572	0.116	0.45
9	110.23	6.69	6	-1.363	0.173	0.39
12*	110.11	11.30	6	-1.992	0.046	0.57
Glenohumeral abduction						
3	110.49	11.98	5	-1.753	0.080	0.50
4	110.81	12.02	6	-0.734	0.463	0.21
5	106.04	12.02	6			
7	111.19	10.83	6	-1.572	0.116	0.45
9	109.05	6.88	6	-1.153	0.249	0.33
12*	113.12	11.37	6	-2.201	0.028	0.63
Glenohumeral external rotation						
3*	163.77	10.00	5	-2.023	0.043	0.58
4	158.41	20.31	6	-0.943	0.345	0.27
5	152.68	16.94	6			
7	156.05	23.01	6	-0.734	0.463	0.21
9	154.17	25.70	6	-0.105	0.917	0.03
12	154.67	24.99	6	-0.105	0.917	0.03
Elbow flexion						
3	115.04	7.48	4	-1.183	0.068	0.34
4	113.23	8.19	5	-1.214	0.225	0.35
5	117.56	8.81	5			
7	117.46	5.89	5	-0.135	0.893	0.03
9	110.49	6.02	5	-1.214	0.225	0.35
12	113.94	6.98	5	-0.135	0.893	0.03

Note. * = $p < .05$ denoting significant change from 5 ounce baseball control condition. All joint angles measured in degrees.

Table 3

Wilcoxon Signed Ranks Test for Pitch Velocity and Total Pitch Time Across Ball Weights

Ball Weight (ounces)	*M*	*SD*	N	Z	Asymp. Sig.(two tailed)	ES
Pitch velocity (mph)						
3*	83.56	7.09	5	-2.207	0.027	0.63
4	80.50	6.57	6	-1.363	0.173	0.39
5	78.83	6.56				
7*	74.78	8.86	6	-1.992	0.046	0.57
9*	68.45	5.37	6	-2.207	0.027	0.63
12*	63.61	0.54	6	-2.201	0.028	0.63
Total pitch time (sec)						
3	0.62	0.16	5	-1.826	0.068	0.52
4	0.62	0.12	6	-1.625	0.104	0.46
5	0.64	0.11				
7	0.64	0.15	6	-3.650	0.715	1.05
9	0.65	0.14	6	-0.213	0.832	0.06
12	0.65	0.12	6	-0.422	6.730	0.12

Note. * = $p < .05$ denoting significant change from control 5 ounce baseball. Total pitch time is defined as the cocking and acceleration phases.

CHAPTER V

DISCUSSION

This study was conducted to examine the effects of under- and over-weight balls on glenohumeral flexion, glenohumeral abduction, elbow flexion, pitch velocity, and total pitch time during the pitching motion. The results support the hypothesis that there would be a significant increase in peak glenohumeral joint angles when pitching with over-weight balls, but do not support the hypotheses that there would be no significant changes in peak glenohumeral joint angles when pitching with under-weight balls. Further, the results support the hypothesis that there would be no significant changes in peak elbow flexion when pitching with under-weight balls, but do not support the hypotheses that there would be significant changes in peak elbow flexion when pitching with over-weight balls. Finally, the results do not support the hypothesis that total pitch time would increase as ball weight increases, but do support the hypothesis that pitch velocity would decrease as ball weight increases.

Glenohumeral flexion and abduction were significantly greater for the 12 ounce ball indicating some changes to the pitching motion with an over-weight ball. Additionally, glenohumeral external rotation was significantly higher with the 3 ounce ball compared to the 5 ounce control baseball. Together, these results indicate that pitching with substantially under- or over-weight balls alters the pitching motion. Additionally, pitch velocity was significantly higher with the 3 ounce ball and significantly lower with the 7, 9, and 12 ounce balls, indicating potential stimulation of muscle spindles or other physiological mechanisms limiting muscle function at the shoulder with heavier balls.

The use of heavier balls by pitchers is becoming more common training implement. However, to date, most of the published research on the effectiveness of throwing programs utilizing under- and over-weight balls has included balls that were no more than 20% below and/or 20% above a standard 5 ounce baseball. This is one of the first studies to examine the biomechanical effect of balls with weights outside of these ranges and, interestingly, all statistically significant differences identified were for balls outside of the ± 20% range.

