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The Effect Of Pitching With Underweight And Overweight Balls On Pitch Velocity In Collegiate Baseball Pitchers.

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THE EFFECT OF PITCHING WITH UNDERWEIGHT AND OVERWEIGHT BALLS ON PITCH VELOCITY IN COLLEGIATE BASEBALL PITCHERS

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ABSTRACT

BACKGROUND: In an effort to improve overhand throw velocity in baseball pitchers, weighted implement training, which utilizes balls that are heavier or lighter than a competition ball, have been employed. Weighted ball programs have previously been used in baseball pitchers ranging from high school to professional with varying ball weights with mixed results (Straub, 1966; Brose and Hanson, 1967; DeRenne, 1985; DeRenne, 1990; van den Tillaar and Ettema, 2011).

PURPOSE: To determine the effect of a commercially available weighted ball program on the throwing velocity of collegiate baseball pitchers over the course of an off-season.

METHODS: This retrospective study examined pitch velocity for 56 varsity collegiate baseball pitchers at the University of Mississippi between 2012-2015. The weighted implement (WI) group (n=35) used weighted implement training in addition to normal throwing activities throughout the off-season while the normal throwing (NT) group (n=21) participated in normal throwing activities only. The WI group used baseballs that were 20% overweight (6 ounces), 20% underweight (4 ounces), and regulation weight (5 ounces) while the NT group used only the regulation weight baseball. A repeated measures ANOVA was conducted. Statistical significance was set at $p \leq 0.05$.

RESULTS: Pitch velocity did not significantly increase from the beginning of the off-season to the end of the off-season ($p=0.071$) for either group and there was no significant difference between the two groups ($p=0.271$).

CONCLUSION: In varsity collegiate pitchers involved in general and sport specific training, the current weighted implement throwing program is no more effective than a normal throwing protocol.

DEDICATION

This thesis is dedicated to the man who fostered my love of working with college athletes, who valued education above all else, and who will forever be my favorite left-handed pitcher, my grandfather, Charles "Lefty" Smith.

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Most importantly, I would like to express my gratitude for the Ole Miss Baseball team, especially the seventeen pitchers that I had the opportunity to work closely with. To these pitchers: I am thankful that you put up with me and did everything I asked of you all year. I am so proud to know each of you and I hope this research benefits you, your team, and the program.

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CHAPTER I

INTRODUCTION

The baseball pitcher is the foundation of the team's defense and maintaining maximal pitch velocity and accuracy are the pitcher's main objectives (Cimino, 1987). The ballistic and powerful pitching motion commands maximum speed for minimum travel time (Indiana University, 2013). The ability to repeatedly produce maximal pitch velocity is closely linked to kinematic and kinetic associations of the segments of the body (Seroyer, 2010) as they relate to the pitch motion.

The pitch has six phases: wind-up, stride (early arm-cocking), (late) arm-cocking, arm positive acceleration, arm negative acceleration, and follow-through (Fleisig, 1996a). The pitching motion begins with the wind-up, which places the pitcher in the optimal position for all body segments to contribute to the pitch (Pappas, 1985), and also allows the pitcher to distract the hitter and hide the ball (Seroyer, 2010). This phase begins when the pitcher begins movement and ends when the pitcher's stride leg (left leg in a right-handed pitcher) is at maximum height and the pitcher is facing the batter (Fleisig, 2010). As the stride foot moves forward toward the batter, the hip of the supporting leg (right leg in a right-handed pitcher) flexes to lower the body and the trunk rotates slightly toward third-base. The pitcher separates his hands, swinging his arms downward, and then upward again. The stride phase ends when the non-dominant stride foot makes contact with the ground (Fleisig, 1996a; Fleisig, 2010).

While still striding, the pitcher arm begins to raise his arm above his head and back behind his body into a cocking position (Dillman, 1993; Fleisig, 1994) as his trunk arches backwards. During the arm-cocking phase, the arm is fully cocked, which means the arm is as far back behind the pitcher as possible, the elbow is bent, and the shoulder is in maximum external rotation (Dillman, 1993; Fleisig, 1994). At maximum external shoulder rotation the forearm is perpendicular to the trunk and the palm of the throwing hand is facing upwards with the ball in it (Fleisig, 1996a). Once the throwing arm is in the cocked position, arm positive acceleration begins and continues until the ball is released from the throwing hand (Pappas, 1985; Werner, 1993). Immediately following ball release the throwing arm begins to negatively accelerate as the shoulder internally rotates and the forearm is moved across the body (Dillman, 1993; Fleisig, 2010). Finally, the follow-through motion begins when the shoulder reaches maximum internal rotation and concludes when the throwing arm stops moving (Pappas, 1985; Fleisig, 1996a), the trunk tilts forward into a neutral position, and the dominant leg steps forward to regain balance, allowing the pitcher to resume a fielding position (Seroyer, 2010).

The body segments that contribute to the different phases to the pitch motion are linked through the kinetic chain of the body (Putnam, 1993) that allows transfer of energy and velocity between these segments. The kinetic chain of the overhand pitch includes five segments: the pelvis, upper trunk, upper arm, forearm, and hand (Atwater, 1982). As the body moves through the phases, the movement of the most proximal segment affects the action and velocity of the most distal segment, resulting in an additive effect of velocity throughout the sequence (Atwater, 1982; Alexander, 1982; Mero, 1994; Hong, 2000). The explosive velocity at the most distal segment is then the summation of the velocities of each of the five body segments (Atwater, 1982; Alexander, 1982; Mero, 1994; Hong, 2000; Garner, 2007).

To increase pitch velocity, the pitcher must be able to produce either additional force or velocity through the kinetic chain to result in a more powerful pitch (Ettema, 2008). This can be done by manipulating the force-velocity curve (Hill, 1938), which states that when the a heavier load is to be lifted, more force is required and thus the load is lifted slower while a lighter load required less force and can be lifted with greater velocity. The power behind the pitch can be increased through training that overloads the muscle with resistance (Lachowetz, 1998) and increases muscle strength and maximal force development (Tojo and Kaneko, 2004; Escamilla, 2011) as well as through velocity-overload training, which requires exercises to be completed at high speeds (Van den Tillaar and Ettema, 2004), resulting in increased velocity. Increases in strength are established by hypertrophy and neural drive while speed increases are related to muscle fiber type expression and number of sarcomeres in series in a fiber (Ettema, 2008). While general resistance training has been shown to increase pitch velocity by increasing muscle strength (Mero, 1994), ballistic exercises that are performed rapidly and explosively have also increased throw velocity (Zaras, 2013). For pitchers, this means that exercises should be done along the force-velocity curve in order to improve both speed and strength.

It seems likely then, that sport-specific exercises that mirror the movement and power output required for the actual sport motion would also result in increased velocity through neuromotor specificity (Logan, 1966; DeRenne, 1985). Variable resistance training, which involves using different loads throughout the movement, can produce both an increase in speed and an increase in strength. In baseball pitchers, weighted balls can be used to provide variable resistance. Using weighted baseballs consists of using a modified standard competition ball that is identical to the competition ball in size and shape, but differs in weight. Throwing with a ball that is lighter than a regulation baseball allows arm to generate greater speed (Yang, 2013) while a ball that weighs more than a regulation baseball trains the arm with a higher load for greater strength (van den Tillaar and Ettema, 2011). Thus, utilizing a combination of overweight and underweight balls should contribute to improved speed-strength when using a competition baseball (DeRenne, 1994; Morimoto, 2003).

While the current literature has mixed results on weighted baseball programs, these programs remain prolific in college and professional pitchers today. There is still a need to find the optimal ball weight and program duration to increase pitch velocity. Additionally, in programs that found an increase in pitch velocity, it is unknown if this increase is different from an improvement that would be seen in an athlete that is still training and developing.

Purpose

For this reason, the purpose of this study was to determine the effect of using overweight and underweight balls on the throwing velocity of collegiate baseball pitchers over the course of an off-season. Weighted ball programs up to ten weeks have previously been used in baseball pitchers (Straub, 1966; Brose and Hanson, 1967; DeRenne, 1990; Van den Tillaar and Ettema, 2011) ranging from high school to professional with varying ball weights and varying acute results. It is not known if practicing with 20% overweight and underweight balls in collegiate pitchers results in a greater increase in pitch velocity than practicing with competition baseballs.

Hypotheses

The hypotheses for this study were as follows:

H_{01}: The individualized weighted ball program will not alter pitch velocity over the course of a fall off-season.

H_{a1}: The individualized weighted ball program will alter pitch velocity over the course of a fall off-season.

Research (Brose and Hanson, 1966; Litwhiler, 1973; Pollock, 1975; DeRenne, 1985; DeRenne, 1990; DeRenne, 1994; Yang, 2013) has supported that a weighted ball program will elicit increases in pitch velocity in baseball pitchers. Weighted ball programs specifically designed for individual pitchers have not yet been researched.

H_{02}: There will be no difference in throw arm feel after training with the underweight or overweight balls.

H_{a1}: There will be a difference in throw arm feel after training with the after training with the underweight or overweight balls.

There has been research (Straub, 1966; Neal, 1991; Fleisig, 1996; Southard, 1998; van den Tillaar, 2004; Pallett, 2015) done to determine whether there is a change in throwing motion mechanics when using weighted balls but no research has been done on the pitcher's acceptability and perception of the program based on how their arm feels while throwing, and after throwing the weighted ball.

CHAPTER II

LITERATURE REVIEW

The Overhand Throw

Purpose

Maximum speed is one of the objectives of throwing. Speed must be employed in order to get an object to a maximum distance, as is used in shot put, or to get an object to a specified distance in the shortest time. Throwing can also be used for precision, such as in throwing darts toward a bulls-eye. Some sports require throwing to be focused on both speed and precision, as is seen in sports such as football and baseball (Indiana University, 2013).

Phases of the Overhand Throw

All throws have three phases: the preparatory phase, the double-support phase, and the follow-through (Indiana University, 2013). The preparatory phase gives momentum to the thrower and the projectile by placing the body in a position that allows for a long range of motion of the projectile for the beginning of the double-support phase. The double-support phase is where the projectile gains most of its speed by using the leg, and then the trunk muscles, to move the throwing arm in the direction of the throw, placing a large force on the projectile over a long range of motion. The follow-through is the last phase and occurs after the projectile has been released. This phase focuses on negatively accelerating the throwing arm and dissipating the forces acting on the arm during the throwing motion (Indiana University, 2013).

Kinesiology of the Overhand Throw

While there are four main patterns for throwing, the overhand throw will be discussed in this paper. The overhand throw is utilized with lighter objects and can be found in many sports including the baseball pitch, the football pass, the water polo pass, and the javelin throw. Overhand throwing involves a very long range of motion that compensates for bad leverage that the motion involves. It involves a good grip of the projectile and requires external rotation at the shoulder, elbow extension, stopping of elbow extension, internal rotation at the shoulder, and ball release (Indiana University, 2013).

The mechanism of the overhand throwing motion occurs via a kinetic link system, which is when the muscles involved in the throw are activated in a sequential order that allows for transfers of momentum through the body segments (Jacobs, 1987). In sequential muscle activation, the segments of the body are activated in a proximal-to-distal sequence (Garner, 2007). A proximal body segment exerts force against a supporting surface and is activated and undergoes acceleration, while at first the succeeding distal segment does not accelerate (Atwater, 1982; Alexander, 1982; Hong, 2001). Then, once the proximal segment reaches peak velocity around the midrange of the action, it begins to negatively accelerate. Through the theory of transfer of momentum, the angular momentum of the proximal segment is then partially transferred to the distal segment, conserving momentum in the system and following for transfer of velocity (Alexander, 1982; Atwater, 1982). It is thought that the distal segment begins to contract its muscles to contribute muscular torque as the proximal segment reaches peak velocity (Jacobs, 1987) and the distal segment begins to acquire the velocity of the proximal segment, conserving the angular momentum of the proximal segment. This continues with each proximal segment negatively accelerating and transferring angular momentum to the next segment in the sequence, and each segment contributing its own force to the movement, leading to an additive effect of velocity throughout the succession of each segment (Atwater, 1982; Alexander, 1982; Putnam, 1993; Mero, 1994; Hong, 2001). As each segment accelerates and then slows down, forces are coupled from segment to segment (Jacobs, 1987) and the summation of all the forces results in explosive velocity at the most distal segment (Putnam, 1993). The final velocity, that of the thrown ball, is the sum of the velocities of each of the body segments (Jacobs, 1987; Putnam, 1993). In the overhand throw, the pelvis, upper trunk, upper arm, forearm, and hand are the five segments that are sequentially coordinated in time to reach peak angular velocity of the pitched baseball (Atwater, 1982).

There are four factors that influence ball velocity: the distance from the end of the backswing to the release point; the number of body parts contributing force; the speed of each contributing body segment; the transfer of the body part's force onto the ball (Jacobs, 1987). A greater distance from backswing to release, larger number of force-contributing body parts, and greater speed of each body part will result in increased ball velocity. A properly synchronized kinetic link system that does not have any weak links will result in the highest ball velocity (Jacobs, 1987).

Because the overhand throw occurs rapidly and explosively, it is thought that the muscles involved are preactivated by the negative acceleration of the previous segment and forces of inertia (Grezios, 2006). The greater the preactivation level of the muscle, the better the muscle can compensate for stretch loads and the more elastic energy the muscle can store in the stretch-shortening cycle (SSC) (Grezios, 2006). In an overhand thrower, the arm segments move through an extreme range of motion, which allows the muscles to pre-stretch prior to the concentric muscle action (Neal, 1991). Then when the muscle is stretched and undergoes a concentric muscle action, the stored elastic energy provides additional force for the action, suggesting that the stretch load placed on the muscle affects SSC performance (McEvoy & Newton, 1998) and additional stretch load yields higher power output (Carter, 2007). For example, when the thrower's arms are brought overhead, the abdominal area is prestretched, allowing for greater force production when the obliques are activated later during energy transfer from the lower body to the upper arm. SSC involves a neurophysiological adaptation, which means that the upper and lower extremities will response similarly to exercises focused on the SSC (Carter, 2007).

