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The relationship between bat velocity, upper and lower extremity power and the rotational kinetic chain in NCAA Division II softball players

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The Relationship Between Bat Velocity, Upper and Lower Extremity Power and the Rotational Kinetic Chain in NCAA Division II Softball Players

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Of the Requirements for the Degree
Master of Science

Liza S. Teichler
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Abstract

Fastpitch softball has undergone a relative resurgence in popularity in the NCAA in recent years as marked by a greater than two fold increase in participating teams and athletes. This trend has coincided with rises in NCAA employment of strength and conditioning professionals as well as attention paid to the generation of maximal bat velocity. The development of bat velocity positively affects the hitter's decision-making time, ability to make solid contact with the ball, increase hit distance and velocity. Thus, the purpose of this study was to determine if there were significant correlations between lower extremity power, upper extremity power and kinetic chain efficiency and linear bat velocity in NCAA Division II softball players. Performance testing was conducted on subjects utilizing the seated medicine ball shot put, medicine ball hitter's throw and countermovement jump in combination with bat swings. Maximal velocity of the bat's sweet spot was measured using a 7-camera motion analysis system. Bivariate correlations and linear regressions were applied to determine relationships between the performance variables and bat velocity. The most correlated performance-related variable was the seated medicine ball shot put ($r = 0.312$, $p < 0.05$), which contributed to 6.6% of variance between subjects.

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Keywords: softball; bat velocity; kinetic chain

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Chapter I: The Problem and Its Scope

Introduction

The sport of fastpitch softball has become increasingly popular since the early 1980s, where participation rates in the National Collegiate Athletics Association (NCAA), have more than doubled to over 16,500 athletes since 1982 (Bracken, 2007). Furthermore, an expansion in the number of players engaging in competition at the NCAA Division I, II and III levels can be attributed to the two-fold increase in teams (Bracken, 2007). The last decade has also given rise to vast increases in NCAA employment of strength and conditioning coaches for the enhancement of athletic performance through training (Magnusen & Rhea, 2009). While few training studies have been conducted on softball players, improved performance on strength and power tests have been related to enhanced bat velocities observed in baseball players (Reyes & Dolny, 2009; D. Szymanski et al., 2007a). Training to increase bat velocity has included a wide array of methods, such as plyometric programs, linear periodization resistance training, Olympic lifts, under and overweight training and dry swings. Despite investigation, the results have not been confirmed whether more attention should be paid to strength and power aspects or the enhancement of the sport-specific kinetic chain used in hitting.

The development or improvement of bat velocity by a baseball or softball athlete may vastly improve their offensive production as a function of three variables. First, hitters will have a longer period of time to make the decision regarding whether or not to swing based on the type of pitch and location of the ball. Longer decision-making time may enhance the athlete's ability to make contact on the "sweet spot" (ideal contact location on the bat) of the bat, maximizing hit distance (DeRenne, Ho, Hetzler & Chai, 1992; D. Szymanski et al., 2007a). Secondly, decision-making time also coincides inversely with the amount of time necessary to execute a swing; which includes the time necessary to reverse the bat's path from the loading phase and the initiation of the swing through the point of contact (D. Szymanski, DeRenne & Spaniol, 2009). Lastly, after contact, higher ball velocities have been related to increased bat velocity during the swing (Adair, 2002; Reyes & Dolny, 2009; D. J. Szymanski et al., 2009).

Purpose of the Study

This study was designed to explore the relationship between maximal linear bat velocity and tests of upper and lower extremity power and kinetic chain efficiency in NCAA Division II softball players. Additionally, a multiple regression was applied to explore the prediction of maximal bat velocity from a linear combination of the upper extremity and lower extremity power and kinetic chain variables. A secondary objective of this study was to determine if body height was significantly related to the performance predictors and linear bat velocity.

Experimental Hypothesis

The linear combination of lower and upper extremity power and kinetic chain performance will be significant predictors of bat velocity in NCAA Division II softball players with improved performance on these field tests predicting of greater bat velocity. Additionally, each of the performance measures will be highly correlated with linear bat velocity.

Significance of the Study

Assessing the relationship between linear bat velocity and performance variables may aid coaches and strength and conditioning professionals in the selection of optimal training strategies to improve their team's offensive production. The establishment of conclusive relationships may shift training emphasis towards either the development of a more efficient kinetic chain or resistance training to enhance muscular strength and power, or indicate the need for equal time to be spent on both types of training. Additionally, this study allows for the determination of which field tests are the best indicators of maximal bat velocity. Significant findings may help to validate the use of these field tests to monitor improvements in this study population.

Limitations

The major limitation of this study was the use of two collegiate softball teams consisting of thirty-one players as subjects in this protocol. Individual players, even ones from the same team, are likely to display different swing techniques. Thus, variance in the kinetic chain efficiency may be attributed to differences in swing characteristics, such as the position of the hands at release of the medicine ball and may not the effectiveness of the transfer of power from the lower to upper extremities through the trunk. External validity has not yet been proven for the medicine ball hitter's throw, thus it is also possible that it will only indicate muscular strength rather than measuring the efficiency of the kinetic chain. Other limitations may include, athlete's current skill level and bat velocity, degree of familiarity with tests, dissimilarity between testing environment and game-situation. Lastly, all of the subjects in this study used the same bat of a given length, mass and moment of inertia which was instrumented motion analysis markers. Due to individual variability between players, this bat may not be the best selection for all subjects.

Definition of Terms

Batting practice	Swing repetitions against a live pitcher (DeRenne, Buxton, Hetzler & Ho, 1995).
Batting tee	A device used for batting practice off which balls can be hit (Easton-Bell Sports, Van Nuys, CA).
Bat velocity	The maximal speed measured during a baseball or softball swing. Measured in the present study using a marker 15 cm from the end of the bat.
Dry swings	Swing repetitions completed without striking a ball (DeRenne et al., 1995).
Kinetic link theory	Individual segmental patterns and contributions to a whole-body, dynamic movement. (Welch, Banks, Cook & Draovitch, 1995).
Linear periodization	A strength training model in which cycles and macrocycles are utilized to provide progressive resistance (Baechle & Earle, 2000).
Loading phase	See trigger phase.

Medicine ball hitter's throw (MBHT)	A field test developed by Szymanski et al. (2007a; 2007b) during which the baseball or softball player executes his or her swing and releases a medicine ball at the point of contact (D. Szymanski et al., 2007a; D. Szymanski, Szymanski, Bradford, Schade & Pascoe, 2007b).
Muscular power	The ability of a muscle or muscle group to do work at a rapid rate (Baechle & Earle, 2000).
Muscular strength	The amount of force exerted by a muscle or muscle group (Baechle & Earle, 2000).
NCAA	The National Collegiate Athletics Association that is composed of Divisions I, II and III (Bracken, 2007).
Non-linear periodization (undulating)	A resistance training model in which alterations are made to the load and volume on a weekly basis (Baechle & Earle, 2000).
Overweight training	Using a weighted implement heavier than a standard bat for swing repetitions (DeRenne et al., 1992).
Plyometrics	A rapid action which employs a countermovement to stimulate the stretch-shortening cycle for the generation of power (Baechle & Earle, 2000).
Repetition maximum (RM)	The greatest weight moved at a predetermined number of repetitions (Baechle & Earle, 2000).

Seated medicine ball shot put (SMBS)	A field test used to measure upper extremity muscular power during which the subject was seated against a wall with their knees flexed to 90° angles with the feet remaining flat on the ground. A medicine ball is held to the sternum and projected forward for maximal distance (Mayhew et al., 1993).
Stance	A hitter's basic set-up position in the batters box, prior the delivery of a pitch (Monteleone & Crisfield, 1999).
Stride	A timing mechanism whereby the hitter takes a step toward the pitcher's mound during the delivery or release of a pitch. Represents the change in distance from the initial stance width to the width at the end of the swing (Monteleone & Crisfield, 1999).
Sweet spot	The center of percussion of the bat which is the ideal point of contact between the bat and ball occurring at between 80-85% of the distance from the knob of the bat to the end of the barrel (Bahill, 2004; DeRenne et al., 1992).
Swing	The acceleration phase of the swing is marked by the utilization of the stretch reflex generated during the loading phase, which results in the hips and upper extremity creating a "whip-like" motion of the bat through the hitting area. At the end of the swing phase the bat is decelerated, with the hands

	coming to a rest on the left shoulder (Monteleone & Crisfield, 1999; Welch et al., 1995).
Trigger phase	The countermovement action of the softball swing during which the upper extremity and torso move as a unit as they shift backward and slightly clockwise. This movement occurs in order to preserve the stretch reflex and generate peak power during the swing (Monteleone & Crisfield, 1999; Welch et al., 1995).
Underweight training	Using a weighted implement lighter than a standard bat for swing repetitions (DeRenne et al., 1992).

Chapter II: Review of Literature

Introduction

A relatively small body of research has been conducted on the kinematics of the softball swing. As baseball and softball swings involve similar muscles and movement patterns, baseball studies comprise the majority of the body of research synthesized in this literature review. Modified weight implement training, underwater and dry swing repetitions are among the methods reviewed below each with the aim of improving bat velocity.

Phases and Kinetics of the Swing

Kinetic descriptions of a baseball or softball swing are typically divided into the following phases: set-up, stance, stride, trigger and swing (Flyger, Button & Rishiraj, 2006). Individual players may exhibit different techniques; however, general swing mechanics have been established and are described below for a right-handed batter. A right-handed orientation is such that the left side of the body is closest to the pitcher whereas the right side is closest to the catcher.

Set-up. The batter begins by grasping the bat with both hands with the right hand resting above the left. The bat should be gripped lightly using the fingers and with no space between the hands. Additionally, both of the hitter's second set of knuckles (proximal interphalangeal joints) should be aligned in order to facilitate proper position of the hands at contact with the ball (Monteleone & Crisfield, 1999).

Stance. The hitter typically begins in a balanced position with the feet positioned slightly wider than hip width apart. Hitters may choose to alter the alignment of the feet with orientation to the plate such that their feet are aligned evenly or the front foot is closer or farther away from the plate than the back foot (Flyger et al., 2006). Weight is shifted towards the rear, with the center of mass oriented closer to the right leg of the hitter's base of support. Additionally, the hitter usually maintains an athletic position with the knees flexed, weight on the "balls of the feet" (metatarsophalangeal joints) and the heels slightly elevated off the ground. During this stance position, the bat rests on the anterior aspect of the right deltoid with the forearms forming an inverted "V" shape with the bat as the fulcrum. Bat angles in the sagittal plane vary between hitters from horizontal to vertical based on the individual players' preferences. Less muscle action is required to bring the bat into the swing plane when the bat is positioned with a small vertical slope, whereas a bat with a large vertical slope places less torque on the arm to deliver the bat to the path of the ball (Flyger et al., 2006). Lastly, the head is usually rotated such that the head and eyes are fixed over the batter's left shoulder toward the pitcher (Monteleone & Crisfield, 1999).