Increased glenohumeral joint angles while using the 12 ounce ball could be related to a loss of kinetic energy and subsequent adaptations of the pitching motion. As previously described, Fleisig et al. (2009) found that decreased shoulder abduction during the acceleration phase leads to significantly higher velocities among professional pitchers. The increased glenohumeral abduction found in the current study could be one of the reasons ball velocity decreased when pitching with the 12 ounce ball. Matsuo et al. (2001) identified maximum shoulder internal rotational angular velocity and Werner et al. (2008) identified maximum shoulder angular velocity as a significant variable related to increased velocity. The increased external rotation with the 3 ounce ball may explain the increased pitch velocity. Greater external rotation allows for more range of motion over which force can be generated, increasing the internal rotation angular velocity and shoulder angular velocity.

As previously described by Neal et al. (1991), when throwers reach a threshold weight, the throwing motion transitions away from utilizing the transfer of force from proximal to distal segments to more of a pushing motion. In this study, throwing with the 12 ounce ball resulted in increased shoulder flexion and abduction compared to the control condition. The elevated arm slot could be attributed to a the loss of kinetic energy that was due to improper segment timing, observed as the arm lagging too far behind the body. If this positon and movement pattern are continually trained, it could have detrimental effects on the generalized motor pattern (GMP) or recall schemas associated with overhead throwing.

This concept was also described by Van Den Tillaar and Ettema (2004) with handball players who threw balls ranging up to 28 ounces. With heaver handballs, throwers exhibited elbow extension before shoulder internal rotation and the wrist reached peak angular velocity prior to the elbow. These changes occurred in an attempt to achieve high ball velocities even though the summation of speed principle could not be used. When throwers are utilizing the summation of speed principle, the distal segment lags behind the proximal segment until maximum angular velocity is reached. This lag allows for each segment to generate force, then transfer that force to the next segment, ultimately ending in the arm. When throwers are using a ball that is too heavy, they transition to a throw resembling a shotput throw. This technique cannot utilize the summation of speed principle. Rather it falls under the principle of optimal coordination of partial momenta. This principle states that in order to maximize the speed of the distal segment in a linked system, the angular speeds of all segments must peak at the same time (Jöris et al., 1985). This motion is not as effective for lighter implements and results in less force being generated. The altered mechanics when the pitchers threw the 12 ounce ball in this study could be a similar adaptation. Based on this result, pitching or training with a substantially overweight ball may be detrimental to the highly trained movement pattern associated with pitching in collegiate pitchers.

Another reason that arm position and velocity could change when throwing under- and over-weight balls is muscle spindle stimulation at the shoulder. Muscle spindle afferents, cutaneous mechanoreceptors, and joint receptors, provide critical proprioceptive feedback about limb position, movement, and function as a protective mechanism to prevent overstretching (Grill & Hallett, 1995; Luu, Day, Cole, & Fitzpatrick, 2011). Not only do muscle spindles provide peripheral feedback through the fusimotor loop and afferent feedback, they also provide feedback about limb weight or "heaviness." When a heavier load is placed on a joint, it causes greater stretch and tension in the muscle. In response, muscle spindles cause a reflexive contraction (Scholz & Campbell, 1980). With the 12 ounce ball, the additional load on the joint, and subsequent stretch on the related musculature, may have caused a reflexive contraction of the posterior shoulder musculature and reciprocal inhibition of the anterior musculature, resulting in decreased pitch velocity.

Feedback from the muscle spindles also helps to regulate the strength and timing of a required contraction and provides information to allow for corrections in a movement pattern (Luu et al., 2011). Muscle spindles also supply velocity and acceleration information from the moving limb (Dimitriou & Edin, 2008). The body relies on the feedback from muscle spindles to execute the throwing motion and to make corrections during the motion, allowing for a more accurate throw. Research has shown that when strength training is completed at the same intensity over 8 weeks, participants have better joint awareness and higher muscle spindle sensitivity compared to participant's who completed varying intensity strength training. This was demonstrated by a participant's ability to place his or her arm at a specific joint angle and then accurately reproduce that joint angle on his or her own while blindfolded (Salles et al., 2015). While there is no research that examines this finding with baseball pitching, utilizing the same intensity, or a standard weight baseball, could reinforce the concept of an especial skill, or highly trained movement patterns. The number of repetitions a pitcher completes with a standard baseball allows for the development of an especial skill and the feedback from muscle spindles have a large role in the execution of a pitch. With under- and over-weight balls, the muscle spindles must adapt to new loads and forces, resulting in a less efficient throw, such has decreased accuracy or velocity, and altered arm positioning, as documented in this study.