Grezios et al found that initial force, negative acceleration impact, and end velocity were strongly correlated to initial velocity (Grezios, 2006), suggesting that the preactivation increased by increasing the load. The muscle began recruiting additional muscle fibers before the end of the initial movement, storing elastic energy in the musculature to create the concentric muscle action. Thus the throw velocity was determined before the concentric muscle action took place (Grezios, 2006).

Strength and Conditioning Considerations

Research has shown that overhand throwing velocity can be increased in three ways: improving throwing biomechanics, resistance training, or both. While strength is crucial to controlling forces acting on each segment (Mero, 1994), biomechanics are crucial to fully utilizing the kinetic link to maximize speed and prevent injuries. The general consensus of strength and conditioning coaches for the overhand throwing athlete is that an overall total body resistance-training program should be employed (Jacobs, 1987; DeRenne, 2001). Overall total body general resistance training increases overall maximal strength of the utilized muscle by improving the contractile capabilities of those muscles (DeRenne, 2001). Improvements in strength are related to force production and power output (McGuigan, 2012) at the distal segments that generate momentum, giving the ball greater velocity. Strength of grip, forearm extension, arm extension, and trunk flexion have been found to have a moderate positive correlation to throwing velocity in water polo players (Bloomfield, 1990). Not all research shows that improvements in strength and power translate to sport-specific skills, such as throwing velocity (Bloomfield, 1990; McGuigan, 2012), but it is generally agreed that strength training creates better athletes overall. General resistance exercises are most often used for beginners and during the off-season.

Special resistance exercises may also be used to improve overhand throw velocity by converting general muscle strength into explosive power output (O'Keefe, 2007). Special resistance exercises are exercises that can be performed rapidly and with a high muscle output, such as explosive isotonic exercises (e.g. power cleans), ballistic resistance training, plyometric training, and isokinetics (DeRenne, 2001). These exercises manipulate the SSC by putting the body through repeated bouts of stretch-shortening activation (Wilk, 1993), leading to maximum power output in minimum time (Carter, 2007). Special resistance exercises are natural progression for strength programs and are usually used in conjunction with general resistance training to yield the best results in trained athletes (Carter, 2007). Once baseline strength is built up during the off-season, special resistance exercises can be added in during preseason practices.

It remains unclear if resistance exercises that are performed rapidly and explosively are more beneficial in power athletes, such as overhand throwers. Zaras et al found that shot put performance increased similarly in a general strength trained group and a ballistic power trained group, but through differing adaptations (Zaras, 2013). Increases in strength are established by hypertrophy and neural drive while speed increases are related to muscle fiber type expression and number of sarcomeres in series in a fiber (Ettema, 2008). The strength group saw significantly greater hypertrophy (muscle thickness and cross-sectional area) than the power group and saw a decrease in type IIx fibers, suggesting a change in motor-unit recruitment rate coding (Zaras, 2013), commonly observed in strength training. The power group saw an increase in the cross-sectional area of type IIx muscle fibers, which produce greater power than type IIa (Zaras, 2013), possibly resulting in greater power output at the muscle. Similarly, Cronin et al found that net ball velocity was increased similarly after velocity-specific strength training and general specific strength training (Cronin, 2001), presumably because the velocity reached during the bench press and seated row are not comparable. However, since throw velocity increased, regardless of true velocity-specificity, the authors argue that simply attempting to perform the motion explosively provides a sufficient training stimulus to improve velocity (Cronin, 2001).

Finally, sport-specific resistance training exercises follow the belief of many coaches that the "closer the velocity and movement pattern of the training exercise is to the active competitive sport skill, the greater the transfer of training gains to the athletic performance (DeRenne, 2001)." O'Keeffe et al found that practicing a fundamental overhand throw improved not only the fundamental throw, but also the javelin throw and badminton overhead clear, illustrating that learning effects can be transferred to similar activities (O'Keeffe, 2007). The researchers also showed that practicing a sport-specific skill, such as the javelin throw, improved performance in the javelin throw, but not in the badminton overhead clear, showing that specific skill learning results from practice of that skill (O'Keeffe, 2007). Sport-specific exercises are similar to the motion used in the sport, using the full range of motion of the competitive movement with a power output that is nearly identical to the sport. Sport-specific resistance exercises are believed to improve development of the sport skill through neuromotor specificity (Logan, 1966; DeRenne, 1985).

Research on sport-specific exercises has mixed results. Some researchers argue that the transfer between similar motor tasks is low and performing a sport skill with added resistance may alter the kinesiology of the athlete's movement, inhibiting performance (van den Tillaar, 2004; van den Tillaar and Ettema, 2011). Female handball throwers had altered elbow extension and internal shoulder rotation with ball weight changes. Maximal velocity of the elbow extension with a 20% overweight ball was significantly decreased when compared to the 20% underweight or regulation balls, and elbow extension occurred significantly earlier with the overweight ball, altering the timing of ball release. The maximal velocity of the internal rotation of the shoulder joint was also significantly decreased with the heavier ball compared to the lighter and regulation handball. With decreased elbow extension and internal shoulder rotation, the heavy ball release velocity was significantly slower than both regulation ball release velocity and light ball velocity (Van den Tillaar and Ettema, 2011).

Other researchers have found that adding resistance to a sport-specific throwing motion translates into improved throwing velocity. Ettema et al studied the effects of overhand throwing-specific heavy resistance training with a pulley and additional normal throwing training on overhand throwing velocity in handball players. The researchers found that the group that threw standard balls increased velocity significantly after training, but velocity was not significantly different between the two groups, suggesting that specific training was not superior to the actual sport motion (Ettema, 2008). This is likely because the coordination of the sport motion is more important than overall strength of the limb. Maddigan et al found that high-intensity interval training using Thera-bands in a maximum-effort throwing motion allowed softball players to reach a higher peak velocity and sustain ball velocity during a 20-throw endurance test (Maddigan, 2014).

The Baseball Pitch

Purpose

The main purpose of a baseball pitch is for maximum speed for a minimum travel time. A secondary goal of the pitch is precision (Indiana University, 2013). A pitcher's "velocity, consistency, and durability" may be linked to kinematic, kinetic, and temporal associations of the body segments and motions (Seroyer, 2010) and thus an understanding of the kinesiology of the pitch is crucial to building an optimal program to improve pitch velocity.

Phases of the Pitch

The six phases of the overhead throwing motion (Figure 1) used in baseball pitching are wind-up, stride (early arm cocking), (late) arm cocking, arm positive acceleration, arm negative acceleration, and follow-through (Fleisig, 1996). The wind-up begins when the pitcher begins the movement and concludes as the maximum height of the lead leg, with the pitcher's lead side facing the batter and the ball removed from the pitcher's glove (Pappas, 1985).

The next phase is the stride phase, which is defined as the time from maximal lead leg height to lead foot contact with the ground (Fleisig, 1996). During this phase the supporting leg flexes, lowering the body, while the pitcher's lead leg strides forward and downward towards the mound. The trunk rotates to result in a foot plant slightly towards third base for a right-handed pitcher (Seroyer, 2010). As the lower body is striding, the pitcher's hands concurrently separate and their arms swing down, separate, and then swing upward (Fleisig, 1996; Fleisig, 2010).

Once the lead foot makes ground contact in a full stride, the arm-cocking phase begins. The throwing arm is able to cock back as the pelvis, and then the upper trunk arch backwards (Dillman, 1993; Fleisig, 1994). The correct mechanics of this phase are crucial for ball velocity and will be discussed in further detail in the next section. This phase ends when the throwing shoulder is in maximum external rotation (MER), where the forearm is perpendicular to the truck and the palm of the hand is facing up (Fleisig, 1996).

Arm positive acceleration is initiated from the cocked position of the throwing arm and represents the time from shoulder maximum external rotation (MER) to ball release (REL) (Werner, 1993). During this phase elbow extension velocity increases and maximal shoulder internal rotation velocity is reached (Fleisig, 2010). The phase ends with ball release from the throwing hand and with the lead knee flexed and extending through ball release to slow down the forward motion of the pelvis and transfer energy into ball release (Pappas, 1985; Werner, 1993).

The arm negative acceleration phase is the time immediately following ball release where the throwing shoulder rotates internally and the forearm is horizontally adducted in front of the chest (Dillman, 1993; Fleisig, 2010). The trunk tilts forward as the lead knee continues to extend. The stance, or back, leg steps forward to regain balance and dissipate energy from the throw, concluding the phase, and the pitch (Pappas, 1985; Fleisig, 1996; Fleisig, 2010). Finally, the follow-through phase is the continuation of the arm and body's forward movement until the pitcher's arm stops moving and his body returns to a position of fielding (Seroyer, 2010).

Kinesiology of the Overhand Pitch

The action of the baseball pitch starts with the left foot and ends with the right hand (assuming a right-handed pitcher), and each segment of the body is activated in a proximal-to-distal sequence via the system previously discussed (Atwater, 1982; Alexander, 1982; Hong, 2000). The energy of the pitch originates in the gluteus maximus, quadriceps, and hamstrings while the abdomen and lower back transfer that energy to the upper body. As the trunk of the body begins to accelerate, the arm lags behind. Then as the trunk begins to negatively accelerate, the arm acquires the trunk's velocity (Kuklick, 2013). The velocity of the trunk, combined with the forces that act on the arm, allow the arm to accelerate to an even greater velocity. The motion of the arm in turn, generates the torque that applies force to the pitched ball, to send it toward home plate (Park, 2001).

The following section will explain in detail the forces exerted by each body segment on adjacent segments and the resultant torques about the joints of the shoulder, elbow, and wrist during the phases of the pitching motion. Also discussed will be the roles of specific muscles in the generation of these forces and torques that contribute to the motion of the overhand throw. In the following discussion, a right-handed pitcher is assumed and all kinetics and kinematics referred to are in the dominant pitching arm unless otherwise stated.

Electromyographic analysis of the body during the pitch provides insight into muscle activation during the phases of the pitch motion. EMG is correlated with muscle force for isometric muscle action but does not correlate well with muscle force as muscle action velocity increases or during muscular fatigue, both of which occur during the pitch (Escamilla, 2011). Muscle activity is provided as individual muscle activity, described as a relative percentage of the activity of that muscle during a maximal voluntary muscle action (MVC). During an MVC muscle activity would be 100% and during rest muscle activity is 0% (Jobe, 1984). For the purposes of this paper the following will represent muscle activity: 0-20% of MVC is considered low activity; 21-40% MVC is considered moderate muscle activity; 41-60% MVC is considered high muscle activity; and >60% of MVC is considered very high muscle activity (Escamilla, 2011). Finally, strength and conditioning principles to increase velocity related to the kinesiology of the pitch will be discussed.

Strength and Conditioning Considerations

The pitch is a powerful ballistic movement, and a movement that a starting pitcher may perform 120 times during one game (Cimino, 1987). Pitching is an anaerobic activity (Pottegier, 1992) as each pitch lasts approximately 1-2 seconds with about 18 seconds rest in between each pitch (Potteiger, 1992). Despite the high-intensity, intermittent nature of the pitching position, traditionally, pitchers have been trained in long, continuous running programs (Szymanski, 2009). Aerobically conditioned Major League Baseball (MLB) players did not have significantly different throwing velocity from MLB players who are trained in upper-body plyometrics (Kuklick, 2013). However, plyometric training did significantly increase arm power output. As many coaches agree, beneficial training programs are closely related to the sport skill, biomechanically and physiologically. For this reason, conditioning for pitchers should focus on maximizing the ability to generate power through high-intensity and explosive movements that are short in duration (Potteiger, 1992). Therefore, the focus of this discussion will be on explosive, anaerobic training, rather than aerobic conditioning.

A pitcher's goal is simply to pitch at a high velocity (Kuklick, 2013). This entails the ability to repeatedly generate power (Kuklick, 2013; Potteiger, 1989) through coordination of body movements to minimize loads on each segment and maximize force transferred through the kinetic chain to result in powerful, ballistic propulsion of the ball toward home plate (Kagayema, 2014; Seroyer, 2010). Pitching coaches should assist pitchers in ensuring consistent, correct pitching mechanics to allow for repeatedly throwing the ball at high velocity without injury while strength and conditioning staff should focus on strength development, force production, stability, balance, lateral quickness, and explosiveness (Clah, 2008) targeting the legs, trunk, and throwing arm (Toyoshima, 1976). Programs should be manipulated to maximize the kinetic chain and the transfer of forces from lower body extremities to upper body extremities to the ball during release (Jacobs, 1987).

Each pitch requires maximum explosive force (Cimino, 1987), and both speed and strength play integral roles. Most strength coaches agree that general resistance training yields positive results in pitch velocity via the force-velocity (Hill, 1938) relationship of muscles and movement (Ettema, 2008). This means that pitch velocity can be increased by overloading the muscle using resistance (Lachowetz, 1998) or by overloading the muscle using velocity of the exercise. Since the product of force and velocity is power (Tojo and Kaneko, 2004; Escamilla, 2011), then an increase in maximal force from training increases power capacity, independent of movement speed (Ettema, 2008; Tojo and Kaneko, 2004). Similarly, an increase in velocity from performing exercises at high velocity also increases power capacity, independent of movement force (Ettema, 2008). Thus, baseball coaches can utilize velocity-specific training, sport-specific training, or both, to attempt to improve a pitcher's velocity through increased muscle-power development.

Strength and conditioning practices can be utilized to increase pitch velocity by targeting different phases of the pitch. Overall total body general resistance training should be a staple in any pitcher's training regimen (Lachowetz, 1998). Since most of the body segments provide force that generates momentum in the throwing arm, the entire body must be trained to ensure there is no a weak link in the kinetic chain (Jacobs, 1987). General resistance programs that focus on the lower body are most beneficial during the stride and arm-cocking phases, where lower body plays a large role in the generation and transfer of momentum. Upper body exercises that target the muscles of the rotator cuff will contribute to throwing velocity (Lachowetz, 1988; Kane, 2003) at the arm-cocking, positive acceleration, and negative acceleration phases. A significant relationship between elbow extension strength, shoulder extension strength, shoulder flexion strength, and throwing speed has been found (Pedegana, 1982).