Trigger. The shoulder, arm and torso countermovement action prior to the swing is commonly referred to as the "load" or "trigger" (Welch et al., 1995). These three segments move as a unit, shifting backward with a slight clockwise rotation, generating a stretch and elastic energy in the torso to be released during the swing phase. If the hitter times her swing properly, this is the point when she makes a conscious decision to swing or not. The countermovement action of the trigger should be a fluid motion with the swing in order to preserve the stretch reflex and generate peak power during the swing (Monteleone & Crisfield, 1999). This phase initiates the swing but occurs in very close proximity to the stride (Welch et al., 1995).

Stride. The main function of the stride is to provide proper timing for the swing according to visual information determined about the pitch. During the pitcher's delivery or release of the ball, the hitter takes a step toward the pitcher. A hitter with an even stance strides with the foot remaining perpendicular to the path of the ball towards the plate, however the direction of the stride varies with an open or closed stance (Monteleone & Crisfield, 1999). A short and low stride is employed to keep the trunk height constant for the batter's eye level (Flyger et al., 2006). Stride lengths vary and they may be as large as twelve inches; or the stride is used simply for timing where the batter flexes at the hip and knee to elevate the foot and then place it back into the batter's box (Monteleone & Crisfield, 1999). To initiate the stride, the left hip flexes elevating the thigh approximately one centimeter (Messier & Owen, 1985). During single support one body weight of force is generated in the vertical direction and this force has been shown to increase with a decrease in height of the hitter's center of mass (Messier & Owen, 1985). Prior to reestablishing double support, the hips begin to accelerate in the counterclockwise direction while the torso, shoulders and arms continue to move in the clockwise direction creating counter torques. At the completion of the stride, the vertical force increases to two body weights (Messier & Owen, 1985). At this point, the arms reach their maximal position and begin their approach to the ball with the left leg exerting force towards the pitcher, and the right leg in the direction of the catcher (Messier & Owen, 1985; Welch et al., 1995). Additionally, the left foot pushes anteriorly whereas the right pushes posteriorly with a magnitude of force between 0.2 and 0.4 body weights (BW). The combination of anteroposterior and mediolateral forces, pushing away from the hitter, creates the counterclockwise rotation of the hips, aiding the kinetic chain movement (Messier & Owen, 1985).

Swing. The distinction between the trigger and swing phase occurs as each of the segments reaches their maximal clockwise position in sequence. The lag between segments augments the stretch reflex and elastic energy of involved muscles, beginning first with the muscles between the pelvis and torso and continuing to the shoulders, arms and lastly the bat (Welch et al., 1995). With both feet on the ground a "closed chain energy transfer" begins, with weight shifting toward the left leg as the right thigh internally rotates, decreasing in height approximately seven centimeters thus accelerating the hips (Messier & Owen, 1985; Welch et al., 1995). As internal rotation continues, the right knee flexes and the hitter's right heel lifts off the ground, rotating the foot until the toes are facing the pitcher. Accompanying the hip rotation is a weight shift as vertical ground reaction force lowers to 0.43 BW and the front leg force increases to 1.6 BW (Messier & Owen, 1985). Meanwhile, the front knee goes into almost complete extension to resist forward translation of the center of mass (Monteleone & Crisfield, 1999). Both the left and right legs undergo a deceleration phase prior to contact, during which flexion of the knees and hips occurs. The thighs extend and in effect elevate the body for the remainder of the swing through contact with the ball (Messier & Owen, 1985). These actions provide a stable base necessary to support the upper extremity's rotation. As each segment rotates from its maximally rotated position around the trunk toward the ball, the summation of force is completed by the upper extremity; resulting in humeral and forearm extension which causes the bat to snap through the strike zone (Monteleone & Crisfield, 1999; Welch et al., 1995).

Due to the motion of a softball pitcher's arm (right handed) moving in a clockwise direction, the ball is typically propelled from the hip upward as it moves closer to the hitter. In order to increase the amount of time the bat and ball are on plane with each other, the swing plane of the bat should be angled slightly downward (Monteleone & Crisfield, 1999). Upon contact with the ball, the front leg braces the hips from excessive translation towards the ball while the right leg is used to support the hitter's body weight. Excessive forward translation during the swing is disadvantageous as it disrupts the kinetic chain sequence and timing of the swing (Welch et al., 1995). Ideally, upon release of the ball from the bat, the arms and wrists are in full extension with the arms, forearms and wrists forming straight lines with the bat (Monteleone & Crisfield, 1999). Throughout the swing the eyes and head should follow the path of the ball. After the swing, regardless of the outcome, the hitter's hands continue to follow an angular path around the body until they come to a rest. This occurs as larger muscle groups decelerate the bat until it reaches its final resting position on the left shoulder with the bat crossing over the upper back (Monteleone & Crisfield, 1999; Welch et al., 1995).

Swing Biomechanics

Welch, Banks, Cook, and Draovitch (1995) described kinetics similar to the previous description using video-analysis to develop a kinematic description of the movement. A global coordinate system was used to determine the location of the center of mass and segmental angular velocities during the swing (Welch et al., 1995). Twenty-five right-handed major league baseball players with a batting average above .250 (in a minimum of 100 at bats) were used for this study. Subjects assumed their hitting stance and began their swing with a stride followed shortly by the loading phase and, lastly, a swing. The clockwise rotation during the loading phase was measured at the hips, shoulders and forearms. The greatest rotations were observed in the forearm segments with approximately 150° during the loading phase; whereas the shoulders and hips underwent 30° and 18° of rotation, respectively. The maximally rotated position of each segment during the countermovement was staggered, with the hips reaching maximal rotation at 0.350 sec, the shoulders at 0.265 sec and, lastly, the forearm at 0.230 sec prior to contact with the ball. This lag enhances the stretch reflex, generating elastic energy to be used during the swing. As weight shifted backward in preparation for the stride, the trunk flexed to 21° with 6° of right lateral trunk flexion (Welch et al., 1995). When the hitter raised the left leg to stride, weight is shifted onto the right leg producing ground reaction forces in excess of 102% of the hitter's body weight. This in turn caused the right knee to flex to 32° as 146 N of force are generated horizontally with the production of 26 N of force in the vertical direction. The combination of these movements cause the center of pressure to shift 20 cm posterior to the center of mass and towards the right foot (Welch et al., 1995). Upon the establishment of double foot contact, left foot contact position was analyzed. The hitters analyzed primarily employed a closed stride as they strode an average of 12° above horizontal, planting their left foot closer to the plate. Additionally, internal hip rotation enabled the ball of the left foot to make contact with the ground at a 67° angle in the horizontal plane. As weight moved toward an even distribution in this closed kinetic chain, the left heel dropped so that the whole left foot is in contact with the ground. Thus, the left leg produced ground reaction forces of 123% of the hitter's body weight. Shear forces produced by the leading leg were as great as 292 N in the direction of the plate and 280

N of lateral shear force, which created a counterclockwise rotation and prevented anterior trunk translation and premature weight transfer with 58% of the hitter's body weight on the right leg. At this point, the arms reached their maximal clockwise rotation (185°) around the trunk and began their descent to ball contact. Force applied by the right foot amounted to 80 N posteriorly, away from the plate and 184 N towards the pitcher, shifting the center of pressure laterally. Maximal velocities and time prior to contact are exhibited in Table 1 (Welch et al., 1995).

Table 1:

Maximum segmental velocities and time prior to ball contact (Welch et al., 1995)

Segment	**Maximal Velocity (°/s)**	**Time prior to ball contact (s)**
Hips	714	0.075
Shoulders	937	0.065
Arms	1160	0.065

The kinematics described were based upon a coordinate system composed of three directions, x, y and z. The x direction runs between the pitcher's mound and home plate and refers to movement in the same direction of the ball. The y-axis runs vertically, perpendicular to the x-axis and denotes changes in slope of the swing. The z direction refers to an axis running through the hitter's umbilicus, anterior-posteriorly towards home plate. Components in all three planes contribute to linear velocity of the hands as bat approaches the ball. Maximal velocities of the hands reached 19 $m \bullet s^{-1}$ in the z-axis and 16 ms^{-1} along the y-axis, 0.040 s prior to contact with the ball. Bat velocity then becomes dominated by the linear component of the hands travelling toward the ball when the inertial lag of the bat behind the arms is rectified and the last of the kinetic energy is utilized. This occurs approximately 0.020 sec prior to contact with the ball, with the bat reaching angular velocities as high as 1588°/ sec, as seen in Table 2. Proper striking position of the ball is achieved at 0.015 sec prior to contact when the leading elbow extends, creating a maximal linear velocity along the x-axis of 31 m/s (Welch et al., 1995). Contact with the ball is made as the bat nears 29 m/s in the x direction. At this time the front leg is acting as resistance as it braces the rest of the body and produces 84% of the body weight's force. As the right leg pivots, 16% of the body's GRF acts through it. Meanwhile, the trunk has almost completed its 26° counterclockwise rotation, coming to a stop with 9° of trunk extension and 20° of right lateral flexion. Once in this position, the body is able to decelerate the bat (Welch et al., 1995).

Table 2:

Maximal Segment Velocities (°s^{-1}) (Welch et al., 1995)

Segment	**Linear or Rotational Velocity**	**Mean Velocity (°s^{-1})**	**Standard Deviation (°s^{-1})**
Hip	Rotational	714	76
Shoulder	Rotational	937	102
Arm	Rotational	1169	96
Bat	Linear	31	2

Messier and Owen (1984) conducted a kinematic analysis of softball batters using a force platform and motion analysis system. All of the subjects in this study (n=8) were current or previous members of a NCAA Division I softball team. Each hitter was instructed to swing only at pitches above her waist. Two swings producing a hard-hit ball into fair territory were used for this study. The same coordinate system was used for this study as was used in the study by Welsh (1995). Kinematic analysis indicates a slightly downward swing pattern in the y-axis, which varied between hitters. More powerful hitters were found to have a slightly larger upward component immediately prior to contact with the ball. Furthermore, as the hands near contact, they tended to deviate away from the body and towards the plate (in the z-axis), generating maximal linear velocity 65 ms prior to contact with the ball. Movement in the x-direction reached maximal linear velocity 20 ms before ball contact. Upon combining all of the linear swing components the resultant bat velocity was found to be 19.08 ms^{-1}. Since maximal velocity is reached prior to contact, power is not maximized during the swing at ball contact. Linear and rotational kinetic energy (KE) were also determined. Linear bat KE composed 59.8% of the total KE whereas rotational KE accounted for 40.2%. A decrease was found in rotational KE as it decreased to 29.4% of the total KE at contact with the ball.