Pitching is a highly trained, especial skill, that utilizes a specific motor program and recall schema (Simons et al., 2009). Especial skills are ones that have their own GMP and recall schemas separate from the standard overhead throwing GMP. These skills are developed because every pitch is from 60 feet 6 inches with a 5 ounce ball. Such a highly trained skill is further developed with practice, repetition, and feedback to better develop the recall schema. Increased shoulder flexion and adduction when throwing the 12 ounce ball, or increased shoulder external rotation with the 3 ounce ball, altered the arm slot and throwing mechanics of the pitcher. Any changes in arm slot would no longer be training the pitching motion because a different weight ball is causing a deviation from the trained especial skill (Keetch et al., 2005). While not measured in the study, it was observed that participants struggled with accuracy during the study. When pitching with under-weight balls, the participant's throws were short of the target and with over-weight balls, the throws were above the target, at times missing the target completely. It is unexpected for highly skilled pitchers to miss a 44 inch by 65 inch pad while throwing from the standard pitching distance. Alterations in accuracy could be a result of new or altered proprioceptive feedback that deviates from the learned especially skill or even an associated baseball throwing recall schema, and would be valuable to study further.

When pitching, there is a strong eccentric load exerted by the posterior shoulder to decelerate the arm (Zachazewski, Magee, & Quillen, 1996). Muscle spindles are one of the main feedback sensory structures that cause the eccentric contraction. When a muscle is rapidly stretched or stretched near the end ranges of motion, muscle spindles are stimulated and cause a reflexive contraction in the muscle. The reflexive contraction resists the stretch being placed on the muscle to limit the risk of injury to the muscle and joint (Burke, Hagbarth, & Lofstedt, 1978). Muscle spindle activation is directly proportional to the amount of force being placed on the muscle. When there is a greater amount of load applied, more force is required by the agonist muscle, which results in greater muscle spindle activity and a stronger contraction by the antagonist muscle (Burke et al., 1978; Dimitriou, 2014). If the increase in resistance is too great or occurs too rapidly, this can cause reciprocal inhibition in the antagonist muscle (Dimitriou, 2014). This mechanism, in addition to the force-velocity principle, which states as velocity decreases force increases during concentric contractions, could be part of why pitch velocity decreased as ball weight increased (Hill, 1938). As the weight of the ball increased, more muscle spindles in the posterior may have been stimulated as a result of greater force exerted by the anterior shoulder, resulting in a stronger resistance to the movement. The reverse could potentially explain why there was a significant increase in pitch velocity with the 3 ounce ball. Muscle spindles in the posterior shoulder could be under-stimulated, resulting in a decreased eccentric contraction in the posterior shoulder. Not only can the increased contraction force by the posterior shoulder with heavier balls be detrimental to pitch velocity, it can result in muscular adaptions over time.

Typically, pitchers have more glenohumeral external rotation range of motion than glenohumeral internal rotation range of motion (Wilk et al., 2014). This is due to over rotation in the cocking phase in an attempt to increase velocity. Additionally, the eccentric strain placed on the shoulder during deceleration can also lead to decreased internal rotation (Zachazewski et al., 1996). Increased external rotation most often results in the loss of internal rotation and sometimes to the total arc of motion as well. If the loss of internal rotation or total rotational range of motion is great enough, it can predispose a pitcher to shoulder or arm injuries (Wilk et al., 2014). Increased external rotation and increased eccentric posterior shoulder contractions from throwing a substantially over-weight ball could amplify the loss of internal rotation and potentially increase the risk of injury.