In baseball, plyometric training that primarily utilizes the lower body is a popular method for strength coaches to attempt to link strength and speed of movement. Ballistic resistance training that involves lifting light loads at a high-velocity, in an attempt to mimic the speed of the sport movement, has also been utilized in baseball players (McEvoy & Newton, 1998). The argument for velocity-specific training is that the velocity of the movement, not the load, develops explosive power. It is thought that velocity-specific training results in adaptations to the neuromuscular system that are more easily translated to the ballistic throw than training with heavy loads and slow velocity (McEvoy & Newton, 1998). McEvoy and Newton performed a study in which Major League Baseball (MLB) players who performed ballistic weight lifting improved throwing speed while those players who performed additional, normal baseball throwing and batting training did not (McEvoy & Newton, 1998).

Finally, sport-specific exercises have been shown to improve the baseball-specific muscle contributions of the proximal segments, resulting in a greater pitch velocity. In pitchers this means any exercise that imitates the pitching motion and can be completed with high velocity such as weighted baseballs, pulleys, surgical tubes, and Exer-genie cords (Logan, 1966; DeRenne, 1990; DeRenne, 1994; van den Tillaar and Ettema, 2011). Since these exercises put the arm through the entire range of motion of the pitching motion, they can improve velocity most during the arm-acceleration phase of the pitch, where the rotator cuff muscles that influence the shoulder joint are most active.

A pitcher's training program should include aspects of all three of these training properties. Pitchers should perform general total-body isotonic resistance exercises that achieve peak torque earlier in the ROM as well as specific upper-body exercise that achieve maximum overload near the end of the ROM (DeRenne, 2001). For this literature review, strength and conditioning as it focuses on each phase of the baseball pitch will be discussed.

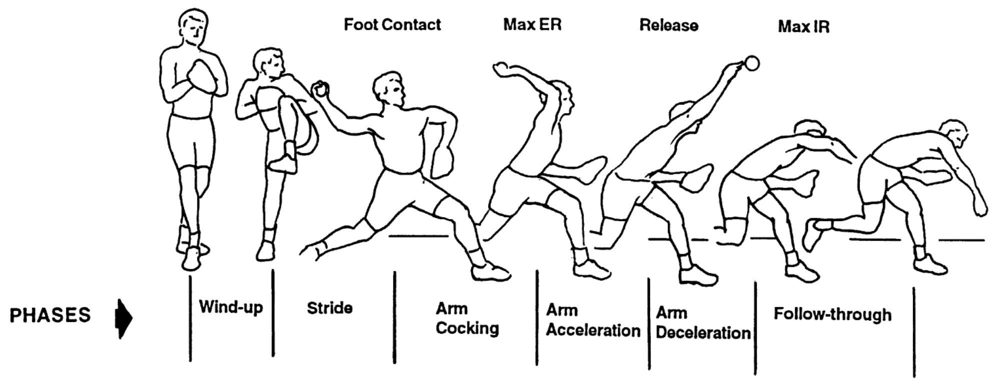


Figure 1: Phases of the overhand baseball pitch. The six phases of pitching. (Fleisig, 1996) The phases are broken down into: windup, stride, arm-cocking, arm positive acceleration, arm negative acceleration, and follow-through.

The Wind-Up

Although at first thought to be used as a mechanism of distracting the hitter and concealing the ball, the wind-up phase is essential as it puts the pitcher in an optimal position for all segments of the body to contribute to the pitch and establishes the rhythm for the pitch that will result in correct timing of succeeding steps (Pappas, 1985). The phase, which lasts between 500 milliseconds (ms) to 1 second (s), varies widely between pitchers (Pappas, 1985).

Kinematic Parameters

Simply put, the wind-up phase begins when the pitcher initiates the pitching motion and ends when he removes the ball from his glove while his lead leg is at maximum height. The pitcher begins on both feet with weight distributed evenly. The pivot, or stance foot, which is ipsilateral to the pitching arm (right foot for a right-handed pitcher), moves to be parallel to the rubber while the stride foot, contralateral to the pitching arm (left foot for a right-handed pitcher), pushes off the ground, shifting body weight onto the pivot foot (Pappas et al, 1985; Park et al, 2002).

The arms are brought in front of the body and the ball remains in the pitcher's glove while the trunk rotates 90° so the glove side contralateral to the pitching hand, faces the batter (Pappas et al, 1985; Park et al, 2002). Simultaneously, the stride leg elevates in front of the body, resulting in a balanced form toward home plate. At the instant of maximum stride knee height the upper torso is rotated -30° and the pelvis is rotated -36°(Stodden, 2001). At this time the pitcher removes the ball from his glove and the phase concludes.

Kinetic Parameters

As previously discussed, the pitching motion consists of a sequence of linked body movements that start with the lead foot and end with the right hand (Atwater, 1982; Alexander, 1982; Hong, 2000). During this phase, the most distal segments, the legs and trunk, are activated (Seroyer, 2010) as they produce mechanical energy through ground reaction forces (GRF). These GRF reflect body weight (BW) and are concentrated in the vertical axis and the path of the ball (MacWilliams, 1998; Elliot, 1988). The push-off limb, or the pivot leg, exhibits a gradual increase in GRF and peaks just before stride foot contact, with a maximum anterior-posterior shear of 0.35% BW (MacWilliams, 1998). The anterior-posterior shear push-off force results in a vector force of 1.0 BW in the direction of the pitch, which initiates the forward momentum of the upper body, allowing the trunk to rotate and drive over the stride foot after contact (Elliot, 1988). The greater the magnitude of the forward trunk tilt and rotation, the more kinetic energy there is in the direction of the pitch (MacWilliams, 1998).

Muscle Activation

While the lower body and trunk are activated during the wind-up phase, the forces and torques acting on the upper body are negligible during this time (Feltner and Depena, 1986). This phase is important for generation of large forces and velocity in the distal segment (arm) later on in the pitching motion. As there are few forces acting on the upper extremity during this phase, the activity of all upper extremity muscles was considered low (0-20% of MVC) during this phase (DiGiovine et al, 1992).

The legs and the trunk effectively serve as the main force generators of the kinetic chain (Seroyer, 2010) as they produce mechanical energy through ground reaction forces, and then later in the pitch sequence link the energy to the hips, pelvis, and trunk, and the upper arm. The stance leg supports the body mass while the stride leg is raised to maximum knee height during this phase. At maximum knee height this leg generates linear energy that propels the body forward during the stride (Crotin, 2015).

Strength and Conditioning Considerations

It is clear that the strength of the lower extremity muscles is of upmost importance for the pitcher and for the generation of force that will eventually affect the velocity of the pitched ball (Atwater, 1982; Alexander, 1982; Mero, 1994; Hong, 2000). The acceleration of the joints in the kinetic link needs to be great enough to produce inertial forces that are able to overcome the increased force of the next joint (Grezios, 2006). In order to increase the initial force, the initial movement speed must be as fast as possible. Ground reaction forces should be controlled and maximized (Grezios, 2006; MacWilliams, 1998) by the lower body to generate maximum initial force. Anteriorly directed GRF of the stride foot have been shown to contribute to overall ball speed (Kass, 2015). The strength of the lower body, specifically the pivot leg, will maximize GRFs and will enable weight transfer to the stride leg as the body moves forward (Elliot, 1984). The quadriceps, hamstrings, hip internal and external rotators should be targeted during strength and conditioning to ensure that enough power can be generated at the beginning of the pitch sequence. Lower-body resistance training, lower-body plyometric training (DeRenne, 2001), and complex training (Dodd, 2007), which is a combination of heavy resistance and high-velocity training, have all been shown to increase muscular power in the lower body, which will ideally lead to an increased initial force in the pitching sequence. Additionally, balance and pelvic strength are important components of a successful wind-up and should be considered by strength coaches (Milewski, 2012).

Stride (Early Arm-Cocking)

Kinematic Parameters

The stride phase begins when the pitcher is in maximal stride leg height and ends when the stride foot makes ground contact. During this phase the hip and knee of the pivot leg extend, lowering and moving forward the body's center of gravity (Pappas et al, 1985). Simultaneously the stride leg moves forward and downward towards the batter. The stride functions to increase the distance over which linear and angular trunk motions will occur to allow for increased energy production to be transferred to the upper limbs (Seroyer, 2010). Stride length needs to be long enough to stretch the body but not too long so that the legs and hips cannot rotate, which would reduce the energy contribution of the lower body to the pitching motion (Dillman et al., 1993). At the instant of foot contact, ideal stride length from ankle to ankle is approximately 85±6% of the pitcher's height and the lead knee is flexed 48±12°(Fleisig, 1999; Werner, 2001).

As the stride foot reaches forward, at first the trunk is kept back as far as possible to maximize its potential for rotation and contribution to the pitch (Dillman et al, 1993). As the stride leg extends toward the batter, the hip and knee of the pivot leg extend as well, pushing the body forward into the stride (Park et al, 2002). Greater pivot leg knee extension allows for increased rotation and forward motion of the trunk, resulting greater momentum transfer, leading to a greater pitch velocity (Kageyama, 2014). Then as the hips begin to rotate forward, the trunk rotates forward in the transverse plane to result in a foot plant slightly towards third base for a right-handed pitcher (Crontin, 2015; Feltner & Depena, 1986; Pappas, 1985). This slightly off-center plant allows the pelvis and trunk to maximally rotate prior to ball release.

As the lower body is striding, the pitcher's hands concurrently separate and their arms swing down, separate, and then swing upward. The coordination of the pitching arm and the striding leg is crucial to the throw. If this is executed properly, the arm will be in a semi-cocked position at stride foot contact (Dillman et al, 1993). The semi-cocked position occurs when the upper arm is adducted 14±9°, horizontally abducted 18±7°, and in a position of internal rotation 45± 44° for college pitchers (Feltner, 1989) and the elbow is flexed at about 96±18° for professional pitchers (Werner, 2001).

At the instant stride foot contact the upper arm is experiencing horizontal adduction angular acceleration. Shortly after contact, the upper arm begins to experience abduction angular acceleration and the distal segment is weakly angularly accelerated in the valgus direction (Feltner, 1989). After stride foot contact, body weight is transferred forward as the head and upper body are driven over the stride leg (Crotin, 2015). Pitchers are either in neutral or slightly leaning toward the pitching arm at stride foot contract and as the pitch progresses; they lean away from the pitching arm (Solomito, 2015).

Kinetic Parameters

Kinetics in the upper body begin to increase during the stride phase and at the instant of stride foot contact. As the shoulder is abducted the adduction/abduction torque decreased rapidly after stride foot contact, indicating a directional change, to a peak abduction value of 117±34 Nm in professional pitchers (Werner, 2001). Then as the shoulder adducts through the following phases, this torque increases. Similarly, the shoulder external/internal rotation torque decreased rapidly after stride foot contact as the shoulder begins to externally rotate (Werner, 2001).

There is a strong linear relationship between the GFR in the ball direction during this phase and pitch velocity (r^2=0.82) (MacWilliams; Kageyama, 2014) as the force from the ground is transferred to the pivot foot and then to the pivot leg. The hip and knee torques that are generated in the pivot leg during this phase increase the inertial forces of the body as it moves forward, increasing hip adduction torque of the stride leg at stride foot contact (Kageyama, 2014).

After foot contact, a vertical anterior shear in the stride foot begins to increase gradually, anchoring the body, and peaks just before ball release (MacWilliams, 2008). This landing force acts as a brake to slow the motions of the lower limb (MacWilliams, 2008), preventing overextension of the stride knee or hip. It also allows the momentum generated in the stride foot push-off to be dissipated into rotational components (MacWilliams; Stodden, 2001) that are transformed into kinetic energy later in the pitch (Mastsuo, 2006; Stodden, 2001).

Muscle Activity

The trapezius and serratus anterior are moderately active during this phase as they position the glenoid to provide stability for the abducting arm in the early cocked position. They form a force couple to upwardly rotate and protract the scapula (DiGiovine, 1992), allowing the middle deltoid to reach peak activity as it generates most of the force of abduction. While the middle deltoid assists the arm in abduction, the supraspinatus, which inserts closer to the joint axis than the deltoid, abducts the humeral head, positioning it into the glenoid (Park, 2002) using a compressive force to stabilize the joint. The deltoid and supraspinatus work in synergism, with the deltoid functioning as a driver, positioning the arm in space, while the supraspinatus steers, carefully positioning the humeral head into the glenoid (DiGiovine, 1992). The extensor carpi radialis longus and the extensor carpi radialis brevis were also highly activated during this phase as the wrist was moved from slight flexion to extension as the arm abducts (DiGiovine, 1992).

Just before foot strike, as the trunk and hips rotate toward the batter, the left external oblique becomes activated, presumably to oppose the upper torso from rotating with the trunk and hips (Hirashima, 2002). As the left oblique assists in preventing the upper trunk rotation, the upper trunk muscles would become stretched, assisting in force generation via stored elastic energy in the upper trunk that could be transferred to the upper arm. The hip adductors are also activated during this phase (Clayton). At foot strike the stance leg gluteus maximus fires to maintain dominant-sided extension and to provide pelvic and trunk stabilization (Seroyer, 2010). The rectus femoris of the stride leg has shown to be contracted in javelin throwers. First, it lengthens as the stride leg extends and then it concentrically contracts as the trunk tilts forward and the hips flex (Kageyama, 2014).

Almost at the moment of foot strike, the right external oblique activates, nearly at the same time as the serratus anterior at the eighth rib becomes active (228.1±80.4ms) and before the serratus anterior at the sixth rib becomes active. Since the right external oblique is a trunk muscle (proximal) and the serratus anterior is a upper arm muscle (distal) and both are activated at the same time, rather than the proximal and then the distal being activated, this is an example of two muscles that do not seem to follow a proximal-to-distal sequence (Hirashima, 2002). During this phase the obliques, hip adductors, and gluteals of the stance leg offer single-leg support, and pelvic stabilization and core stabilization (Clayton, 2011).