A follow-up study by Messier and Owen (1985) further investigated lower extremity (LE) kinematics and GRF produced during a softball swing. Each of the subjects (n=7) had experience at the collegiate level and in the Amateur Softball Association (ASA) prior to college. A force platform and motion analysis system was employed to quantify lower extremity motion during swings against a pitching machine shooting softballs at 85.26 $km \bullet h^{-1}$. Joint markers were placed on the bilateral foot, ankle, knee and hips to measure their location throughout the swing. Location of the force platform was alternated between the front and back foot in order to quantify the stride and rotational components of the right leg. Results from the kinetic analysis are described in the previous section. The protocol for this study mirrored Messier and Owen's (1984) previous study. Lower extremity kinematic analysis of the player's swings revealed several commonalities between hitters. The initial 0.20 s of angular joint accelerations (transverse plane) of the right thigh were negligible, suggesting a steady velocity. As the swing progressed to 0.30 and 0.20 sec prior to contact with the ball, increases in angular velocities of the right thigh segment reached accelerations as high as 15 rad•s^{-2}. The left thigh, however, experienced a significant increase in angular acceleration to nearly 37 rad•s^{-2}, followed by a rapid deceleration to -20 rad•s^{-2} prior to contact. Meanwhile, approximately 0.10 sec before contact, after hip rotation, the left knee extended to 161° whereas the right knee reached an angle of 124°. During the last 0.1 s prior to contact, the right ankle transitioned from dorsiflexion into plantarflexion as the hips rotated. This rotation was also associated with slight inversion and plantarflexion of the left ankle in order to balance the body after the swing (Messier & Owen, 1985).

The Kinetic Link

The kinetic link theory is used to explain individual segment contributions during whole-body movements such as a baseball or softball swing and is commonly referred to as the inertial force. The creation of an efficient kinetic chain depends on the mechanical and sequential aspects of the movement, both of which play a vital role in the development of bat velocity (Welch et al., 1995). During a kinetic chain movement, accelerations and decelerations of individual segments are responsible for the summation of torque and velocity visible at the distal segment (Atwater, 1979; Kreighbaum & Barthels, 1981). The magnitude of the clockwise movement occurring in the loading phase and the appropriate unlocking sequence of the joints are major considerations in the generation of power (Welch et al., 1995). Within a kinetic chain, each distal joint becomes active as its proximal joint reaches its peak angular velocity (Kreighbaum & Barthels, 1981). Kreighbaum and Barthels (1981) describe an “inertial lag” that occurs when a delay is experienced between segments and this increases the elastic recoil of the stretched muscle in a whipping action. Transfer of angular velocity occurs with the slowing of the proximal segment. In the case of a softball swing, the backward momentum occurring during the load stretches the torso muscles eccentrically and, upon initiation of the swing, the muscle action of the upper extremity is enhanced by the activation of the torso musculature. The largest segments in the chain rotates counterclockwise first, followed by smaller segments in the following sequence: hips, torso, shoulders, arms, wrists and bat. As large segments begin to decelerate, angular and linear momentum is transferred to smaller segments and, lastly, the bat (Welch et al., 1995). The efficient transfer of energy between segments during the swing is reliant on torso rotational strength regardless of swing patterns (D. Szymanski et al., 2007b). Bat velocity represents the summation of individual segmental velocities which are transferred to the ball upon contact (Atwater, 1979).

The kinetic link theory’s application to the baseball swing was explored by (Miyanishi, 2005). Each of the subjects (n=8) completed eight swings through three axes where angular impulse and momentum of the “body” (without arms) and “arms and bat” was measured. The bat velocity at impact was not significantly different between the unaltered swing (28.1±2.2 ns) and the elbow extension swing (28.7±2.6 ns). Therefore, it was determined that consciously extending the left elbow during a swing had no significant effect on bat velocity. The findings of this study suggest a relationship between the angular impulse generated with the lower extremity's base of support and the angular momentum exhibited by the bat and arms during the swing (Miyanishi, 2005).

MacWilliams, Choi, Perezous, Chao and McFarland (1998) conducted a study to evaluate ground reaction forces and their contribution to the kinetic chain during a pitch delivered by pitchers at the collegiate or high school level (n=8). A custom-built pitcher's mound with a pitcher's rubber was constructed for this study using two Bertec force platforms. Both instruments were inlaid into the mound with the push-off plate located immediately next to the rubber. The second plate, which was used to measure landing forces of the stride, was tilted forward about the y-axis 4.8° and was adjusted for each individual pitcher based on stride length. Five pitches were thrown to a catcher and the GRF was measured for direction and force (in body weight) with respect to time before ball release. The local coordinate system was set-up such that the x-axis was oriented horizontally from the pitcher's mound toward the catcher; the y-axis ran the parallel to the length of the pitcher's rubber and the z-axis acted vertically through the center of the rubber. Data on the landing platform was reported in terms of the forces applied by the foot through the center of pressure. Pitch velocity was determined to be a reflection of the pitcher's ability to apply linear and horizontal momentum during the landing phase. A strong correlation was determined between the resultant push-off shear force (R^2=0.76), and anterior-posterior shear (r^2=0.82) and medial-lateral shear

(r^2=0.74) force and linear wrist velocities, suggesting a strong contribution of the lower extremity to overall pitch velocity. Ball velocity was also highly correlated with anterior-posterior (r^2=0.86), medial-lateral (r^2=0.70) and resultant (r^2=0.88) shear force at landing and linear wrist velocity at ball release. Thus, the baseball pitch represents a rotational motion in which leg strength is highly correlated with the generation of maximal velocity at a distal segment (MacWilliams, Choi, Perezous, Chao & McFarland, 1998).

Sport Specific Training: Hitting

Various modes of training have been employed and studied by coaches and strength and conditioning professionals working with baseball and softball players to improve bat speed, trunk rotation and muscular power. Ebben, Hintz and Simenz (2005) conducted a survey of Major League Baseball (MLB) strength and conditioning coaches to determine the training trends for baseball's most elite level athletes. A total of twenty-one coaches responded to open-ended questions on topics such as: strength and power, flexibility, physical tests, plyometrics and sprint speed development. The results indicate several notable trends. Only 28.6% of coaches reported using Olympic style lifts whereas all programs used machines for at least one aspect of strength development. Large muscle groups such as squats, lunges and step-ups were listed as the most important sport specific exercises; other notable exercises included lat-pull downs, various rowing techniques, chest and shoulder presses and shoulder stabilization exercises. Linear periodization was used by over 85% of the coaches surveyed with three teams using non-linear, undulating programs. Furthermore, the majority of coaches indicated plyometrics to be an integral part of their program. Power production (80%) and speed (71%) were also developed through the use of lower extremity plyometrics. Approximately half of the coaches reported using upper extremity and whole body plyometrics, including torso rotational exercises with medicine balls (Ebben, Hintz & Simenz, 2005). Underwater training and dry swings are two methods of training not mentioned in this study on the practices of MLB strength and conditioning coaches and will be discussed below.

Warm-up with variable bat weights. This training method addresses the principles of transfer of training and velocity specificity. Sixty high school male baseball players participated in a study by DeRenne, Ho, Hetzler, & Chai (1992), which looked at the effect of variable warm-up bat weights on subsequent swings in a simulated game situation. Two photo-detecting infrared sensors were used to measure bat velocity for each of the swings. Implement ounce weights for this study included: 51, 48, 45, 34, 30, 29, 27, 23, 58 and 62. The length and diameter of each of the bats was consistent with a sweet spot 12.7 cm from the end of the bat. For underweight bats, weight was evenly removed across the length of the barrel. Each subject underwent a full-body warm-up prior to completing four warm-up swings with a designated bat weight. This was followed by three swings with the 30 oz. standardized weight bat. The authors found that warm-up implement weights greater than 34 ounces and less than 27 ounces resulted in the largest decreases in bat velocity. Bats within the range of 27 and 34 ounces produced the greatest average velocities. The authors of this study therefore concluded that warm-up bat weights should remain within ±10% of the player's standard game bat. Alterations of greater than 10% may result in the recruitment of a different set of motor units from those used during a swing with a standard bat (DeRenne et al., 1992).

These results were contrary to findings by Montoya, Brown, Coburn, & Zinder (2009) who measured nineteen previously competitive baseball players. The players were assigned to one of three bat weight conditions: light (9.6 ounces), normal (31.5 ounces) and heavy (55.2 ounces). Each player completed a five-minute warm-up on an upper-body ergometer prior to completing testing. Three sessions occurred with 48 hours between testing with trials using the light, normal and heavy bats. Each of the subjects executed five warm-up swings with a given bat followed by five maximal swings with the normal weight bat. Maximal velocity was determined for each of the maximal swings with the normal weight bat. The slowest velocities were observed when the heavy bat was used (41.79±3.58 mph), followed by normal bat weight (51.25±3.01 mph) and, lastly, the light bat (63.57±3.58 mph) (Montoya, Brown, Coburn & Zinder, 2009). These results support of the role that load specificity may have on the selection of a warm-up weight bat. The differences in ounce weight between the heavy and light bats selected for this study and the previous study were considerable. Therefore, alterations in swing mechanics and motor units recruited may account for the differences with respect to light bat velocities found in each of the aforementioned studies (Montoya et al., 2009).

Swing repetitions with variable bat weights. DeRenne, Buxton, Hetzler, and Ho (1995) investigated changes in bat velocity as a result of swing repetitions on 60 NCAA Division I baseball players across three conditions: batting practice, dry swings and a control group. The batting practice group completed their repetitions off a live pitcher, whereas the other two groups practiced dry swings only. Additionally, both the batting practice and dry swing groups were assigned to 5 sets of 10 repetitions, alternating the use of light (-1-3 oz), heavy (+1-4 oz) and game-weight bats for their training. Alternatively, the control group completed the same number of repetitions using their game weight bat. Players completed 150 repetitions four times each week for the duration of the 12-week study. Fifteen seconds were allotted for alternating between bats and 30 seconds were allowed between each set during training. Statistically significant increases in bat velocity were found across all three groups with the batting practice (10%), dry swing (6%) and the control group (1%). The results of this study suggested that the employment of swing repetitions during training increased bat velocity as attributed to transfer of training and movement specificity. The original study on bat velocity by DeRenne, Ho, Hetzler and Chai (1992) recommended no more than a 10% variance when selecting a warm-up implement; however, it was determined in this study that a 12% change in bat weight provided the proper amount of overload or underload during swing training for favorable improvements in the force-velocity curve (DeRenne et al., 1995).