Further research is required to determine the safety and effectiveness of under- and over-weight throwing programs. This study shows that ball weights that deviate from the established 4 to 6 ounce range result in altered arm position during the pitching motion and altered pitch velocity. The mechanisms that may be the cause of these observed changes may result in decreased performance, especially with regard to accuracy, and increase the risk of shoulder and arm injuries. Future research should also focus on pitch accuracy, torque exerted at the shoulder and elbow, and the effects of altered arm positon when throwing with under- and over-weight balls. Additionally, further research on effects of warming-up with under-and over-weight balls in addition the effects of short-and long-term throwing programs is needed.

There has been no research examining the effects of throwing over-weight balls in youth or adolescent athletes. Young athletes are still growing and developing and the higher levels of force and torque that throwing over-weight balls generates could have negative developmental effects. Further research is needed to better understand the effects of throwing under-and over-weight balls can have in this population. All athletes should use caution when using under and over-weight balls to warming-up and in training until the acute and chronic effects are better understood, especially youth and adolescent athletes.

One limitation of this study was saturation of the sensors for the motion capture system. The Noraxon myoMotion system is a relatively new system. The current sensors become saturated at high rates of acceleration, such as with the pitching movement. This resulted in loss of data for some trials and the loss of data for several joint angles. New sensors are currently being developed. In future research, the use of sensors that can capture higher rates of acceleration or laboratory based motion capture systems may be beneficial. While the relatively small sample size is also a limitation of this study, significant results were found. Future research incorporate larger sample sizes will allow for greater understanding and generalization of these findings.

In summary, the use of balls that are 60% under-weight or 240% over-weight results in changes to the fastball pitching motion. Additionally, balls that are 60% under-weight or 140% over-weight or higher result in significantly different pitch velocities. Despite the limitations of this study, the results show that acute training with balls 20% under or over the weight of a standard baseball could be detrimental to performance in collegiate pitchers.

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APPENDIX

APPENDIX A

IRB Letter of Approval

Wednesday, November 30, 2016

Investigator(s): Christopher Proppe (PI), and Dr. Jenn Caputo (FA)
Investigator(s') Email(s): cep4u@mtmail.mtsu.edu
Department: Exercise Science

Study Title: The Effect of Throwing Under- and Over-Weight Baseballs on the Pitching Motion
Protocol ID: **17-2094**

Dear Investigator(s),

The above identified research proposal has been reviewed by the MTSU Institutional Review Board (IRB) through the EXPEDITED mechanism under 45 CFR 46.110 and 21 CFR 56.110 within the category *(4) Collection of data through noninvasive procedures* A summary of the IRB action and other particulars in regard to this protocol application is tabulated as shown below:

IRB Action	APPROVED for one year from the date of this notification	
Date of expiration	11/30/2017	
Participant Size	15	
Participant Pool	Current Division I collegiate baseball pitchers with 4 yrs experience	
Exceptions	N/A	
Restrictions	Division I pitchers must be cleared by their team physician to participate. Pitchers with musculoskeletal injury will be excluded.	
Comments	N/A	
Amendments	Date	Post-approval Amendments
	N/A	None

This protocol can be continued for up to THREE years (11/30/2019) by obtaining a continuation approval prior to 11/30/2017. Refer to the following schedule to plan your annual project reports and be aware that you may not receive a separate reminder to complete your continuing reviews. Failure in obtaining an approval for continuation will automatically result in cancellation of this protocol. Moreover, the completion of this study MUST be notified to the Office of Compliance by filing a final report in order to close-out the protocol.

The investigator(s) indicated in this notification should read and abide by all of the post-approval conditions imposed with this approval. Refer to the post-approval guidelines posted in the MTSU IRB's website. Any unanticipated harms to participants or adverse events must be reported to the Office of Compliance at (615) 494-8918 within 48 hours of the incident. Amendments to this protocol must be approved by the IRB. Inclusion of new researchers must also be approved by the Office of Compliance before they begin to work on the project.

All of the research-related records, which include signed consent forms, investigator information and other documents related to the study, must be retained by the PI or the faculty advisor (if the PI is a student) at the secure location mentioned in the protocol application. The data storage must be maintained for at least three (3) years after study completion. Subsequently, the researcher may destroy the data in a manner that maintains confidentiality and anonymity. IRB reserves the right to modify, change or cancel the terms of this letter without prior notice. Be advised that IRB also reserves the right to inspect or audit your records if needed.

Sincerely,

Institutional Review Board

Middle Tennessee State University