The goals of the stride phase are to provide a stable base for the trunk and core musculature to rotate and flex (Seroyer, 2010) and to transfer energy through the trunk to the upper extremities (Matsuo, 2006). The lower body provides power behind the pitch while trunk rotation allows for energy transfer to shoulder and elbow (Milewski, 2012). A stable pivot leg allows generation of momentum in the stride foot during the stride, and that energy is transferred to the leg and trunk upon stride foot contact (Crotin, 2015), and then is transferred to the pitching arm (Solomito, 2015; Seroyer, 2010).

Strength and Conditioning Considerations

An increase in explosive upper-body power in baseball players has been shown to result from an increase in overall muscle mass rather than isolated upper-body musculature (Myers, 2005), signifying the importance of the body as a whole during the pitching motion. This phase illustrates the importantance of the lower body and trunk contributions to the overhand pitch sequence. Pitchers with higher ball velocity have greater velocity in the pelvis and upper torso during the pitching motion (Kageyama, 2014; Stodden, 2001) and 90% of the work needed to achieve high ball velocity is generated at the hips (Roach, 2014). This is likely due to the energy generated by the hip rotators in the wind-up and stride phases that powers torso rotation (Roach, 2014), which passively stores elastic energy at the shoulder (Wilk, 1993) during arm-cocking and may shorten the temporal variables of positive acceleration, thereby increasing overall ball velocity (Dun, 2008). In fact, stride phase variables such as lead knee flexion and forward trunk tilt are correlated with increased pitch velocity (Seroyer, 2010). Additionally, well-trained trunk muscles may decrease the force demanded by the shoulder and elbow joints to produce high ball velocity (Stodden, 2008). Therefore, the goal of a pitcher's strength and conditioning program in regards to the stride phase should be to maximize the contribution of the lower limbs during the pitching sequence by focusing on lower extremity strength and power, trunk stability, and torso-rotation strength (Stodden, 2008; Szymanski, 2007).

Muscular endurance training of the proximal stabilizers does not improve explosive muscular power as is required for the pitcher (Palmer, 2015; DeRenne, 2001) but does provide stability at the spine in anticipation of movement. Therefore it seems that strength and power training, rather than endurance training, is warranted for power sport-skills, such as pitching (Palmer, 2015). Palmer et al found that multiplanar, heavy resistance training resulted in improved strength and power capabilities of the muscles that support the proximal segment. These strength improvements translated into improved throwing velocity, suggesting that the training the lower body musculature affects the power of the upper body in throwing (Palmer, 2015). Thus, ballistic training and power exercises that target muscles the muscles that support pelvis and trunk may be more appropriate than the traditional lower body endurance activities for pitchers (Palmer, 2015; Potteiger, 1992).

Increased leg strength can contribute to increased torque around the hips and torso as they rotate during the stride (Szymanski, 2007). Gluteal maximus and gluteal medius exercises should be used to provide a platform for the pelvis to transfer energy to the core (Grezios, 2006) during the outward hip rotation and extension of the stride leg (Jacobs, 1987). Simple resistance exercises, such as the lunge, side lunge, and Russian hops (Jacobs, 1987), simulate the forward driving motion of the stride leg and the static, isometric muscle action of the pivot leg during this phase while the leg press and leg extensions stress the hip and knee extensor muscles utilized during the stride (Jacobs, 1987).

Adding speed to these lower-body exercises may further elicit power and velocity improvements. Plyometric exercises focusing on the lower body have been correlated to high throwing velocity (Lehman, 2013). Unilateral jumps in the frontal plane mimic the action of the stride and lateral to medial jumps exhibit a specificity to power in a specific direction and plane of movement, similar to the pivot leg in the pitching stride (Lehman, 2013). Thus, plyometric exercises such as depth jumps, box jumps, and squat jumps should be included in a pitcher's strength program. Additionally, traditional squats, lunges, and the leg press are revered as staple exercises in MLB pitchers (Ebben, 2005). Szymanski et al recommends that the concentric portion of the lift be performed explosively to mimic the high-velocity, powerful movement of the pitch (Szymanski, 2007), resulting in velocity-specific training effects (McEvoy & Newton, 1998).

The next link to be activated in the pitching motion is the trunk, which becomes active during the stride phase, and begins to transfer forces from the lower body to the upper body through rotation and flexion (Stodden, 2001). A higher trunk tilt translates into greater energy generation for ball release (van den Tilllaar and Ettema, 2011). Trunk exercises for pitchers should focus on promoting range of motion, rotational velocity, and explosiveness (Stodden, 2008; Jacobs, 1987). Rotational torso and core exercises should be performed to provide a stable core and efficient torso-rotation strength and should be performed on both sides of the body to provide balanced strength and power development (Szymanski, 2007). Clayton et al found that the Backwards Overhead Medicine Ball (BOMB) throw was significantly related to all measures of isokinetic core strength in collegiate baseball players and the BOMB throw was also strongly correlated with trunk flexion (r=0.680) (Clayton, 2011). Trunk flexion is also significantly related with body weight (r=0.614), percent body fat (r=0.555), and lean weight (r=0.630) (Clayton, 2011). Szymanski et al observed significant increases in rotational torso strength in high school pitchers who participated in normal baseball practice and resistance training, and attributed this to the rotational movement of swinging a normal baseball bat (Szymanski, 2007). Szymanski also found that pitchers who performed rotational medicine ball exercises and full body medicine ball throwing in addition to normal practice and training, had significantly greater increases in rotational torso strength than the players who only completed normal training (Szymanski, 2007). Since pitchers may be less likely to bat during games or practice batting during practice, it is important that rotational torso exercises are a part of their training regimen.

Stodden et al found that exercises designed to enhance trunk rotational velocity specific to throwing did not allow for maximum rotation and provided less than 50% of maximum upper torso angular velocities exhibited in throwing (Stodden, 2008). Exercises such as medicine ball throws, cross-overs, twisters, and seated band rotations, mimic the range of motion of the trunk during the throw but not the velocity, suggesting that these exercises are appropriate to improve ROM and stability, but not power (Stodden, 2008). Explosive trunk rotation exercises, such as Russian twists with a partner or explosive medicine ball throws, could be used to enhance trunk rotational velocity (Stodden, 2008).

Arm-Cocking

Kinematic Parameters

As previously discussed, the arm cocking phase, which lasts approximately 60 ms in professional pitchers (Pappas et al, 1985), is essential to arm acceleration and ball velocity because the external rotation of the shoulder influences the acceleration of the arm and hand forward in the next phase. Immediately after stride foot contact, the stance knee and hip continue to extend as the trunk begins to move laterally toward the catcher and hip rotation is initiated, followed by trunk rotation, and upper torso rotation while the arm remains behind the line of the shoulder (Seroyer, 2010; Pappas et al, 1985). It is during this phase that maximum pelvis angular velocity (670°±90°/sec) and maximum upper torso angular velocity (1190°±100°/sec) are achieved (Fleisig, 1991; Fleisig, 1996; Fleisig, 2011).

As the trunk begins to negatively accelerate, the throwing arm begins to accelerate forward (Pappas et al, 1985). The shoulder is brought forward of the trunk and assumes a position of 90-100° horizontal abduction and remains in this position until ball release. The elbow is flexed and this also remains constant until shortly before the arm reaches MER, when the elbow begins to extend from 85° to 20° near the time of ball release (Werner et al, 1993).

As the upper trunk begins to rotate counterclockwise, it contributes to the inertial velocity of the upper arm, allowing it to begin to rotate counterclockwise to the ground (Feltner, 1989). The shoulder continues to rotate externally during the first 80% of the arm cocking phase, increasing to up to 178° of external rotation (Dillman, 1993; Werner, 2001). When the shoulder is in maximal external rotation, and the forearm is perpendicular to the trunk and palm of the hand is supine, the arm-cocking phase ends (Fleisig, 1991; Fleisig, 1996; Fleisig, 2011). This dynamic degree of external rotation at the shoulder “allows the pitcher to apply an accelerating force to the ball over the greatest possible distance” during the acceleration phase (Park, 2002).

During this phase, from stride foot contact to maximal external shoulder rotation, the stride leg negatively accelerates and energy is transferred to rotation of pelvis and trunk (Crotin, 2015; Seroyer, 2010). As the trunk rotates, the horizontal adduction muscles activate and maintain adduction angular acceleration (82±13 Nm) of the upper arm by applying an anterior force of about 310 Nm and an internal rotation torque of about 54 Nm (Feltner, 1989; Fleisig, 1996; Park, 2002). This force and torque stabilize the glenohumeral joint during the valgus angular acceleration of the elbow (82 ±13 Nm), which allows the upper arm to continue to externally rotate.

Kinetic Parameters

At the point of MER, the vertical GRF and braking GRF reach their peak at 1.10 BW and 0.55 BW, respectively (Elliot, 1984), creating a resultant vector of 0.78 in the direction of the ball (MacWilliams, 1998). These forces then gradually diminish during the rest of the pitch sequence.

At the elbow, the internal rotation torque creates tension in the medial aspect of the joint and compressive forces in the later aspect of the joint and these forces combine to exert a varus torque on the forearm. The varus torque has a peak value of about 120 Nm right before MER and this also contributes to the external rotation angular acceleration of the distal segment (Felter, 1989). Additionally, the varus torque seeks to prevent hyperextension at the elbow (Werner et al, 1993).

The resultant force acting on the long axis of the upper arm and representing shoulder distraction remains low at the beginning of this phase and increases at the instant of MER, when shoulder distraction at the glenohumeral joint reaches a mean of 63±22% of body weight (Werner, 2001). The position of the shoulder at MER and the external rotation torque are two of the main factors that affect shoulder distraction. Increased external rotation torque and the greater the degree of external rotation, the greater the magnitude of shoulder distraction will be (Werner, 2001). The rotator cuff muscles provide a compressive force of 550-770 N to resist shoulder distraction causes by the torque of the rotating upper torso (Seroyer, 2010).

Muscle Activity

The supraspinatus remains active but is less active than it was during the stride phase. The arm is no longer increasing its level of elevation during this phase but simply maintaining it, requiring less activation of the supraspinatus (DiGiovine, 1992). Horizontal abduction is maintained by the humerus, which was being actively rotated by the infaspinatus and teres minor. The middle trapezius, rhomboids, and levator scapulae retract the scapula while the serratus anterior opposes the scapular retractors. This force couple tips the scapula, provides a positioned and stable glenoid against which the humeral head externally rotates (Park, 2002; DiGiovine, 1992; Jobe, 1984), as well as sufficient subacromial space for the humerus without impingement of the tendons (Dillman, 1993; Werner, 2001). At the moment of MER, the pectoralis major and latissimus dorsi become active and provide stability to the anterior glenohumeral joint while the deltoids become less active as the humerus concludes abduction.

The biceps, which are moderately active during this phase, oppose elbow extension, which can be seen during initial shoulder rotation immediately after foot contact, when the biceps contract to prevent the centrifugal force of the shoulder rotation from swinging the forearm away from the body (Werner et al, 1993). The biceps induce a shear force that alleviates the strain on the glenohumeral joint during MER by opposing the superior compressive force from the upper subscapularis that is compressing the humerus into the glenoid (DiGiovine, 1992). The triceps begin to activate at the end of the cocking phase when the elbow is most flexed. They apply a varus torque to the forearm that prevents hyperextension (Werner, 1993).

Finally, all of the wrist and finger muscles demonstrated high or very activity during this phase (DiGiovine, 1992). Passive varus torque may be provided by the ulnar collateral ligament (UCL), however the UCL does not solely contribute to active varus torque. Instead, the wrist flexor-pronator group contracts to contribute to the active varus torque, which stabilizes the elbow and opposes the valgus force caused by the rapid internal rotation of the humerus during arm cocking (Feltner & Dapena, 1989; Fleisig, 1995). The muscle action of wrist and finger muscles provides a stable ball from which to throw the ball (DiGiovine, 1992).

Strength and Conditioning Considerations

As the external rotators are concentrically contracting during arm-cocking, there is a relationship between external rotator strength and throwing velocity (Wang, 1995). Wooden et al found that isotonic and isokinetic resistance training both increased peak external rotation torque as a ratio of body weight compared to the control group while only isotonic resistance training significantly increased throwing velocity (Wooden, 1992). Unlike isokinetic exercises in which speed is fixed, isotonic resistance exercises change resistance to match the motor performance curve (Wooden, 1992), meaning the limb can accelerate at any point throughout the ROM according to the effort of the pitcher. Isotonic exercises allow the pitcher to accelerate according to their abilities, rather than a set pace. Since isokinetic devices only allow maximum velocities of 500°/sec and during the pitch the shoulder joint accelerates more than 6,000°/sec, isokinetic training may limit limb acceleration and improvement in torque production (Wooden, 1992).

To avoid impingement in the subacromial space during humeral abduction, which would decrease external rotation, the scapula needs to be elevated and upwardly rotated (Seroyer, 2010), a task that is completed by the rotator cuff and upper back muscles. For this reason, special attention should be paid to the strength and stability of the rotator cuff (Carter, 2007). The Ballistic Six upper extremity plyometric exercises are functional exercises originally designed to simulate movements, positions, and forces of the overhead throwing motion to rehabilitate the overhand throwing athlete, but have since been used in an attempt to strengthen the lengthening action of the rotator cuff muscle and improve pitch velocity. The Ballistic Six include: Thera-band latex tubing external rotation, latex tubing 90/90 external rotation, overhead soccer throw using 6-lb medicine ball, 90/90 external rotation side-throw using a 2-lb medicine ball, negative acceleration baseball throw using a 2-lb medicine ball, and a baseball throw using a 2-lb medicine ball (Carter, 2007). Performing the Ballistic Six in addition to regular baseball conditioning has been shown to improve throwing velocity significantly more than regular, isotonic exercises performed slowly (Carter, 2007), however these exercises do not seem to increase isokinetic strength. Thus it is likely that the muscle action and joint velocities reached during the Ballistic Six are more readily transferrable to the overhand throw than the slow, isotonic exercises.