Sergo and Boatwright (1993) conducted a similar study, which yielded different results on the relationship between bat weight and velocity. This six-week study utilized two groups of 12 NCAA Division I baseball players to determine the effect of swing repetitions using a heavy bat (62 oz.) when compared to a “standard bat” (31 oz.) on bat velocity. All subjects completed 20 sets of five swings three times each week. Post-testing revealed no significant changes in bat velocity for either group. The authors attributed these results to a small number of athletes participating in the study

(Sergo & Boatwright, 1993). Additionally, the short training period and lower total repetitions may have limited force-velocity and neural adaptations during this study.

Underwater swing training. Water resistance was used by Stuempfle, Crawford, Petrie, and Kirkpatrick (2004) as a method to increase the force demands while decreasing maximal velocity. Twenty-five female college students with softball experience were recruited for this study, while sixteen of the subjects used for the experimental groups were NCAA Division III softball players. Bat velocity testing was completed off a batting tee. Ten swings were analyzed for each subject with a five second rest between each repetition. The contact point for the ball was set in the middle of the plate with the height adjusted to the subject's greater trochanter. Each hitter performed ten swings with five seconds of rest between each repetition. The intercollegiate players of the experimental groups underwent pre-testing and were divided evenly into dry (n=8) and underwater (n=8) swing training groups. An additional control group (n=9) was composed of students who were not participating on the collegiate team. An "Easton T1 Thunderstick" (weighing 737.1 g, 76.20 cm in length and 2.54 cm in diameter) was used for testing and training in place of a softball bat. The Thunderstick is a uniform diameter for the length of the bat and was used to potentially eliminate changes in the hitter's swing patterns when training underwater (Stuempfle, Crawford, Petrie & Krirkpatrick, 2004).

The underwater group's training protocol was composed of three sets of fifteen swings in shoulder-deep water three times each week for the duration of the eight-week study. Subjects were allowed thirty-seconds of rest between each set. The same protocol was used for the dry swing group who performed their repetitions in a practice setting at a field house. All experimental subjects participated in a concurrent periodized resistance training program with an initial intensity of 70% of the 1 RM, which increased for the duration of the eight-weeks until reaching 95% 1 RM during the last week of the study. This program consisted primarily of isotonic exercises with the goal of improving muscular strength. No resistance or swing training was administered to the control group during the study. Post-testing was conducted after eight weeks, using the same protocol as pre-testing. Results revealed a significant decrease in bat velocity in the experimental groups for both the dry land (14%) and underwater (21%) training. The authors of this study suggest that the slow-velocity isotonic resistance training was responsible as the control group did not experience any notable changes between pre and post testing. The authors speculated that hypertrophy of the Type I slow twitch fibers and shift of Type IIb fibers towards the intermediate Type IIa decreased the hitter's ability to perform at high velocities. It was also suggested that the strength program did not adequately emphasize core training, resulting in possible trunk muscle fatigue throughout the study. Water may have provided too much overload, preventing the hitters from training at a velocity similar to testing and game situations (Stuempfle et al., 2004). Furthermore, it is possible that the water simulated more of a strength endurance type training adaptation rather than one associated with power. An additional confounding factor was the subject population for each group. Instead of randomizing subjects, the experimental group was composed of current players whereas the control group was composed of students not participating in athletics.

Resistance Training Programs

Grip strength and forearm training. Training studies have focused heavily on forearm and wrist strength and the associated contribution to the baseball swing. Three studies have determined that grip strength has little impact on high school and college baseball player bat velocity (Hughes, Lyons & Mayo, 2004; D. Szymanski et al., 2006; D. Szymanski, Szymanski, Molloy & Pascoe, 2004). Hughes, Lyons and Mayo's (2004) study on collegiate baseball players (N=23) investigated changes in bat velocity as a result of a six-week forearm training protocol. Experimental subjects performed six various forearm exercises (3 x 10) three times each week for the duration of the study, with progressive increases in repetitions. Both the experimental and control groups also participated in regular sport specific training. Minimal improvement in grip strength was observed in the experimental group during post-testing which also revealed no significant correlation between grip strength and bat velocity as both groups made similar improvements in bat speed (Hughes et al., 2004). These results suggest that the performance of sport specific training may have been adequate stimulus to produce improvements in bat velocity over the period of six weeks.

Szymanski (2006) also conducted a training study to determine the effect of forearm training on high school baseball players (N=46). A motion capture system was used to track linear bat end velocity (velocity immediately prior to contact with the ball), center of percussion velocity, mean hand velocity and time to ball contact (the slope of the bat's approach to the ball) for six swings off of a tee. The swing plane was adjusted to the height of the player's pubic arch and twenty seconds of rest were allowed between each swing. Hitters were allowed to select between two bats, 30 oz.

(33 in.) and 29 oz. (32 in.) with a pre-determined moment of inertia (MOI). The premise behind this study was that the generation of bat speed is highly dependent on strong wrists and forearms. Training and control groups in this study participated in a whole-body resistance training program. Pre and post-testing protocols measured improvement in the back squat, barbell bench press and a grip test. As expected, there was no influence of training on percent change between the control and experimental groups on bat velocity (3.5%, 3.2%), center of percussion (4.3%, 3.4%) or hand velocity (4.9%, 6.3%), respectively. Grip strength was an additional performance parameter determined to have little impact on variables measured in this study. Both groups exhibited increases across all variables, and there was no statistically significant difference between the two groups. While forearm and wrist strength is required for the application of power to the ball upon contact, these studies demonstrate that they play only a small role in the generation of power during a baseball swing. As a result, the focus of further study shifted to other parts of the kinetic link (D. Szymanski et al., 2006).

Progressive forearm resistance applied to overload the elbow and shoulder muscles has also been applied in the form of weighted neoprene sleeves over a three and 12-week study in novice college-age subjects, and high school baseball players, respectively. The untrained college students underwent an eight-week periodized dry swing training protocol (105 swings x 3 days per week) using weighted forearm sleeves for progressive resistance. Research variables included lean body mass (LBM), body fat percentage (% BF) parallel squat (PS), bench press (BP), dominant grip strength (DGS) and non-dominant grip strength (NDGS). Post-testing revealed a moderately high positive correlation between bat velocity (BV) and dominant grip strength (r=0.79), between non-dominant grip strength (r=0.77) and LBM (r=0.70) as well as between batted ball velocity and LBM (r=0.78)(Reed et al., 2008). A similar protocol was followed in a 12-week study of high school baseball players. When analyzing the same variables, the only significant relationship found was a low positive relationship between BV and PS strength (r=0.37) (J. Szymanski et al., 2008).

Resistance training and plyometric programs. The effects of dynamic core training programs on improvements in baseball specific parameters have also been examined. Szymanski et al. (2007a) studied the effect of resistance training and upper body plyometrics on torso rotational strength, angular hip, angular shoulder and linear bat velocity in two groups of high school baseball players (N=55). Three RM tests were conducted on torso rotational strength using a torso rotation machine (Cybex International, Inc, Medway, MA), in addition to "medicine ball hitter's throw", parallel squat and bench press. The medicine ball hitter's throw is a ballistic rotational power test recently introduced to represent torso strength, power and torso rotational strength in baseball and softball players. This test is particularly relevant since maximal distance is achieved through the combination of torso rotational strength and appropriate segmental timing of the torso, hips and upper extremity in the kinetic chain. For this field test, subjects assumed their hitting stance holding a 1-kg medicine ball above their back shoulder. Then, using a movement pattern that closely mirrors their swing that may include a countermovement, subjects were cued to project the ball for maximal distance. Both the control and experimental groups underwent a periodized resistance training program and dry swings, however, the experimental group also participated in a progressive resistance upper extremity plyometric program. Resistance intensity was adjusted every four-weeks when athletes underwent follow-up testing in bench press and parallel squat. Intensity was set between 65-75% of the subjects' 3 RM in the first month and progressed toward 75-85% 1 RM at the end of the 12-week study. The training protocol for the experimental group also included medicine ball exercises such as the hitter's throw, standing figure eights, speed rotations, standing side throw, "granny throw", backward overhead throw and the squat and throw (D. Szymanski et al., 2007a; D. Szymanski et al., 2007b). Linear bat velocity, angular hip and angular shoulder velocity were measured using a motion analysis system. At the end of the twelve-week study both groups made large improvements in bat end velocity, with the experimental group (pre ≈30.0 ms^{-1}, post ≈ 32.0 ms^{-1}) demonstrating a significantly greater improvement when compared to the control group (pre ≈29.0 ms^{-1}, post ≈ 30.0 ms^{-1}). Interestingly, increases in bat end velocity were found to correlate with increases in torso rotation strength, medicine ball hitter's throw, parallel squat, and bench press tests. Improvements were observed by both groups by each of the aforementioned examinations; however, the medicine ball trained group exhibited the only increases in angular hip and shoulder velocities as well as the largest increases in torso rotational strength and medicine ball hitter's throw (D. Szymanski et al., 2007a). The improvements in torso rotational strength and medicine ball hitter's throw as seen by the control group can be attributed to the dry swings and resistance training components of the protocol. This indicates that 100 dry swings performed three times each week with a game weight bat is sufficient stimulus for improvements in rotational torso strength. Furthermore, provided there is an efficient transfer of energy from the hips to the rest of the kinetic chain, an increase in parallel squat strength was reflected by an increase in the medicine ball hitter's throw as seen in both groups. The significantly larger increases in both the dominant and non-dominant torso rotational strength, MBHT distance, maximal BEV and segmental velocities observed in the experimental group can simply be explained by the additional stimulus of the medicine ball program, which included the MBHT, across the twelve-week program (D. Szymanski et al., 2007a).

Similar variables were investigated in a sport specific training protocol conducted on a NCAA Division I softball team (Albert, J. Szymanski, & Stanley, 2008) in a conference presentation. The softball specific tests of strength and power used in this analysis included: BV, batted ball velocity (BBV) and throwing velocity (TV). Three repetition maximum parallel squat (PS), bench press (BP), hang clean, grip strength and dumbbell row were measured along with lean body mass (LBM), percent body fat (% BF), vertical jump 300 yd shuttle, flexibility, agility and running speed. Pre and post-testing revealed only a moderately high positive correlation between LBM and TV (r=0.61) and moderate positive correlation between LBM and batted ball velocity (BBV) (r=0.41). These results led the authors to conclude that improvements in strength should be emphasized to improve batted ball velocity (Albert, J. Szymanski & Stanley, 2008). Bonnette (2008) analyzed the same variables in a cross sectional study on NCAA Division I baseball team in a study on rotational power, bat velocity (BV) and BBV. A moderately high positive correlation was found between the following variables: LBM and BV (r=0.67), DGS and BV (r=0.52), BW and BBV (r=0.58) and LBM and BBV (r=0.60), indicating a strong relationship between torso rotational power, batted ball velocity and bat velocity (Bonnette et al., 2008).