Arm-Positive Acceleration

The acceleration phase, which occurs immediately prior to ball release, is one of the most explosive motions recorded in sport. The phase lasts about 50 milliseconds and accounts for just 2% of the time for the pitching sequence and yet the ball is accelerated from a stationary position in the pitcher’s hand to more than 90 miles per hour (Pappas, 1985). Unlike the wind-up phase, the mechanics of this phase are very consistent among pitchers (Stodden, 2006).

Kinematic Parameters

Acceleration is initiated from the cocked arm position, where the shoulder is in MER, and continues until ball release (Werner et al, 1993). During the arm-cocking phase, the trunk rotates to move the arm forward in relation to the trunk. Immediately prior to ball release, the arm moves backward in a horizontally abducted direction as the humerus rapidly internally rotates around the shoulder. The shoulder continues to internally rotate until ball release, creating the large internal angular velocity (9,940°/sec ±1080°/sec) that is essential for pitch velocity and is the fastest joint rotation in any sport (Feltner and Depena, 1986; Dillman 1993; Fleisig, 1996). As the shoulder internally rotates, the elbow extends at a peak angular velocity of about 2300°/sec in college pitchers (Feltner, 1989) and up to 2500°/sec in elite professional pitchers (Werner, 2001). These powerful and explosive movements occur about 5 ms prior to ball release (Pappas, 1985).

The positive acceleration phase ends with ball release from the throwing hand, where the lead knee is flexed 40° and extends through ball release to negatively accelerate the forward motion of the pelvis and transfer energy into ball release (Dillman, 1993). At the instant of ball release, the arm is 0° abducted, the elbow is flexed 22°, and the shoulder is horizontally adducted 7°. The arm appears perpendicular to the body but it is actually 10-15° behind the trunk line as the trunk is flexed forward 58° and sideways 124° while the lead knee continues to extend (Dillman, 1993; Fleisig, 1996a).

Through the theory of transfer of momentum, the proximal segment must decrease velocity in order for the distal segment to increase velocity (Atwater, 1982). Thus, wrist and hand velocities should be expected to decrease just before ball release (Wang, 1995).

Kinetic Parameters

After MER, the elbow begins a varus rotation torque that is supported by the horizontal abduction and adduction angular accelerations of the upper arm, as well as the internal rotation joint torque at the shoulder and upper arm (Fleisig, 1996a). This motion is associated with the varus proximal joint torque that is exerted on the upper arm. Shoulder internal rotation was aided by elbow extension (Werner, 2001), which decreased the moment of inertia of the distal segment and favored a larger angular acceleration (Feltner & Dapena, 1986; Fleisig, 1995). Ball velocity release time and time in the acceleration phase are related in that it is thought that once the shoulder reaches MER, ball velocity can be increased by speeding up the internal rotation of the shoulder (Wang, 1995).

At ball release, as the energy from the throw is dispersed throughout the throwing arm, a distraction force of 96±19% of body weight acts on the shoulder joint and the upper arm, attempting to pull the arm away from the glenohumeral joint, putting stress on the rotator cuff muscles (Werner, 2001). A proximal flexor joint torque is exerted on the distal segment to reduce this shoulder distraction (Fleisig, 2011). This torque, along with a decrease in magnitude of centripetal acceleration of the pitching shoulder, and decreasing values of adduction and horizontal abduction angular accelerations, contributes to elbow flexion.

Muscle Activation

The very large angular velocities seen during this phase can be attributed to the sequential muscle activation through the previous three phases of the pitch. As the upper arm lags behind the upper trunk, the agonist muscles are stretched; creating elastic energy that can be converted to the proximal segment's velocity (Alexander, 1982). The transfer of energy from the trunk is amplified by the latissimus dorsi and the pectoralis major, the main upper extremity muscles that actively contribute to ball velocity (DiGiovine, 1992).

It is thought that the pectoralis major and latisssimus dorsi initiate positive acceleration by acting on the humerus to produce internal rotation (Jobe, 1984), and as humeral adduction and internal rotation reach high values, as they do during positive acceleration, the pectoralis major contracts, making it highly active (54% of MVC) during this phase. Meanwhile the latissimus dorsi, which is anatomically positioned to generate greater torque than the pectoralis major, has very high activity (88%) during acceleration (DiGiovine, 1992; Jobe, 1984). These two muscles not only assist in thrusting the throwing arm forward, but also assist the subscapularis in steering the humeral head into the glenoid (Jobe, 1984).

The major activation of the serratus anterior occurs during this phase as the scapula is moved laterally and rotated downward by the large torque associated with high angular velocity shoulder internal rotation (Park, 2002). The activation of the serratus anterior remains high through the follow-through phase. The teres minor restrains and posteriorly stabilizes the scapula to limit the humeral head translation when the humerus is abducted or extended, as it is at the beginning of acceleration.

The longer the forearm velocity is delayed, the more the forearm and hand "trail" the upper arm, causing a greater stretch in the agonist muscles of the upper arm, which transfers stored elastic energy to the forearm (Alexander, 1982). This forearm lag, along with the shoulder abduction and horizontal adduction musculature leads to maximum external rotation of the shoulder (Feltner & Depena, 1986). The subscapularis remains similarly activated as during the arm-cocking phase to maintain glenohumeral stability as the humerus continues to rapidly internally rotate. The posterior deltoid is optimally positioned to be the primary humeral horizontal abductor and again works synergistically with the supraspinatus (DiGiovine, 1992). The biceps are also moderately active as they also play a role in elbow stabilization and in resisting shoulder distraction at the glenohumeral joint (Jobe, 1984; Fleisig, 2011).

The major players in arm positive acceleration are the triceps, whose action increases after the arm-cocking phase in conjunction with the rapidly extending elbow (Hirashima, 2002) and continues until ½ second after ball release (DiGiovine, 1992). The triceps maintain elbow position, providing the optimal moment arm needed to propel the ball. The initial muscle action of the triceps opposes elbow extension and then forward momentum of the forearm extends the elbow (Werner, 1993). The torque generated by the rotating trunk and arm at the end of the late-cocking phase exerts a centripetal force on the inertia of the forearm, hand, and ball, and the triceps resist this centripetal flexion torque at the elbow (DiGiovine, 1992). The long and lateral triceps heads have similar action patterns, however the long head is active for a longer period of time. When the triceps are paralyzed, the arm does not internally rotate, likely due to hyperextension of the elbow, and pitch velocity is significantly reduced (Roberts, 1971), however the triceps cannot act alone and thus the rotator cuff muscles, mainly the pectoralis major and the latissismus dorsi, are also involved in arm acceleration as described above.

The pronator teres, flexor carpi radialis, flexor digitorum superficialis, and flexor carpi ulnaris all exhibit very high activity during arm positive acceleration. As they all originate on the medial epicondyle of the elbow, their shared site of origin provides a way to dynamically assist with medial joint stabilization against the valgus stress caused by rapid internal rotation of the humerus. Finally, the extensor capri radialis brevis was responsible for the slight extension of the wrist to a more neutral position just prior to ball release (DiGiovine, 1992).

Strength and Conditioning Considerations

Elbow extension velocity begins as arm acceleration is initiated from a cocked position and the timing of maximal elbow extension velocity can affect ball release velocity (van den Tillaar and Ettema, 2011). Kaneko et al found that maximum power development of the elbow flexors occurred from training at a load of 30% maximal isometric strength (Kaneko, 1983) and in a later study, found that both concentric and isometric muscle actions were equally effective at increasing maximal isometric strength as well as velocity (Kaneko and Toji, 1983). Pitchers can train with different loads using weighted implement training, which is pitching with balls that are either heavier or lighter than a regulation baseball. Weighted implement training is thought to be specific to the overhand throw motion, as well as velocity-specific (Morimoto, 2003), and can improve power output and increase velocity (Kaneko, 1983). However, similar to other overhand throwing sports, weighted implement training in baseball has been studied with mixed results and the weight, duration, and number of pitches required for maximal performance enhancement is yet to be found. For the purpose of this discussion, final pitch velocity is in regulation baseballs (5 oz), unless otherwise stated.

<u>Ball Weight</u>

Pitching with lighter balls allows a pitcher to throw with supramaximal speed, which would be impossible with a regulation ball while pitching (Morimoto, 2003). Throwing using heavier balls involves slowing the velocity of the muscle action and overloading the muscles involved in the pitch so greater force is required from the muscles involved in the specific movement of the pitch (van den Tillaar, 2004), resulting in greater power output while lighter balls require less force to reach high velocities (van den Tillaar, 2004). The first weighted implement studies were conducted in Soviet shot put throwers, which found that the most effective force was developed in weights that were no more than 20% different from the regulation weights (Vasiliev, 1981), which is 4 oz and 6 oz for a baseball pitcher.

Despite Vasiliev's work, the earliest studies conducted in baseball pitchers used balls more than twice the weight of a regulation ball. Pollock trained high school pitchers with either a regulation ball or an 11 oz weighted baseball in additional to a regulation ball. The weight ball group progressively increased the amount of pitches thrown with the weighted baseball. For example, the first week they threw the weight ball for five minutes and the regulation ball for fifteen minutes until eventually throwing with the weighted ball for the full twenty-minute warm-up. Pollock found the group that utilized the weighted baseball significantly increased velocity over ten weeks while those using the regulation balls did not (Pollock, 1975). Straub et al employed a progressive resistance program where throwers began using 7 oz balls during the first week and ball weight increased by 2 oz each week until the last week when 17 oz balls were being used. The progressive resistance group did not improve velocity more than the control group, who practiced with regulation balls, but found large intra-group variability (Straub, 1966). Litwhiler's progressive resistance training program with the heaviest ball being 12 ounces saw increased pitch velocity in collegiate pitchers (Litwhiler, 1973). However, heavier loads may not be required since a modest 20% overload (5 oz) has been shown to significantly increase pitch velocity after ten weeks of training (DeRenne, 1985). Lightweight balls (4.4 oz) have been shown to significantly increase regulation ball pitch velocity in adolescent pitchers while pitchers who trained with regulation weight balls did not change velocity after ten weeks of training (Yang, 2013). Four-ounce balls have also improved pitch velocity after ten weeks of training (DeRenne, 1985).

Based on research on variable speed training in track and field athletes (Vasiliev, 1981), DeRenne et al conducted a study in baseball pitchers that sought to find overweight and underweight baseballs that were effective in improving pitch velocity without altering the pitcher's normal throwing motion or injuring their throwing arm. To do this, they had collegiate baseball pitchers practice with either a modest 20% overload ball (6 oz) or a 20% lightweight ball (4 oz) for ten weeks. During underweight or overweight bullpens, pitchers concentrated on normal wind-up and deliver with an exaggerated hand wrist snap. The researchers found that both groups significantly improved pitch velocity (DeRenne, 1985) and concluded that weighted implements should be as close in size and weight to the regulation ball as possible while still improving performance. From this study and the research that followed, we can conclude that weighted balls that are 20% heavier or higher than regulation balls are sufficient to improve pitch speed while maintaining the thrower's normal throwing mechanics (DeRenne, 1985; DeRenne, 1990; DeRenne, 1994; van den Tillaar, 2011).

Overweight vs. Underweight

In 1990, DeRenne compared the effects of overweight implement training to underweight implement training in thirty high school pitchers. The pitchers were split into three groups that pitched three sessions a week and threw 50 pitches per session using overweight balls, underweight balls, or standard baseballs for ten weeks. The underweight and overweight groups progressively decreased or increased ball weight by ¼ an ounce biweekly, resulting in a final ball weight that was either 20% underweight (4 oz) compared to a standard baseball, or 20% overweight (6 oz), respectively. The intervention groups pitched in a 2:2:1 ratio of standard (20 pitches) to weighted (20 pitches) to standard pitches (10 pitches), for a total of 50 pitches per session. The control group threw 50 pitches with a regulation ball each session. Both the overweight and underweight implement training groups significantly increased pitch velocity compared to the control group, and there were not significant differences between the overweight and underweight groups (DeRenne, 1990).

Overload warm-up, rather than training, has also been studied with mixed results. Warming-up with ten ounce or fifteen ounce balls had no effect on throw velocity of regulation baseballs in teenager pitchers (Straub, 1966) however; balls that were lighter in weight to regulation baseballs did improve velocity (Morimoto, 2003). Morimoto et al used regulation baseballs, 10% lighter balls, 10% heavier balls, or both heavier and lighter balls for a warm-up prior to velocity testing. Participants did eight training sessions of six or eighteen pitches with a weighted implement and then immediately did velocity trials with regulation balls. Mean maximal pitch velocity was significantly higher after training with six light pitches, eighteen light pitches, and a combination of heavy, regular, and then light balls than any other condition (Morimoto, 2003). The results of this study suggest a dose-response relationship between the number of pitches with the light ball and the degree of effect of pitch speed. Additionally the authors found that there were not immediate effects on pitch speed seen with the heavier ball, regardless of pitch count, however pitchers may have the illusion of increased speed once they use a standard ball after using a weighted one. This finding is consistent with other studies that have not found an increase in speed of sport motion after an overload warm-up (Van Huss, 1962).

Combination Training

While pitching with heavier balls increases strength, pitching with lighter balls trains the arm for greater speed, while reducing the likelihood of injury (Yang, 2013) from increased resistance (van den Tillaar, 2011). It appears that combining overweight ball training with underweight ball training has a synergistic effect on pitch velocity, resulting in improved speed-strength (DeRenne, 1994; Morimoto, 2003). Five weeks of pitching with overweight (6 oz) and regulation balls followed by five weeks of pitching with underweight (4 oz) and regulation balls significantly increased pitch velocity in high-school and college pitchers compared to the control group pitchers that threw with only regulation weight balls. However, the weighted implement group did not significantly improve pitch velocity over the weight-training group (DeRenne, 1994).

Powe et al. provided three professional minor-league baseball players a six-week individualized throwing program that utilized both overweight and underweight balls. Each of the pitcher's programs detailed when they would throw, how long they would throw, what distance they would throw, which weighted ball they would throw, and how much rest they were to take (Powe, 2011). All pitchers significant increased their pitch velocity over the course of the training program. Pitcher A increased velocity by 3mph, pitcher B by 4-8 mph, and pitcher C by 3-5 mph (2011). It is important to note that pitcher B was a relief pitcher with an average of 50 pitches per game prior to the throwing program while pitchers A and C were a starter and a closer, respectively. Pitchers, especially those playing at a high-level, have been shown to have variations in response to a weighted program (Straub, 1966), and this study shows that different types of pitchers may respond differently to a weighted program, based on their usual position and bullpen routine. Individualized throwing programs utilizing both overload and underload balls and customized pitch counts may be the ideal way to train pitchers.

Ratio

A 2:1 ratio of weighted ball pitches to regulation ball pitches has been demonstrated to be most effective at increasing throwing velocity (Vasiliev, 1981; DeRenne, 1994). When using a combination of light and heavy balls, it appears a 2:1:1 ratio results in the most significant improvements in pitch speed (DeRenne, 1990).

Duration

Straub et al did not see significant changes in pitch velocity after three or six weeks (Straub, 1966), while Brose and Hanson saw significant increases after six weeks, but this research was done in a combination of pitchers and position players (Brose and Hanson, 1966). Other researchers have described significant changes after ten weeks (Pollock, 1975; DeRenne, 1994; Yang, 2013). It is possible that training effects cannot be seen after a shorter period of time. However, Litwiler and Hamm found significant increases in pitch velocity every two weeks during a twelve-week program (Litwhiler & Hamm, 1973). Although further research is needed in this area in baseball pitchers, ten weeks is the most frequently used time period for successful weighted implement training (Vasiliev, 1981; DeRenne, 1985; DeRenne, 1994; Yang, 2013).

Possible Issues

Some researchers argue that use of overweight or underweight balls changes the biomechanical motion of the pitch, which may leave the pitcher susceptible to injury. Brose and Hanson had pitchers throw with balls that were double regulation weight and did not see any change in pitch accuracy (Brose and Hanson, 1966), suggesting that mechanics were not changed by a significant overload. On the other hand, Straub et al found that pitchers who warmed-up with a ten or fifteen ounce ball suffered loss of accuracy for the first ten pitches with a regulation ball and each of the first ten pitches became progressively more stable until normal accuracy was achieved, suggesting that the normal biomechanics of the pitch were altered (Straub, 1966).

While some researchers have found no changes in accuracy or biomechanics with weighted balls and others have found changes, it is reasonable to hypothesize that pitchers respond different to overload or underweight training (Straub, 1966; Neal, 1991). We know that there is significant variation among pitchers in the biomechanics of the pitch motion (Fleisig, 1999; Stodden, 2006; Fleisig, 2009), especially in pitchers at different throwing levels (Matsuo, 2001), and it is feasible that there would also be variation among pitchers in response to a training program involving changes in ball weight. Neal et al described three components to throwing velocity: directional, proximal versus distal velocity, and movement of the hand and arm (Neal, 1991). The directional component varies little between throwers and relates to the general overhand throwing motion. Proximal versus distal peak velocity has a considerable amount of variation among throwers, reflecting each thrower's style. Finally, the movement of the hand and arm reflects the effect of varying ball weights on each thrower's style, with showed high variation among the throwers (Neal, 1991).

Straub et al found also large within-group variability in performance after an overload warm-up, while some pitchers performed better, others performed less well, and the majority failed to change (Straub, 1966). The high velocity throwers had a significantly more varied response immediately following the overload warm-up than the low velocity throwers, meaning that the high velocity pitcher may be more sensitive to the weighted warm-up. The authors explain that a high velocity pitcher is more likely to experience a neuromuscular tremor following overload warm-up that negatively affects their accuracy for the first few throws taken with a regulation ball. They may still be able to pitch at a high velocity, but with impaired accuracy (Straub, 1966). This may signify that pitch biomechanics and temporal measures change while using a weighted ball and pitch performance is hindered as the body adjusts to using a regulation weight ball. Previous studies had allowed pitchers to warm-up before maximal testing with regulation balls, which may have allowed the pitchers time to adjust back to their normal rhythm.

While a high-level pitcher may have altered accuracy immediately following the use of a weighted ball, they also have altered velocity when using a weighted ball due to a change in the proximal-to-distal sequence. Adding additional mass to the ball may alter the sequence of the kinetic chain, resulting in the forearm, not the hand, being the last segment to reach peak velocity, preventing momentum transfer to the hand and ball (Southard, 1998), but only when throwing at maximal speed (Southard, 1998). At 100% effort the high-level throwers saw a change in timing of peak velocity of the segments (Southard, 1998), causing the forearm to lag behind the hand, compromising the proximal-to-distal transfer of velocity (Fleisig, 1996), resulting in a lower ball velocity. This is because the distal segment is usually smaller in proportion to the proximal segment, which allows the distal segment to increase in velocity when the torque from the large proximal segment acts on it (Southard, 1998). Additionally, the addition of weight to the most distal segment (the hand and ball) has been showed to have an inverse relationship with kinetic measures such as maximal angular velocity of wrist flexion, elbow extension, and internal rotation of the shoulder (van den Tillaar, 2004), and when the angular velocity of the segments decrease, so also will the velocity of the most distal segment decrease (Atwater, 1982; Alexander, 1982). This illustrates that higher-level throwers are able to maintain their mechanics despite mass (Neal, 1991) and velocity changes and only deviate from their usual motion when throwing the weighted ball at 100% effort (Southard, 1998). A high-level thrower, such as a collegiate baseball pitcher, is usually able to compensate for interferences in their normal throwing motion (Roach, 2014). When throwing with a heavier ball, the pitcher adjusts by throwing slower, preventing overload at the joints.

Lower-level throwers, on the other hand, have the largest variability in pitching biomechanics (Fleisig, 1996), and are most sensitive to changes in mass (Southard, 1998). Less skilled throwers tend to have less range of motion, causes the forearm to reach peak velocity prior to the hand (Neal, 1991). These throwers increased velocity when using a weighted ball because the added mass at the most distal segment allows changes the timing of segment involvement, allowing the throwing arm to utilize the proper proximal-to-distal sequence, upper arm to forearm to arm, to transfer velocity to the distal segment (Neal, 1991; Southard, 1998). A lower-level thrower, such as a high-school pitcher, may throw faster with the weighted ball, potentially increasing loads at his joints and putting him at risk for injury. Additionally, throwing a heavier baseball stresses the internal rotators of the shoulder to work harder and in high-school baseball pitchers ROM of the internal rotators decreased after a six-week weighted ball program (Pallett, 2015), which decreases the ability to produce force and places the thrower at higher risk of overuse injury. Thus, a weighted ball program may not be suitable for a novice or intermediate thrower.

Yang et al did not find a significant difference in the shoulder joint MER in high school pitchers who used a lightweight ball (Yang, 2013), suggesting that pitch biomechanics were not compromised by changes in ball weight, even in a lower-level pitcher. This finding agrees with previous research that did not find kinematic differences in the throwing arm of 9-12 year old pitchers when using lightweight balls (Fleisig, 2006).

Many researchers argue that a lighter ball reduces the load on the elbow and surgery during training, allowing pitchers to develop arm speed without altering proper mechanics and thus minimizing the risk of injury (Fleisig, 2006;Yang, 2013). There were significantly lower kinetic values resulting from pitching the lightweight ball compared to the regulation ball, which may lessen the risk of injury from the repeated pitch (Fleisig, 2006).

Arm Negative Acceleration

Kinematic Parameters

Immediately after ball release the elbow continues to extend and the shoulder continues to internally rotate, beginning the arm negative acceleration phase. During this long phase (350 ms) the negative acceleration of the arm is crucial in preventing injuries to the throwing arm (Pappas et al, 1985). If the elbow reaches maximum speed of extension prior to the instant of full extension, the pitcher would risk injury to the posterior elbow joint where the elbow is locked straight and to prevent this, the pitcher would have to limit the speed of the ball just prior to release. Rather than reduce arm speed, and therefore ball speed, the pitcher stops elbow extension before the elbow is fully extended and simultaneously rapidly internally rotates the shoulder joint (7,550°/sec). These mechanisms allow the hand to move forward past the position of the elbow without slowing down, avoiding injury to the posterior elbow joint (Feltner and Depena, 1986).

The arm is negatively accelerated and moved into a horizontal abducted position across the chest while the throwing arm reaches maximal internal rotation. The trunk and upper torso tilts forward (470°/sec) (Fleisig, 1996). The lead knee extends forward and the pivot leg steps forward to regain balance and dissipate energy from the throw, concluding the phase (Fleisig, symposium).

Kinetic Parameters

As the shoulder begins to internally rotate to prevent hyperextending of the elbow, the adduction torque (79 Nm) acting on the shoulder and the shoulder compressive force (850 Nm) provided by the shoulder muscles work to stop the motion of external rotation (Fleisig, 1996). As the elbow extends through the acceleration phase, the arm swings away from the pitcher's body. Centrifugal force around the elbow attempts to distract the forearm out of the elbow joint, but a compression force applied by the shoulder muscles resists this distraction. The compression force begins at the time of lead foot contact and steadily increases until prior to ball release when maximum force is 780 Nm (Werner et al, 1993). Then during the negative acceleration phase, a compression force (710 Nm) is needed to stabilize the elbow and prevent elbow distraction (Fleisig, 1996). During this phase, the compression force reaches a peak of 90% of the pitcher's body weight (Werner et al, 1993).

Muscle Activation

The aims of this phase are to slow down the limbs, dissipate energy, and prevent injury. All of the elbow, forearm, wrist, and finger muscles are highly activated and the wrist flexors demonstrate very high activity during this phase. It is thought that the most distal joint have the most kinetic energy to dissipate (DiGiovine, 1992). Opposing muscles around the shoulder, elbow, and wrist all fire simultaneously to control the rapid negative acceleration of these three joints. The trapezius, serratus anterior, and rhomboids all demonstrate high or very high activity to attempt to stabilize the scapula. All three deltoid heads are also activated while the brachialis increases activity after ball release as it begins to assist in negatively accelerating the arm. The compression force that resists elbow distraction is provided by the muscle action of the triceps, anconeus, and wrist flexor muscles (Werner, 1993).

The active force acting on the shoulder to stop external rotation is exerted by the stretched subscapularis, as well as the latissimus dorsi and pectoralis major, which remain activated after ball release and assist in internally rotating the throwing arm and carrying it across the chest. The latissimus dorsi is more active than the pectoralis major since the humerus is no longer elevated above 90° and the pectoralis major no longer has a mechanical advantage on the humerus. The passive torque is exerted by the joint capsule near the limits of the joint range of motion (Werner, 1993; Werner, 2001). The teres minor, which had been activated during positive acceleration to limit humeral head translation during humeral extension, continued to demonstrate high activity levels to limit humeral head translation as the shoulder externally rotated. Rotator cuff pain can often be isolated to the teres minor during this phase (DiGiovine, 1992).

Strength and Conditioning Considerations

The rotator cuff concentrically and eccentrically produces internal and external rotational torques during the pitch. During this phase and the follow-through, the elbow flexor muscles and the shoulder external and internal rotation muscles are lengthening to control and slow down the limb (Wooden, 1992; Mikesky, 1995). Strength of the external rotators has been shown to be correlated with throwing velocity (Pedegana, 1982) and without a strong external rotator musculature to slow down the rapidly moving arm after ball release, shoulder injuries can occur (Carter, 2007). Weighted implement training may be beneficial during this phase as well as it allows the arm to go through the entire range of motion (Logan, 1966), including the slowing down and follow-through of the throwing limb. Additionally angular isolatory dumbbell exercises such as bent-over dumbbell raises, lateral dumbbell or cable rotation, and reverse wrist curls can be used to increase eccentric strength of the shoulder (Jacobs, 1987).

Follow-Through

Kinematic and Kinetic Parameters

The follow-through phase begins after the throwing shoulder begins to negatively accelerate and continues until the motion in the pitching arm has ceased. The shoulder continues to rapidly rotate inward, continuing to move the arm horizontally across the body. As the arm moves, the humerus medially rotates to pronate the forearm and the hand. As the shoulder adducts across the body, shoulder adduction/abduction torque reaches its peak at 26±5 Nm (Werner, 2001). Similarly, the shoulder internal rotation torque reverses and becomes positive during this phase.

Muscle Activation

The follow-through phase is characterized by dissipation of the rest of the kinetic energy and putting the pitching back in a fielding position. DiGiovine et al found that during follow-through all shoulder girdle and upper extremity muscle exhibit activity before 42% of MVC and considered this phase to consist of non-critical motion due to the lack of muscular activity (DiGiovine, 1992). However, other authors have found that the muscles involved in extending the trunk and moving the throwing arm across the body are highly active.

Jobe et al found that the biceps and brachialis reach their peak activity during the follow-through, as they pronate the arm and contract to negatively accelerate elbow extension. To aid in humeral adduction across the body, the latissimus dorsi is moderately active after the moment of maximum medial rotation of the humerus. The deltoids are moderately active as they abduct the shoulder as it moves the arm across the body. The lateral rotator cuff muscles and the upper trapezius were also moderately activated to help negatively accelerate the arm at the shoulder (Jobe, 1984).

Strength and Conditioning Considerations

The external rotators are lengthening to control arm movement during follow-through (Wooden, 1992) and many of the same isolated, eccentric exercises can be employed to strengthen the movements of the arm negative acceleration phase can also be used in the follow-through (Jacobs, 1987).

CHAPTER III

METHODS

The purpose of this retrospective study was to determine the effect of a weighted ball program on the throwing velocity of collegiate baseball pitchers over the course of an off-season.