Measurement of Power, Kinetic Chain Efficiency, and Bat Velocity

The tests described below have been reviewed in literature as measures of upper and lower extremity power, rotational kinetic chain and bat velocity.

The medicine ball hitter's throw (MBHT). Selected for its utilization of the kinetic chain in a matter that approximates that of hitting, the MBHT is similar to other measured standing upper extremity plyometrics (Reiman & Manske, 2009; D. Szymanski et al., 2007a; D. Szymanski et al., 2007b). Given the rapid nature of this test and sport specific movement pattern, it would seem the MBHT would represent torso rotational power. Furthermore, it may be an indicator of the optimization of the kinetic chain where the torso effectively propagates power from the lower extremities to the upper extremities to project the medicine ball in a movement similar to contacting a ball. Additionally, rest periods and resistance can be manipulated to reflect sport specific situations during training and testing (D. Szymanski et al., 2007a; D. Szymanski et al., 2007b). Repeatability for the MBHT was established by Szymanski et al. (2007b) to be statistically significant (r=0.96, p<0.001) during a pilot study.

Seated medicine ball shot put (SMBS). The SMBS has been employed to measure upper extremity muscular power in many athletic populations. A study conducted by Lyttle, Wilson and Ostrowski (1996) investigated the relationship between the SMBS and upper extremity power. During this study, recreationally active males (n=39) propelled a 4.6 kg medicine ball for maximal distance. The results indicated that the SMBS was highly correlated with upper extremity power (r=0.84) as measured by an explosive plyometric push-up conducted on a force platform (Lyttle, Wilson & Ostrowski, 1996). The SMBS was also studied in female NCAA Division II athletes (n=64) where body mass was determined to be a significant contributor (r=0.61) to SMBS performance. This indicates that body mass should be accounted for when using the SMBS as a measure of relative upper extremity power in female athletes (Mayhew, Bemben, Rohrs & Bemben, 1994). Thus, normalizing test results may be warranted in order to account for differences in body size.

Countermovement jump (CMJ). The vertical jump height as determined using the Vertec™ measurement system is among the most frequently used lower extremity strength and power tests (Reiman & Manske, 2009). One-third of the Major League Baseball (MLB) strength and conditioning coaches surveyed by Ebben, Hintz and Simenz (2005) reported testing lower extremity power/strength measures. Five of seven coaches surveyed indicated the use of the vertical jump. Additionally, when comparing professional baseball players to amateurs, there was a significant intergroup difference with MLB players scoring higher than amateurs at all minor league and rookie levels. The finding that elite players possessed greater leg strength and power presents a possible connection between vertical jump height and performance (Hoffman, Vasquez, Pichardo & Gershon, 2009). Nuzzo, McBride, Cormie and McCaulley (2008) found significant relationships between back squat power and CMJ peak power (r=0.676), and height (r=0.690) in Division I AA football players (n=12) when normalized for body mass (Nuzzo, McBride, Cormie & McCaulley, 2008). Another study, conducted by Requena et al. (2009) found a significant correlation between CMJ height and peak power at 75% (r=0.65) and 100% (r=0.56) of the subject's body weight during a concentric-only squat in male soccer players (n=21) (Requena et al., 2009). Lastly, a study was conducted on college-age women (n=50), ages 18-35 using a computerized squat machine, which directly measured power at variable angular velocities. This study found a significant relationship between a modified vertical jump, where only the non-dominant arm was used in the countermovement, and squat peak power at $70°s^{-1}$ (r=0.69) and $85°s^{-1}$ (r=0.65) (Ashley & Weiss, 1994). Listed below are norms established for NCAA Division I softball players (Table 3).

Table 3

NCAA Division I Softball Players Vertical Countermovement Jump Norms (n=118) (Hoffman, 2006)

	Height	
Percentile	in.	cm
90	18.5	47.0
80	17.0	43.2
70	16.0	40.6
60	15.0	38.1
50	14.5	36.8
40	14.0	35.6
30	13.0	33.0
20	12.0	30.5
10	11.0	27.9
Mean	14.6	37.1
σ	2.9	7.4

Linear bat velocity using motion analysis. None of the studies reviewed in this body of literature have utilized motion analysis to measure linear velocity of the bat, however, Messier and Owen's (1984) study utilized motion analysis to measure lower extremity kinematics of the softball swing. A few studies have used accelerometry video analysis and force platforms to measure the swing, however, photo-detecting infrared sensors are most frequently used.

Summary

The ability of a player to sequentially accelerate and decelerate individual segments is imperative in the generation of distal segment velocity through the utilization of elastic recoil and transference of backward momentum into rotational power (D. Szymanski et al., 2007b; Welch et al., 1995). Furthermore, an efficient propagation of force along the kinetic chain is reliant on torso rotational strength (D. Szymanski et al., 2007b). This has been noted in both the baseball and softball swings as well as the baseball pitch (MacWilliams et al., 1998; D. Szymanski et al., 2007a; D. Szymanski et al., 2007b). GRFs generated during both the baseball pitch and baseball or softball swing represent muscular force that is being produced at the base of the kinetic chain to be transmitted across segments towards the distal end segment (e.g. bat or ball) (MacWilliams et al., 1998; Welch et al., 1995). Studies conducted on various training methods, such as progressive forearm resistance training (Hughes et al., 2004; D. Szymanski et al., 2006; D. Szymanski et al., 2004), have concluded that the wrists and forearms simply transmit force to the ball and themselves, have little influence on force generation. Alternatively, a dynamic core training program was determined to have a positive effect on bat velocity and angular joint velocities. Furthermore, several studies have noted a relationship between lean body mass and bat velocity or batted ball velocity suggesting muscle mass to be a contributory factor in the production of maximal bat velocity (Albert et al., 2008; Bonnette et al., 2008; J. Szymanski et al., 2008).

Increases in bat velocity, as described in the literature, can be achieved through training (to improve muscular strength, power and torso rotational strength) and an efficient kinetic chain sequence. GRFs and lower extremity muscular strength and power tests can be used to evaluate the capacity of a hitter to generate power in the legs. This power can result in high bat velocities if propagated along the kinetic chain efficiently between segments in the kinetic chain. Thus, it is imperative that individual segments achieve maximal velocity in the proper sequence at the appropriate time for kinetic energy to be transmitted from the bat into the ball. In the present study, lower extremity power will be captured using the vertical jump, SMBS, and the MBHT will be used to quantify the kinetic chain efficiency. The employment of these three measurements will allow for analysis to determine which variable contributes most significantly to bat velocity in softball players.

Chapter III: Methods and Procedures

Introduction

The aim of this study was to determine factors that might be related velocity, among collegiate softball players. One testing session was used to measure the relationship of upper (SMBS) and lower extremity power (CMJ), the hitter's ability to propagate power through the rotational kinetic chain using the MBHT and the generation of maximal bat velocity during a swing.

Description of the Study Population

Recruitment for this study began upon the approval of the methods by the human subjects committee at Western Washington University. Collegiate softball players and alumni from two NCAA Division II Softball teams were recruited for this study (n=31). The subjects were females, with a minimum of four years of playing experience prior to engaging in this study. Additionally, all subjects had previous resistance training experience in a periodized weight program including all major muscle groups. Both right and left-handed hitters were used for analysis. All subjects were tested in-season during practice time, which accompanied resistance training, conditioning and sport specific practice.

Quasi-Experimental Design

This study will utilize a single-order correlation to identify relationships and a regression equation to evaluate the strength of prediction between the independent variables of the MBHT, SMBS and vertical jump, and the dependent variable of maximal bat velocity in collegiate softball players.

Data Collection Procedures

One testing session was scheduled for each individual subject. Subjects first signed an informed consent form in order to acquire general information. Next, subject data and anthropometrics were recorded for each subject including height, body weight, arm length and stance width. Prior to testing, a five-minute, whole-body warm-up and 5-minute static stretching period was completed by each subject. Subjects were instructed to warm-up as though they would prior to practice or other sport specific activities. This warm-up was chosen to prevent undue fatigue or inadequate warm-up that could potentially interfere with performance tests. Next, subjects were assigned their exercise order at random and were introduced to the MBHT, SMBS exercises and CMJ protocol and were allowed familiarization with both movements until they felt comfortable. Three maximal trials of the MBHT, SMBS and vertical jump were collected. Linear bat velocity was tested last. Prior to maximal velocity swing testing, subjects were allowed twenty warm-up swings (2 x 10 swings) followed by five maximal trials using a bat instrumented with motion analysis markers to measure linear bat position (D. Szymanski et al., 2007a). A batting tee was used for maximal swings. In order for a trial to be included, it was required that the subject did not make contact with the tee.

Anthropometrics. Body height was measured in cm using a stadiometer. Using a tape measure, arm length (cm) was measured from the lateral aspect of the acromion process of the right shoulder to the head of the 3rd metacarpal of the third digit on the right hand. Stance width was also measured from the middle of the calcaneous on the front foot to the ball of the foot on the back foot.

Medicine ball hitter's throw. The MBHT was introduced to participants and familiarization trials were allowed for each hitter until they felt comfortable with the movement. Subjects were instructed to assume their normal hitting stance, and simulate their swing, projecting the medicine ball laterally at the point of contact for maximal distance (D. Szymanski et al., 2007a; D. Szymanski et al., 2007b). Each individual was allowed to practice throw repetitions until they felt comfortable with the movement pattern. Three maximal distance medicine ball throw trials were conducted using a 1 kg medicine ball with the longest throw being selected for analysis. Subjects were required to keep their feet behind a line marked on the floor with tape. Spotters were used to detect maximal distance and trial distances were measured to the nearest inch. Fifteen seconds of rest was allowed between trials in order to more accurately reflect competition during which batters are allowed ten seconds to get set after the pitcher receives the ball from the catcher in the circle (Abrahamson, 2009). Maximal distance in meters was recorded for the trials, and the longest distance throw was used for analysis.

Seated Medicine Ball Shot Put (SMBS). During this field test, the subject was seated against a wall with their knees flexed to 90° angles with the feet remaining flat on the ground. A 4.55 kg medicine ball was held in the middle of the chest and projected forward for maximal distance. Spotters were used to determine and mark maximal trial distances which were measured from the subject's sternum to the medicine ball's landing position of the middle of the medicine ball. Separation of the torso from the wall was grounds for trial disqualification (Mayhew et al., 1993). Three maximal distance trials were conducted and the longest distance throw was used for analysis.