Participants

Varsity, male, collegiate pitchers were recruited from a single NCAA Division I baseball team in the Southeast United States. Recruitment was done via word of mouth from the coaches and investigators to all eligible athletes. Only those participants who are of varsity level, free of current injury, and who had not had surgery in the past year were included in this study. Participants were informed that participation in the study would not affect their status on the team. Athletes met with the principal investigator to provide written consent.

Table 1: Subject Characteristics

	Age (yrs)	**Height (in)**	**Weight (lbs)**
Weighted-Implement (WI) Group (n=34)	19.765 ±1.046	73.882 ± 2.889	202.969 ± 23.434
Normal Throwing (NT) Group (n=21)	19.952 ± 1.322	74.714 ± 3.052	210.476 ± 21.777

Baseline Testing

All participants underwent baseline data collection during the 2015 off-season, which extends from August to November. Three members of the baseball staff performed baseline testing: the Certified Strength and Conditioning Specialist (CSCS), the Athletic Trainer, Certified (ATC), and the Director of Operations. The information that was collected and recorded from baseline testing was then sent to Velocity Arm Care, the third-party sport performance company, who created individualized plans for each pitcher based on the results from baseline testing.

Height was be measured using a stadiometer and was recorded in centimeters (cm). Weight was measured on a medical grade weight scale as kilograms (kg). Broad jump distance was recorded. Scapular position was palpated and a score of pass or fail was recorded. The position of the subscapularis was palpated by the ATC by standing behind each pitcher while each pitcher was in the upright standing position. Each pitcher placed his dominant arm behind his back, keeping his elbow bent at a 90° angle and his dominant hand supine against the middle of his lower back. The ATC placed his right hand thumb on the posterolateral corner of the acromion and his middle finger on the anterolateral acromial edge. He put the thumb of his left hand on the inferior angle of the scapula and his index finger on the medial end of the spine of the scapula and gently pressed medially. A passing score was recorded when a pitcher's scapula allows a gentle push inward and a fail score was recorded when it did not.

Finally, velocity of pitch was measured from three different foot positions: a kneeling position, a modified crow hop, and normal stride, while the pitching coach held the radar gun at a safe distance behind the net. After completing their usual warm-up (calisthenics, bands, holds, long-toss), each pitcher threw three maximal pitches per ball (1 ounce, 2 ounce, 4 ounce, 5 ounce, and 6 ounce) for a total of 9 pitches per position and 45 pitches overall for baseline testing. The average of these three velocities was recorded.

Pitch velocity was measured using the Stalker Pro Sport 2 Radar Gun (Applied Concepts, Inc, 2015). This radar gun can detect a baseball for a range of 500 feet and measures speeds up to 150 mph. It is accurate to +/- 3% of the reading.

Weighted Implement Program

Velocity Arm Care used a specialized equation that take into account five parameters (height, weight, pitch velocity, broad jump length, and scapular position) to create individualized lesson plans for each pitcher. The weighted implement program utilized a regulation college baseball (5 oz.), a 20% underweight ball (4 oz.), and a 20% overweight ball (6 oz.). The 1 ounce and 2 ounce balls that were used in testing were not used during training for this program. Each pitcher was emailed their specific program that included ball weight, ball weight order, and pitch number for each ball weight. Each pitcher was supplied with all three weighted balls to use for the duration of the program.

During the first two weeks of the program, all pitchers completed the same general program, known as the familiarization phase. This involved pitching practice four days a week on all weekdays but Wednesday. The pitchers threw three pitches from flat ground with each of the balls: overweight, regulation, and underweight, from each of the three positions, as was used in baseline testing, for a total of 27 pitches per day.

After completion of the familiarization phase, each pitcher received their controlled lesson plan, which composed of pitch totals for each weighted ball and a specific sequence in which to use the balls. This progressive pitching program increased pitch count throughout the program, however the ball weights remained the same throughout the program. Volume was not controlled for these individual programs and some pitchers did not use heavy balls and some did not use light balls. The ratio of weighted balls to regulation baseball also varied between pitchers.

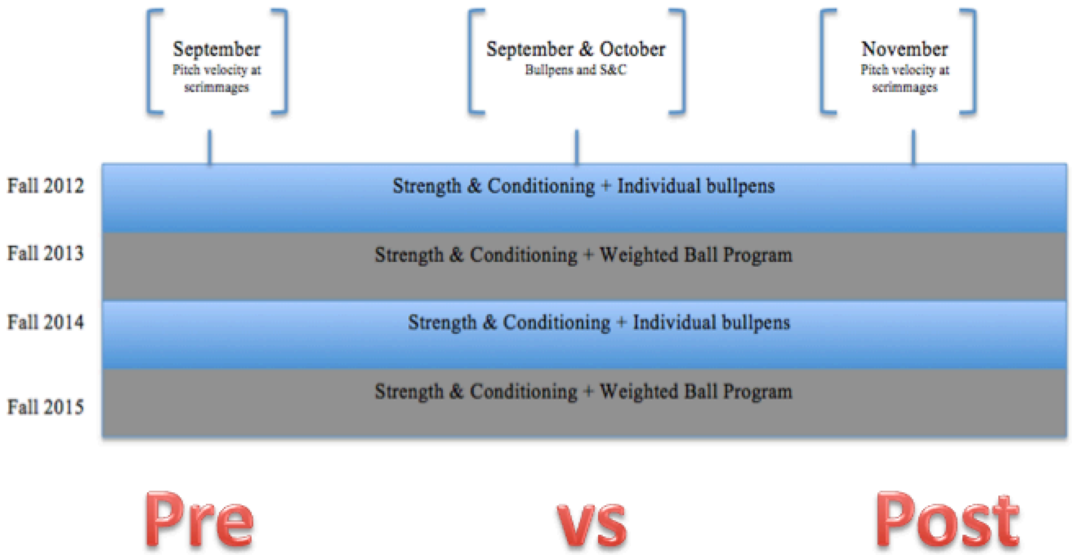
The individualized programs began after the two week familiarization phase, with the strength phase, in which each pitcher followed their lesson plan for four days a week for four weeks. After the strength phase, the pitchers continued their individual plans three days a week with a day of rest in between. They continued this maintenance phase for the remainder of the off-season. For incoming pitchers, this program was roughly 10 weeks and for returners it was about 6 weeks, for a total of 16 and 12 weeks, respectively. However, all returners participated in summer baseball leagues where they completed organized workouts and practices, and competed regularly in games.

Pitchers completed their weighted ball program on their own after a routine warm-up of calisthenics and long toss, and before the pitchers begin their individual bullpen session with catchers and pitching coaches. Each pitching session, complete with warm-up, weighted ball program, and normal bullpen, will take roughly one hour.

Velocity Data Collection

Pitchers did not participate in weighted implement training during the 2014-2015 baseball season. Games pitched, pitch count and type, and pitch velocity data from testing sessions and scrimmages during the 2014 off-season was obtained from baseball pitching staff. Games pitched, pitch count and type, and pitch velocity data from testing sessions and scrimmages during the 2015 weighted implement off-season was also obtained from baseball pitching staff.

Figure 2: Study Timeline



<u>Statistical Analysis</u>

The IBM Statistical Package for the Social Sciences, version 19 (SPSS, IBM Corp, Armonk, New York) was used to analyze all data. To determine the effect of the training method on velocity, a 2x2 repeated measures Analysis of Variance (ANOVA) was conducted comparing the two groups (weighted implement group and the regular training group) and the two time points (the beginning of the off-season and the end of the off-season).

CHAPTER IV

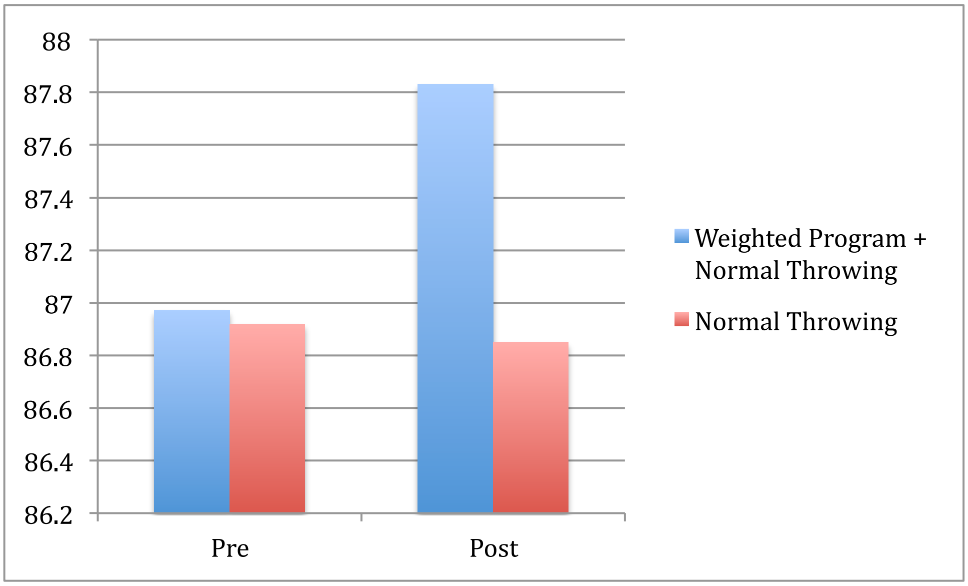
RESULTS

The purpose of this retrospective study was to determine the effect of a weighted ball program on the throwing velocity of collegiate baseball pitchers over the course of an off-season. After running a 2x2 repeated measures Analysis of Variance (ANOVA) comparing the two groups (weighted implement group and the regular training group) and the two time points (the beginning of the off-season and the end of the off-season), we found no significant interaction. There was no main effect for time ($p=0.071$) and no main effect for group ($p=0.271$). Group descriptive statistics are listed in Table 2. Graphical representation of group descriptive statistics appears in Figure 3.

Table 2: Group Mean Velocities

	Pre-Velocity (mph)	**Post-Velocity (mph)**
WI Group (n=34)	87.249 ± 2.317	87.541 ± 2.730
NT Group (n=21)	86.800 ± 1.319	86.993 ± 1.271

Figure 3: Group Mean Velocities



Graphical representation of pre-velocity and post-velocity for each pitcher who completed the weighted implement program appears in Figure 4. Graphical representation of pre-velocity and post-velocity for each pitcher who completed the normal throwing program without weighted implements appears in Figure 5.

Figure 4: Velocity for Each Pitcher in the Weighted Implement Program

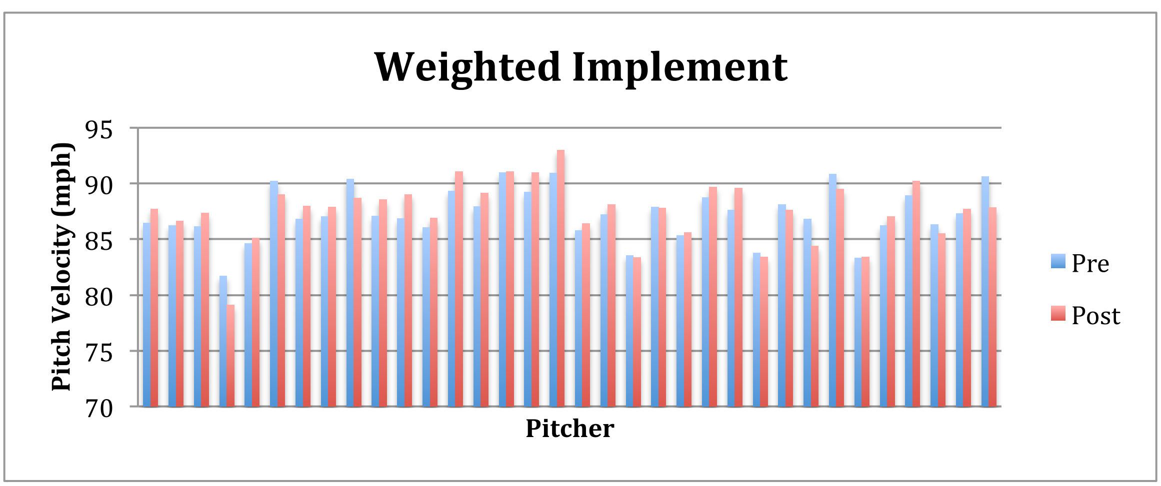
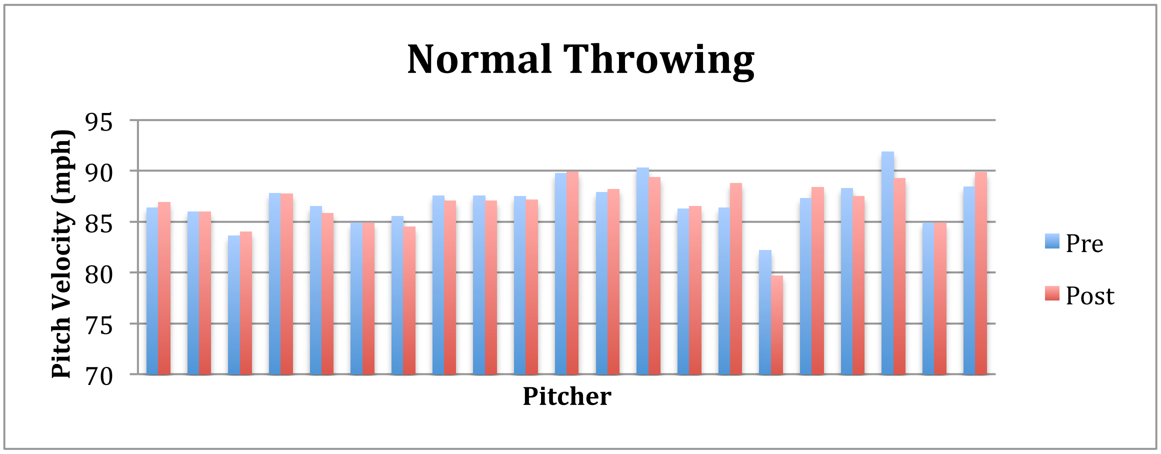


Figure 5: Velocity for Each Pitcher in the Normal Throwing Program



CHAPTER V

DISCUSSION

Because weighted implement programs are widely used today, especially in collegiate baseball programs, further research into this type of training program was warranted. The purpose of this study was to determine the effect of a commercially available weighted ball program on the throwing velocity of collegiate baseball pitchers over the course of an off-season. This study retrospectively examined the change in collegiate pitcher's pitch velocity during team scrimmages from the beginning of the off-season to the end of the off-season. Both groups underwent similar strength and conditioning programs and similar bullpen conditions with the same pitching staff. However, one group threw individual throwing programs that employed balls that were 20% heavier (6 oz.) and 20% lighter (4 oz.) than competition baseballs (5 oz.) while the other group threw individual throwing programs that utilized competition baseballs only.