Vertical jump. Maximal height was measured using the Vertec™ (Sports Imports, Columbus, OH) to determine lower extremity power. Subjects began by standing adjacent to the Vertec™ with their right arm extended above their head and body weight distributed evenly to determine baseline vertical reach. Next, subjects were allowed to reset their body then, without moving their feet, subjects were instructed to perform a countermovement jump for maximal height with the upper extremities allowed to contribute to force production. False stepping was grounds for trial disqualification (Reiman & Manske, 2009). Jump heights were recorded and the highest trial was used for analysis.

Maximal bat velocity. Trials were conducted using an Easton Synergy fastpitch softball bat (Easton-Bell Sports, Van Nuys, CA) of standard size (24 ounces, 34 inches). A batting tee (Easton Portable Bucket Tee, Easton-Bell Sports, Van Nuys, CA) was adjusted to the height of the hitter's umbilicus and aligned with the contact point for the middle of the plate. The bat was instrumented with reflective markers at 10, 15 and 20 cm from the end of the bat. These markers were used to represent the "sweet spot" of the bat, indicated to be located at the 15 cm mark. Marker positions during the swing were measured using a Qualisys 7-camera motion analysis camera system (Gothenburg, Sweden). Calibration, prior to trials, was completed using a global reference frame (L-frame) and wand. Standard deviation of the markers was required to be no larger than 0.99 mm during a 90-second calibration trial. Participants were instructed to take a stance and swing like they would in a game situation. Fifteen seconds of rest were given between swings in order to more accurately reflect game situations (Abrahamson, 2009). Furthermore, subjects were instructed to hold the bat such that the markers would not contact the tee upon contact. Five maximal swings were measured, with the highest velocity used for analysis.

Statistics

A standing trial using the instrumented bat was conducted to establish the mass and length of the bat. The Qualisys Track Manager (QTM) was used to identify each of the markers for the standing trials. Next, each of the static trials was exported to Visual3D (C-Motion, Inc., Gaithersburg, MD) from which static models were created. These models were used to identify the set length (0.863 m) and mass (0.681 kg) in each of the subsequent movement trials. A "pipeline" was created to analyze the position data of the 15 cm landmark. An 8-Hz low pass Butterworth filter was applied to the position data prior to analysis to calculate linear velocity of the 15 cm marker. Labels were applied to all of the markers for each swing, and then exported to V3D. Next, trials were assigned to the appropriate models and processed for linear velocity of the 15 cm landmark.

PASW Statistics 18 (SPSS inc., Chicago IL) was used for statistical analysis. A Kolmogorov-Smirnov test for normality was run on each of the variables to determine their distribution. In order to determine if arm length and stride width would contribute to bat velocity, variables were also tested for normality to determine if swing characteristics or anthropometrics (above body mass and height) were related to bat velocity. Bivariate correlations were calculated for normally distributed indepentent variables using Pearson's correlation coefficient, whereas Spearman's Rho was used for non-normal variables. Anthropometric measurements, performance measures and swing characteristics were tested for correlations with linear bat velocity. Performance variables and bat velocity were also represented in body heights, in order to evaluate the contribution of body height on these variables, since each of them may depend on height or arm length of the individual. Significance was established at $p < 0.05$ (1-tailed). Two linear regressions were derived using non-normalized performance measures and bat velocity, as well as normalized performance measures and bat velocity. R^2 values, R^2 change, Durbin-Watson statistics, B coefficients, and variance inflation factor (VIF) were also examined to determine the independent contribution of each variable and the potential bias of the regression model.

Chapter IV: Results and Discussion

Results

Descriptive statistics. Means, medians and standard deviations (±SD) for performance variables, swing characteristics and anthropometric results are included in Table 4. Normalized values are normalized for body height (BH).

Table 4:

Means and Standard Deviations of Bat Velocity Predictors

Variable	**Mean**	**± SD**
Body Mass (kg)	72.70	13.64
Height (m)	1.69	0.06
Arm Length (m) †	0.66	0.05
Stride Width (m) †	0.01	0.09
Pre-Swing stance width (m) †	0.71	0.09
Post-Swing Stance Width (m) †	0.74	0.09
MBHT (m)	8.67	1.66
Normalized MBHT (BH)	5.13	0.93
SMBS (m)	2.29	0.38
Normalized SMBS (BH)	1.35	0.20
CMJ (m)	0.41	0.06
Normalized CMJ (BH)	0.24	0.04
LBV (m/s)	24.07	1.90
LBV (mph)	53.84	4.25
Normalized LBV (BH/s)	14.25	1.09

†*Median presented for non-normal variables*

Diagnostic Test of Normality. Body mass, height, arm length, pre-swing stance width, post-swing stance width, stride width and maximal scores for the MBHT, SMBS, CMJ and linear bat velocity variables to determine if they were normally distributed. The Kolmogorov-Smirnov test determined body height, mass, MBHT, SMBS, CMJ and linear bat velocity to be normally distributed ($p < 0.05$). Variables that were not normally distributed include arm length, stride width, pre-swing stance width and post-swing stance width. As a result, the logarithm of arm length, pre-swing stance width, post-swing stance width and stride width were also processed in an attempt to transform the data into a normal distribution. The logarithms of stride width, stance width and arm length were non-normally distributed (Appendix Table 1). Normally distributed variables were selected for bivariate correlation and linear regression analysis. Non-normal variables were tested for correlations using Spearman's rho.

Bivariate Correlations. Pearson correlation coefficients (r) were calculated between each of the normally distributed predictors (these values can be seen in Table 5). Moderate significance Pearson Product-Moment correlations ($r = 0.40$-0.59) were found between height and SMBS, body mass and SMBS, height and body mass, and body mass and LBV. Weak relationships were identified between the MBHT and SMBS, LBV and height, and SMBS and LBV (correlations including the variables normalized by body height are contained in Table 5). No significant correlations were found among the distance or speed variables when normalized for body height. Stride width, arm length and stance width, three non-normal variables, were processed using Spearman’s Rho however, no significant relationships with bat velocity were found.

Table 5:
Pearson Product-Moment Correlation Coefficients for Bat Velocity and its Predictors (non-normalized)

	MBHT(m)	**SMBS (m)**	**CMJ (m)**	**LBV (m/s)**
MBHT (m)		.344*	.035	-.012
SMBS (m)			.093	.312*
CMJ (m)				.096
LBV (m/s)				

**Correlation significant at the 0.05 level (1-tailed)*

Table 6:
Pearson Product-Moment Correlation Coefficients for Bat Velocity and its Predictors (normalized for body height)

	MBHT - Normalized (BH)	**SMBS - Normalized (BH)**	**CMJ – Normalized (BH)**	**LBV – Normalized (BH/S)**
MBHT - Normalized (BH)		.265	.041	-.086
SMBS - Normalized (BH)			.013	.097
CMJ – Normalized (BH)				.187
LBV – Normalized (BH/s)				

Table 7

Spearman's Rho Correlations for Stance Width, Stride Width and LBV

	Pre-Swing Stance Width (m)	Post-Swing Stance Width (m)	Stride Width - % of Body Height	Linear Bat Velocity (m/s)
Pre-Swing Stance Width (m)		.666*	-.191	.177
Post-Swing Stance Width (m)			.428*	.209
Stride Width - % of Body Height				.290
Linear Bat Velocity (m/s)				

**Correlation is significant at the 0.05 level (1-tailed)*

Table 8

Spearman's Rho Correlations for Logarithms of Stance Width and LBV

	Log Pre-Swing Stance Width (m)	Log Post-Swing Stance Width (m)	Linear Bat Velocity (m/s)
Log Pre-Swing Stance Width (m)		.666**	.177
Log Post-Swing Stance Width (m)			.209
Linear Bat Velocity (m/s)			

***. Correlation is significant at the 0.01 level (1-tailed).*

As indicated in Table 8, the only significant relationship found using transformed values was between pre-swing stride width and post-swing stride width, which was not related to LBV.

Linear Regression Analysis. A linear regression was applied to the data with linear bat velocity as the dependent variable and each of the performance tests as independent variables as seen in Appendix Tables 4-7. The significance level for the regression analysis was established at $p = 0.05$. The backward method used for this linear regression removed the independent variable with the lowest correlation with LBV ($p \geq 0.10$). The best model (as seen in Appendix Table 8) uses SMBS as a variable to predict LBV, and accounts for only 6.6% of the variance in bat velocity. The best regression equation was:

$$\text{LBV} = 20.530 + (1.546 \times \text{SMBS})$$

The Beta standardized coefficients indicate that the SMBS was the only variable identified in the regression analysis that contributed to the variance in LBV but it was not a significant predictor ($p=0.087$) ($R = 0.312$, $SD = 1.833$).

A linear regression analysis was also conducted using the normalized data for body height, as found in Table 14. This secondary regression was added in order to determine if individuals who are shorter in stature are able to produce similar power and bat velocity as individuals who have the advantage of leverage because they are taller. The backward linear regression eliminated all four variables, since the normalized variables failed to produce significant relationships between independent variables with the dependent variable of LBV.

Discussion

The SMBS was the greatest performance-related predictor of LBV accounting for 6.6% of the variance in bat velocity. Additionally, body mass and linear bat velocity were moderately correlated ($r = 0.405$, $p < 0.05$) which may indicate that body mass does in fact play a role in the generation of linear bat velocity in the present population. Furthermore, none of the variables normalized for body height were well-suited for comparison with normalized LBV, indicating that height may not be as advantageous as body mass or possibly lean body mass (LBM). It is also possible that more sport-specific tests of muscular power may reveal a stronger relationship between power and linear bat velocity. However, this attempt to relate bat velocity to field tests of power was not significant.

The use of LBM in this study may have been a better predictor of LBV than the field tests. Lowe et al. (2010) conducted a study on NCAA Division I softball players (n = 20) to determine the contributions of height, lean body mass (LBM), percent fat, grip strength, lower extremity power and bat velocity. The only significant, moderate relationships were found between body mass (r = 0.50, R^2 = 0.25), lean body mass (r = 0.43, R^2 = 0.18), increased body fat (r = 0.41, R^2 = 0.17) and LBV. Current findings are similar to the results in Lowe et al. (2010). Several studies had similar findings regarding the relationship between high LBM and LBV (Bonnette, 2008; Reed et al., 2008) and LBM and BBV in collegiate and high school in baseball and softball players (Albert et al., 2008; Bonnette et al., 2008).

Lowe et al. (2010) also failed to find a significant correlation between lower extremity power and LBV. This represents another major limitation of this study. The use of the CMJ for measurement of lower extremity power did not reflect the movement patterns of the softball swing. As described in the kinematic study by Welch et al. (1995), the swing involves movements that are highly rotational in nature. Thus, following the specificity of training principle, the movements being trained (or tested) should represent sport-specific movements used in competition (Baechle & Earle, 2000). However, currently, there are no tests that examine leg power with a rotary component. Additionally, the CMJ quantifies vertical power, however, during the swing vertical GRF amounts to only 0.43 BW with the front leg exerting 1.6 BW mediolaterally (Messier & Owen, 1985). Thus, a test measuring forces exerted horizontal or in a rotational manner may be better suited for a movement of this nature. Therefore, the development of such a power test may be warranted.

The absence of statistically significant correlations between performance measures and linear bat velocity may be specific to this particular set of field tests and not the overall relationship. As found by Welch et al. (1995), forces produced by a hitter's back foot during a swing can reach as high as 80 N posteriorly and 184 N towards the pitcher. These forces are then transferred to the hips, torso and upper extremity through the kinetic chain, resulting in progressive increases in segmental velocities as you move towards the distal end point, with the arms reaching over 1100°s^{-1} (Welch et al., 1995). This is evidence that the extremities and torso do indeed transfer and contribute to bat velocity and different battery of tests of may better demonstrate the contribution of each component.

Another limitation was that individual swing mechanics greatly influenced the manner in which the ball was released during the MBHT. Different approaches and orientations of the hands and the bat at the point of contact were related to differences in trajectories and directions of force exerted on the medicine ball. Players with a relatively flat swing plane were more likely to exert force laterally, whereas those hitters whose hands followed an uppercut pattern typically projected the ball higher into the air, for a shorter distance. It is also possible that players altered their movement patterns to accommodate for the task of projecting the medicine ball. Interestingly, these considerations were not discussed in D. Szymanski's work (2007a, 2007b) where this test was developed and implemented with high school baseball players. The MBHT was originally developed as a sequential core, arm and hip rotational strength test created to mimic a player's actual swing. D. Szymanski et al. (2007a) proposed that this test accurately measured segmental timing of the kinetic chain. High school baseball players were used in this study, which assigned both the control and experimental groups to a linear periodized resistance program, with the experimental group also doing a rotational core program. After 12 weeks, the control group increased a significant 3.0% in MBHT distance with an insignificant increase 3.6% in bat end velocity. Alternatively, the experimental group increased significantly in both measures with a 10.6% and 6.4% in the MBHT and bat end velocity, respectively. Some of the improvements by both groups were accounted for by bat swings written into the resistance training program. The experimental group's improvement was also attributed to increases in force generation as a result of the torso training program. These authors focused more heavily on the strength component, despite coining it a "sequential" test, as no mention was given regarding the release of the ball, possible alterations in swing patterns or the kinetic chain (D. Szymanski et al., 2007a).

The season in which testing was conducted may have also effected the results. J. Szymanski et al. (2010) conducted a study in which batted ball velocity of NCAA Division I baseball players was found to decrease in season. Active players were tested between the 5th and 7th week of the playing season and may have experienced performance testing decrements as a result. During the measurement period in the present study, players were actively engaged in sport specific activity as well as resistance training and conditioning. Players participated in testing around their daily schedule, which did not account for activity performed earlier in the day. All of these factors may have contributed to potential decrements in the performance tests employed in this study.

Summary

The findings of this study are indicative of the set of tests employed, rather than the overall relationship between LBV and lower extremity power, upper extremity power and the rotational kinetic chain. This is evidenced by the SMBS, the most significant predictor of LBV, accounting for only 6.6% of the overall variance in bat velocity between subjects.

Chapter V: Summary, Conclusions and Recommendations

Summary

The body of literature regarding the linear bat velocity and the contributing factors to offensive production has begun to expand in recent years (Lowe et al., 2010; Reed et al., 2008). The ability of a player to produce maximal linear bat velocity serves to increase batted ball distance and velocity, decision-making time and improve the likelihood of contacting the sweet spot of the bat (Adair, 2002; DeRenne, Ho, Hetzler & Chai, 1992; D. Szymanski et al., 2007a; Reyes & Dolny, 2009). This study was designed to explore the relationship between performance-based tests of lower extremity power, upper extremity power and kinetic chain efficiency with linear bat velocity in NCAA Division II softball players.

Conclusions

Developing an understanding of the factors by which an individual develops high bat velocity is an extremely complex matter. The results of this study indicate that performance measures, such as the SMBS accounted for a small percentage in variance of bat velocity (6.6%), whereas anthropometrics, such as body mass are more highly correlated (18.8%). Relationships between lean body mass and bat velocity and batted ball velocity have been confirmed in the literature, however the remaining variance appears to be unaccounted for.

Recommendations

Given these proposed benefits to offensive production in softball, coaches and strength and conditioning professionals need to consider appropriate training methods to enhance and maximize linear bat velocity. The transfer of kinetic energy should continue to be a point of emphasis for sport specific training for coaches. However, it appears that resistance training to increase body mass, as a function of greater lean body mass, may contribute to higher linear bat velocities. Proposed training methods to increase bat velocity include swing repetitions with variable bat weights (DeRenne et al., 1995) as well as a whole-body resistance training program with a rotational core component, as these have been used with positive results (D. Szymanski et al., 2007b).

Future studies may also focus on the more precisely measuring lower extremity power as it relates to the kinetic chain. Such a study could measure of a hitter’s back foot during a single leg lateral hop or a transverse plane jump using a force platform and relating the findings to LBV. However, based on the results of the present study, it is evident that the development of field tests related to bat velocity still remains a useful area of investigation for both coaches and strength and conditioning professionals.

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Appendices:

Table 9

Kolmogorov-Smirnov Diagnostic Test for Normality

	Kolmogorov-Smirnov[a]		
	Statistic	**df**	**Sig.**
Body Mass (kg)	.240	31	.000
Height (m)	.084	31	.200*
Arm Length (m)	.167	30	.033
Arm Length (m) - LOG	.152	30	.074
Stride Width (m)	.224	31	.000
Stride Length (m) - LOG	.419	17	.000
Pre-Swing Stride Width (m)	0.01	29	0.19
Stride Width - Normalized (% BH)	0.153	31	0.061
Pre-Swing Stride Width (m) - LOG	0.17	29	0.04
Pre-Swing Stride Width (m)	0.17	29	0.04
Pre-Swing Stride Width (m) - LOG	0.13	29	0.18
MBHT (m)	.126	31	.200*
Normalized MBHT (BH)	.124	31	.200*
SMBS (m)	.114	31	.200*
Normalized SMBS (BH)	.119	31	.200*
CMJ (m)	.078	31	.200*
Normalized CMJ (BH)	.066	31	.200*
LBV (m/s)	.088	31	.200*
Normalized LBV (BH/ s)	0.084	31	.200*

[a] Lilliefors Significance Correction

* This is a lower bound of the true significance

Table 10
Backward Linear Regression (Non-Normalized Linear Bat Velocity) - Variables

Variables entered/ removed			
Model	**Variables entered**	**Variables removed**	**Method**
1	CMJ (m), MBHT (m), SMBS (m)	-	Enter
2	-	CMJ (m)	Backward
3	-	MBHT (m)	Backward

New variables account for only a small negative change in the coefficient of determination of Model 3 (R^2 change = -0.016), which is not a significant change in the F statistic (see the column Sig. F change). The Durbin-Watson statistic indicates that adjacent residuals derived from this regression have a positive relationship with each other. Since the Durbin-Watson statistic is not less than one or greater than 3, it is considered within the acceptable range, and there is not concern regarding a violation of the assumption of independence.

Table 11
Backward Linear Regression (Non-Normalized Linear Bat Velocity) – Model Data

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Change Statistics**					**Durbin-Watson**
					R Square Change	**F Change**	**df1**	**df2**	**Sig. F Change**	
1	.344[a]	.118	.020	1.878	.118	1.204	3	27	.327	
2	.337[b]	.113	.050	1.849	-.005	.139	1	27	.712	
3	.312[c]	.097	.066	1.833	-.016	.507	1	28	.482	1.405

[a] *Predictors: (Linear bat velocity), CMJ (m), MBHT (m), SMBS (m)*
[b] *Predictors: (Linear bat velocity), MBHT (m), SMBS (m)*
[c] *Predictors: (Linear bat velocity), SMBS (m)*
[d] *Predictors: Linear bat velocity (m/s)*

Table 12

Backward Linear Regression (Non-Normalized Linear Bat Velocity) – Standardized and Unstandardized Coefficients

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**	**Collinearity Statistics**	
		B	**Std. Error**	**Beta**			**Tolerance**	**VIF**
1	Constant	20.516	3.247		6.318	.000		
	MBHT (m)	-.155	.220	-.135	-.703	.488	.882	1.134
	SMBS (m)	1.746	.957	.352	1.823	.079	.875	1.143
	CMJ (m)	2.200	5.902	.068	.373	.712	.991	1.009
2	Constant	21.340	2.342		9.114	.000		
	MBHT (m)	-.154	.217	-.135	-.712	.482	.882	1.134
	SMBS (m)	1.777	.939	.359	1.892	.069	.882	1.134
3	Constant	20.530	2.029		10.119	.000		
	SMBS (m)	1.546	.874	.312	1.769	.087	1.000	1.000

Table 13 includes the casewise diagnostics for non-normalized data. Table 7 includes statistics of the residuals for the linear regression. It is notable that Cook's Distance is less than one, signifying that an individual case has only a small influence on the overall mode and that single cases are not overly influencing the model.