A review of the current literature shows that research on weighted implement training in baseball has been studied in pitchers from high school to the professional level and has utilized varying ball weights and varying program duration. These studies have produced mixed results (Straub, 1966; Brose and Hanson, 1967; DeRenne, 1985; DeRenne, 1990; van den Tillaar and Ettema, 2011). The main purpose of this study was to determine the effect of a ten-week individualized weighted ball program in collegiate pitchers. The results of this study do not support the notion that weighted implement training will result in increased pitch velocity. Unlike previous research (Brose and Hanson, 1966; Litwhiler, 1973; Pollock, 1975; DeRenne, 1985; DeRenne, 1990; DeRenne, 1994; Yang, 2013), this study did not find any significant change in pitch velocity after weighted implement training (Figure 4). Additionally, it was hypothesized that the weighted ball program in addition to a strength program would increase pitch velocity compared to a strength program alone with normal throwing. The results of this study do not support this hypothesis. This study did not find any significant increases in pitch velocity after weighted implement training or without weighted implement training (Table 2). There were no significant differences between the two groups (Figure 3) and thus the results of this study suggest that weighted implement training had no influence on pitch velocity for athletes undergoing this specific strength and conditioning program.

Training Status

The duration of this program was ten weeks, which is the most frequently used time period for successful weighted implement training programs (Vasiliev, 1981; DeRenne, 1985; DeRenne, 1994; Yang, 2013). However, unlike many of those studies (Pollock, 1975; DeRenne, 1994; Yang, 2013), this study did not find significant increases in pitch velocity. Reasons for this difference are unknown but as those studies did not specify at what point in the season these programs occurred, it is possible that the timing of the program may be related to the changes in pitch velocity. A program that starts in a true off-season, during which pitchers have not been participating in regular strength training or throwing programs, may result in higher increases in velocity. This is because the arm is starting in a relatively untrained state, or a less-trained state, and once the pitcher begins his normal routine again and the arm becomes more conditioned, velocity will improve. For example, a high school pitcher who plays competitively all summer but does not play at all in the fall or winter will be throwing slower than usual during his first few practices but will quickly see an increase in velocity as he returns to his conditioned state. On the other hand, any study that begins in the preseason or during the in-season already has a highly conditioned arm that may see relatively small changes in velocity (van Tillaar, 2004). Finally, any study looking at the end of the competitive season would find very little increase in velocity as the arm is in its most conditioned state and may even find decreases in velocity as the arm fatigues from frequent competition.

The goal of an off-season throwing program, such as the one used in the current study, is to improve arm strength and speed, which is why the authors believe that the off-season is the ideal time for a weighted implement program. However, while the current study was performed in the off-season, it cannot be seen as a true off-season since the majority of the pitchers participated in summer leagues. These pitchers finished the collegiate in-post-season play and shortly after began a summer league where they pitched regularly in bullpens and competition as well as performing strength and conditioning exercises. Summer league play culminates about two weeks before pitchers reported back to their college program to begin the weighted implement program. Because they continued to throw without taking an extended break, the pitchers in the current study did not start the weighted implement program in a completely untrained state, nor were they highly conditioned, which could have impacted the pitch velocity results.

Related to training status, Vasiliev and the earliest pioneers of weighted implement programs in the Soviet Union suggested that strength should be established prior to progressing to velocity training (Vasiliev, 1981; DeRenne, 2001). Many weighted implement studies do not include strength training, and thus any increase found could be from a simple training stimulus alone, which would support the notion that building strength alone without velocity training is sufficient to increase pitch velocity. In the current study, a progressive strength program was started at the same time as the progressive weighted implement program began. This strength and conditioning program has remained consistent for the past four years and no major changes have been made that would alter pitch velocity. However, all incoming pitchers, along with returners, are given summer programs to follow that includes a strength and conditioning component, and thus no pitcher could be considered truly untrained at the beginning of this study. On the other hand, Brose and Hanson studied untrained collegiate freshmen who utilized an implement that weighed twice as much as the regulation baseball for six weeks (Brose & Hanson, 1967). While they saw significant increases in pitch velocity, it is possible that this increase is related to starting any kind of training program and a similar response would have been seen in untrained freshmen athletes who began a strength regimen without a weighted ball program.

Training Volume

Some studies that saw an increase in pitch velocity had participants throw a large volume of pitches and with much larger implements compared to the current study, which focused on moderate volume and weights. Litwhiler and Hamm studied collegiate pitchers for twelve weeks and found significant increases in pitch velocity every two weeks during their progressive weighted implement program. The pitchers began using a seven-ounce ball and progressed up to a twelve-ounce ball, making the weight of the balls much heavier than the balls in the current study. In addition to this increase in weight, the pitchers threw 165 pitches a week (Litwhiler &

Hamm, 1973), giving them a much larger volume of training than the current study, which could have accounted for the significant increase in velocity they found.

Conversely, DeRenne studied high school pitchers who threw four, five, and six-ounce balls, the same weights as used in the current study. However, these pitchers threw a larger volume of pitches, progressing from 54 to 78 pitches per day over the ten-week period (DeRenne, 1994). In the current study, pitchers had individualized programs but threw about 25 pitches with the weighted implements before throwing the regulation baseball for the remainder of the pitching session, which included 20-40 pitchers for starters and 20-30 for relievers, for a total of 45-65 and 45-55 pitches, respectively, during each session. It is possible that the difference in volume of pitches utilizing the same ball weights resulted in the difference in pitch velocity.

The results of DeRenne's study, Litwhiler & Hamm's study, and the current study lead us to suspect that a certain training stimulus needs to be met in order to result in a significant increase in velocity. DeRenne used the same ball weights as the current study, but threw more pitches while Litwhiler and Hamm used heavier ball weights and similar pitch counts to the current, both resulted in significant improvements in velocity. It could be suggested then, that the current study did not produce the ideal stimulus to result in significant change. However, the current study contained a strength and conditioning component, which the previous two studies lacked. The addition of this training program likely resulted in a larger training volume than the previous two studies, however it is difficult to quantify, as the training modalities are different. McEvoy and Newton conducted a study in which MLB players performed either ballistic weight training combined with normal throwing and batting or additional normal throwing and batting to achieve a similar volume of training as the weight training group. In this study those that performed the weight training improved throwing speed while those that did additional throwing and batting did not (McEvoy and Newton, 1998), suggesting that weight training contributes to the training stimulus even though it is a different training modality than throwing.

Still, in the current study all aspects of the strength and conditioning component may not have influenced the training stimulus according to the Specific Adaptations to Imposed Demands principle, which states that exercise results in neuromuscular adaptations specific to that exercise (Tillin and Folland, 2013). Under this principle, the training stimulus must be velocity-specific in order to elicit neuromuscular adaptations that can be translated to the velocity of the throw (McEvoy and Newton, 1998), and thus any strength and conditioning exercises that focus on maximal force production do not contribute to a velocity-specific stimulus. However, under this same principle, throwing with overweight balls would not contribute to the velocity-specific stimulus, so it would not explain why Litwiler & Hamm's pitchers who used 40-140% overweight balls increased velocity. The training volume required from a weighted implement program in order to provide a stimulus for increased pitch velocity warrants further investigation.

Individual Weighted Ball Programs

This study was modeled on DeRenne's early work that showed that a weighted implement group that utilized both underweight and overweight balls did not significantly improve pitch velocity over a control group that performed strength training and normal throwing (DeRenne, 1994). While both studies were ten weeks in length and employed implements that were 20% overweight and 20% underweight, the current study provided pitchers with individualized throwing programs, which meant that some pitchers did not use underweight balls and some did not use overweight balls, and all had different sequences of throwing. Although it has been suggested that individualized throwing programs utilizing both overload and underload balls and customized pitch counts might be ideal for pitchers who have been shown to have varied responses to weighted programs (Straub, 1966), this study did not support this. One other study in addition to this one has researched weighted implement programs that designed for each individual pitcher. Powe et al. provided three professional minor-league baseball players a six-week individualized throwing program that utilized both overweight and underweight balls. Much like the current study, Powe provided each pitcher with a program detailing when they would throw, how long they would throw, what distance they would throw, which weighted ball they would throw, and how much rest they were to take (Powe, 2011). All pitchers in that study saw significant increases in their pitch velocity over the course of the training program.

The major difference in that study was the use of professional pitchers who were specialized throwers, and included a starter, a relief, and a closer. While the current study used specialized throwers, collegiate pitchers are more flexible in their positions. Powe's definition of a closer was a pitcher who came in during the last inning and would only pitch that inning, whereas the current study's closer might pitch up to four or five innings. A relief or closing pitcher practices with fewer pitches and thus by increasing the workload by using weighted implements may have resulted in a greater change. A relief or closer typically has a faster velocity than a starting pitcher and since they throw fewer pitches in a game and is able to maintain a higher velocity for a short number of pitches. Indeed the closer (3-5mph) and relief pitchers (4-8mph) increased pitch velocity to a greater extent than the starter (3mph), who has to throw more pitches in practice and games (Powe, 2011).

The Powe study has a few limitations that make it difficult to make comparisons. They had a very small sample size (n=3) and the pitchers were analyzed individually, rather than as a group mean. Additionally, no statistical analysis was run for the velocity and instead the average throwing velocity from the beginning of the season and the end of the season as used. It is difficult to interpret if this is truly a significant change. The weight of the implements used was not specified, however the authors talk about a progression in weight every two weeks (Powe, 2011), whereas the current study used a progression in number of pitches while using the same implements. The authors also did not specify the other training methods the pitchers underwent during this time period and it is unknown if they completed a strength training program simultaneously. Powe's program was introduced at the beginning of the season and completed after six weeks, during the middle of the in-season, which could have affected the results, as previously discussed. Finally, as the authors discuss, the participants were minor league pitchers in a league where there is not a mandatory drug testing policy and it is possible that pitchers used performance-enhancing tools in an effort to move up in the league, which could have affected their pitch velocity (Powe, 2011).

Weighted Warm-up

In the current study, all pitchers performed holds as part of their warm-up and some used overweight implements as heavy as two pounds. Some pitchers in the current study also warmed up with a throwing motion without a ball or with a weighted sleeve, similar to the weighted bats that batters use to warm-up with. When looking at weighted bats for warm-up, they have not been found to increase bat speed (Pillmeier, 2012), however it is unknown if the same effect is found in pitchers who use an overload warm-up. Even though these were a warm-up, their use must be considered as a factor in the differences between the studies. The weighted sleeve used by some pitchers in this study was similar to the weighted glove used in Southard's study focusing on changes in mass at different segments and how that affected velocity.

Southard found that adding additional mass to the most distal segment, in the case of the current study this would be the ball in the hand, can alter the sequence of the kinetic chain, resulting in the forearm being the last segment to reach peak velocity, which prevents momentum transfer to the hand and ball. However this only occurred when throwing at maximal speed and in high-level throwers (Southard, 1998). Southard similarly added mass to the proximal segment, which is similar to the pitchers who used the weighted sleeve in this study. Southard found there was no effect on the sequence or position of the segments in the higher-level throwers and did not affect velocity (Southard, 1998). Weight at the proximal segment allowed lower level throwers to improve sequential activation by allowing their forearm to reach peak velocity right before the hand reaches peak velocity, resulting in proper momentum transfer to the hand. Depending on the classification of pitching level of the pitchers in the current study, the weighted sleeve could have been beneficial or had no effect on overall throwing pattern and velocity. It is unknown what effect a combination of the weighted sleeve combined with the weighted ball have on pitch velocity and pattern, however the current study suggests that both of these together do not have a significant effect on pitch velocity.

Practical Applications

To increase pitch velocity, the pitcher must manipulate the force-velocity curve (Hill, 1938) by either producing additional force or additional velocity through the kinetic chain to result in a more powerful pitch (Ettema, 2008). The power can be increased through resistance training that overloads the muscle (Lachowetz, 1998) and increases muscle strength and maximal force development (Tojo and Kaneko, 2004; Escamilla, 2011) or through velocity-overload training, which requires exercises to be completed at high speeds (Van den Tillaar and Ettema, 2004), resulting in increased velocity.

Pitching programs that include resistance training to increase muscle strength (Mero, 1994) and ballistic exercises that are performed rapidly and explosively (Zaras, 2013) have each been shown to independently increase throw velocity. This study suggests that training programs for pitchers that focus on general resistance exercises as well as sport-specific resistance exercises are as successful in collegiate pitchers as a weighted implement program. Both approaches manipulate the force-velocity curve (Hill, 1938). The resistance exercises producing increases force development through the kinetic chain by and sport-specific resistance exercises focusing on producing a velocity-overload (Ettema, 2008) whereas a weighted implement program provides both a velocity-overload and force-overload. However, based on the results of this study, it does not appear that weighted implement training that combines velocity and force overload is superior to two different types of exercises that independently provide either a velocity-overload or force-overload.

As previously stated, the training volume required from a weighted implement program in order to provide a stimulus for increased pitch velocity warrants further investigation. Additionally, a threshold for training should also be investigated. The proper amount of pitches and ball weights used to elicit a significant improvement in pitch velocity in specific populations should be further studied before recommendations for weighted ball programs can be made.

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