Table 13

Backward Linear Regression (Non-Normalized Linear Bat Velocity) – Collinearity Diagnostics

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions			
				Constant	MBHT (m)	SMBS (m)	CMJ (m)
1	1	3.947	1.000	.00	.00	.00	.00
	2	.027	12.030	.02	.58	.02	.29
	3	.019	14.591	.00	.35	.85	.10
	4	.008	22.670	.98	.08	.13	.61
2	1	2.966	1.000	.00	.00	.00	
	2	.021	11.962	.06	.93	.33	
	3	.013	15.147	.93	.06	.67	
3	1	1.987	1.000	.01		.01	
	2	.013	12.243	.99		.99	

Table 14

Backward Linear Regression (Normalized Linear Bat Velocity) - Variables

Variables entered/ removed			
Model	**Variables entered**	**Variables removed**	**Method**
1	CMJ (m/ BH), MBHT (m/ BH), SMBS (m/ BH)	-	Enter
2	-	MBHT (m/ BH)	Backward
3	-	SMBS (m/ BH)	Backward
4	-	CMJ (m/ BH)	Backward

Table 15

Backward Linear Regression (Normalized Linear Bat Velocity) – Model Data

Model	**R**	**R Square**	**Adjusted R Square**	**Std. Error of the Estimate**	**Change Statistics**					**Durbin-Watson**
					R Square Change	**F Change**	**df1**	**df2**	**Sig. F Change**	
1	.243[a]	.059	-.046	1.11729	.059	.563	3	27	.644	
2	.209[b]	.044	-.025	1.10598	-.015	.436	1	27	.515	
3	.187[c]	.035	.002	1.09178	-.009	.260	1	28	.614	
4	.000[d]	.000	.000	1.09263	-.035	1.047	1	29	.315	

[a] Predictors: (Linear bat velocity), CMJ Normalized (m/BH), SMBS normalized (m/BH), MBHT normalized (m/BH)

[b] Predictors: (Linear bat velocity), CMJ Normalized (m/BH), SMBS normalized (m/BH)

[c] Predictors: (Linear bat velocity), CMJ Normalized (m/BH)

[d] Predictor: Linear bat velocity (BH/s)

Table 16

Backward Linear Regression (Normalized Linear Bat Velocity) – Standardized and Unstandardized Coefficients

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	Constant	12.703	2.060		6.166	.000		
	MBHT (BH)	-.150	.227	-.128	-.660	.515	.928	1.077
	SMBS (BH)	.695	1.052	.128	.661	.514	.930	1.075
	CMJ (BH)	5.707	5.609	.190	1.018	.318	.998	1.002
2	Constant	12.218	1.905		6.412	.000		
	MBHT (BH)	.512	1.004	.094	.510	.614	1.000	1.000
	SMBS (BH)	5.565	5.548	.185	1.003	.324	1.000	1.000
3	Constant	12.901	1.338		9.643	.000		
	SMBS (BH)	5.603	5.476	.187	1.023	.315	1.000	1.000
4	Constant	14.255	.196		72.638	.000		

Table 17
Backward Linear Regression (Normalized Linear Bat Velocity) – Collinearity Diagnostics

Model	Dimension	Eigenvalue	Condition Index	Variance Proportions			
				Constant	MBHT (body heights)	SMBS body heights)	CMJ (body heights)
1	1	3.949	1.000	.00	.00	.00	.00
	2	.026	12.336	.01	.54	.01	.39
	3	.018	14.662	.00	.39	.65	.16
	4	.007	23.904	.99	.07	.33	.45
2	1	2.972	1.000	.00		.00	.00
	2	.021	11.912	.00		.49	.52
	3	.007	20.265	1.00		.50	.48
3	1	1.989	1.000	.01			.01
	2	.011	13.571	.99			.99
4	1	1.000	1.000	1.00			

Table 18
Backward Linear Regression (Normalized Linear Bat Velocity) – Residual Statistics

	Minimum	**Maximum**	**Mean**	**Std. Deviation**
Predicted Value	23.004	25.246	24.071	.592
Std. Predicted Value	-1.802	1.985	.000	1.000
Residual	-3.858	4.060	.000	1.802
Std. Residual	-2.105	2.215	.000	.983
Cook's Distance	.000	.233	.032	.054

Appendix A

PERMISSION FORM TO CONTACT ATHLETES FOR TESTING

Purpose:
This study was designed to explore the relationship between maximal linear bat velocity and tests of upper and lower extremity power and kinetic chain efficiency in collegiate softball players. Additionally, a multiple regression will be used to explore the prediction of maximal bat velocity from a linear combination of the upper extremity and lower extremity power and kinetic chain variables.

Explanation of procedure:
Subject participation in this study will require only one testing session. During this testing period, subjects will undergo a five-minute whole-body warm-up and five-minute static stretching period, after which the performance tests will be introduced. Tests included in this protocol are the medicine ball hitter's throw (MBHT), vertical countermovement jump and the seated medicine ball shot put (SMBS). Once the subject has been familiarized with the tests and feels comfortable performing them, the tests will be administered in a random order. Three maximal trials will be performed, with the best trial being selected for analysis. Lastly, subjects will complete twenty warm-up swings (2 sets of 10 swings) followed by five maximal bat velocity swings. These trials will be conducted using a 24 ounce (34 inch) Easton Synergy, instrumented with a wireless accelerometer. Swings will be taken using a softball-sized foam ball and batting tee. Five swings, producing line drives, will be performed, with the best trial being selected for analysis.

Risks:
There are minimal risks involved in participation in this study such as discomfort or pain as a result of injury to involved musculature, joints or connective tissue. If the subject experiences pain they may withdrawal from participation in this study at any time, without penalty.

Potential benefits:
The results of this study may help subjects to analyze which areas they need to improve in order to enhance their hitting performance. Additionally, if a correlation is found between bat velocity and the independent variables, these tests may be used to monitor improvements in muscular power and kinetic chain efficiency.

Confidentiality:
The identity of all subjects participating in this study will remain confidential at all times. Furthermore, only the individuals conducting or assisting with this study will have access to information related to my identity.

Voluntary participation:
I hereby voluntarily give consent for Liza Teichler to contact the athletes on my team for participation in her study. Furthermore, I have read and understand this permission form.

____ Coach's Signature	______/_____/_________ Date

____
Coach's Name (Printed)

Appendix B

INFORMED CONSENT FOR EXERCISE TESTING

Purpose:

This study was designed to explore the relationship between maximal linear bat velocity and tests of upper and lower extremity power and kinetic chain efficiency in collegiate softball players. Additionally, a multiple regression will be used to explore the prediction of maximal bat velocity from a linear combination of the upper extremity and lower extremity power and kinetic chain variables.

Explanation of procedure:

I understand that I will participate in one session during which I will undergo a five-minute whole-body warm-up and five-minute static stretching period, after which I will be introduced to the performance tests. Tests included in this protocol are the medicine ball hitter's throw (MBHT), vertical countermovement jump and the seated medicine ball shot put (SMBS). Once I am familiar with the tests and feel comfortable performing them, the tests will be administered to me in a random order. Three maximal trials will be performed, with the best trial being selected for analysis. Lastly, I will complete twenty warm-up swings (2 sets of 10 swings) followed by five maximal bat velocity swings. I will conduct these trials using a 24 ounce (34 inch) Easton Synergy, instrumented with a wireless accelerometer. I will be taking swings using a softball-sized foam ball and batting tee. I will perform five swings, producing line drives, with the best trial being selected for analysis.

Risks:

I understand there are risks involved in my participation in exercise testing. Additionally, I realize that there may be minimal risk, such as discomfort or pain as a result of injury to involved musculature, joints or connective tissue. These are risks associated with any physical activity. If I experience pain, I am aware that I may withdraw from participation in this study at any time, without penalty.

Potential benefits:

The results of this study, in the future, may lead to my improved ability to analyze areas that need improvement in order to enhance my hitting performance. Additionally, if a correlation is found between bat velocity and the independent variables, these tests may be used to monitor my individual improvements in muscular power and kinetic chain efficiency.

Confidentiality:

As a subject in this study I will be assigned a subject number. My individual information will be stored in a metal, locked file cabinet. Only the individuals conducting or assisting with this study will have access to information related to my identity.

Voluntary participation:

I hereby voluntarily consent to participate in exercise testing. I understand that I may withdraw from this study at anytime, without penalty. By signing this form, I certify that I am at least 18 years of age. I have read and understand this informed consent form and will receive a copy of it.

____
Participant Signature

______/_____/_________
Date

____
Participant Name (Printed)

____
Investigator Signature

______/_____/_________
Date

Appendix C

Data Collection Script:

Medicine ball hitter's throw:
The medicine ball hitter's throw is a plyometric test used to simulate a softball swing. You will begin by placing your front foot behind the line marked on the floor. Grasp the medicine ball with both hands, with one hand on top and one on the bottom. Next, you will assume your hitting stance and in one smooth movement you will perform your trigger and swing, propelling the ball for maximal distance laterally, past the line, releasing the ball at the point of contact. I will observe your throw to spot the place where the ball lands and we will measure the distance to the nearest inch.

You will be allowed as many familiarization trials as you need to feel comfortable. When ready, you perform three maximal throws with fifteen seconds of rest between trials. The longest throw will be used for analysis.

Seated medicine ball shot put:
The seated medicine ball show put is an upper extremity plyometric power test used to assess many athletic populations. You will begin by sitting on the floor with your back pressed up against the wall, knees flexed to 90° angle and feet flat on the ground. A 4.5 kg medicine ball will be held in the middle of the chest and projected forward for maximal distance. I will observe your throw to spot the place where the ball lands and we will measure the distance to the nearest inch.

A trial will be disqualified if your back separates from the wall.

You will be allowed as many familiarization trials as you need to feel comfortable. When ready, you will perform three maximal throws with fifteen seconds of rest between trials. The longest throw will be used for analysis.

Vertical jump:
A maximal countermovement jump will be used to measure lower extremity power. The Vertec™ will first be used to measure vertical reach with the right arm extended above the head, weight distributed evenly and the right scapula upwardly rotated. To measure vertical reach, you will walk under the Vertec™ with your arm extended, reaching as many vanes as possible. Next, you will be allowed to set-up under the vanes as I adjust the height of the Vertec™. Next, without moving your feet, you will perform a countermovement jump for maximal height, employing your right hand to reach the highest vane possible. The use of your upper extremity for force production will be allowed. The highest vane displaced after a jump will be moved aside and count towards your maximal jump height.

A trial will be disqualified if you false step.

You will be allowed as many familiarization trials as you need to feel comfortable. When ready, you perform three maximal jumps with fifteen seconds of rest between trials. The highest jump will be used for analysis.

Maximal bat velocity:
Maximal bat velocity will be measured using a 7-camera motion-analysis system and reflective marker set. You will swing an Easton Synergy – Clarity bat of a standard size (24 ounces, 34 inches) and moment of inertia. A tee will be used and set to the height of your belly button and aligned with the contact point for the middle of the plate. The "sweet spot" of the bat has been instrumented with reflective markers in order to measure linear acceleration, from which linear velocity will be calculated. You will assume a resting position with the bat resting on your shoulder, and once signaled you will pick the bat off your shoulder, and execute a swing as you would in a game situation. You will be allowed fifteen seconds of rest between swings in order to more accurately reflect game situations. Please be sure to rotate the bat appropriately so that the camera system will see the markers and that markers will not contact the tee or foam ball upon contact.

A trial will be disqualified if contact is made with the tee.

When ready, you perform five maximal swings with fifteen seconds of rest between trials. The velocity will be used for analysis.