THE EFFECTS OF LINEAR AND ROTATIONAL PLYOMETRIC EXERCISE ON BASEBALL BAT SWING VELOCITY

by

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ABSTRACT

Increasing baseball bat velocity is the goal of many baseball strength and conditioning programs, as fast bat velocity is essential for successfully hitting a baseball. Despite the desire to increase bat velocity, few studies have examined the effectiveness of training using rotational and linear plyometric exercises in baseball batting specific motions. This study investigates the effects of a combination rotational and linear plyometric program on baseball bat swing velocity.

Participants consisted of healthy male NCAA Division I baseball hitters. Twelve participants were randomly assigned to one of two groups, an experimental and a control group. All participants performed standard off-season baseball practice and weight training. The experimental group also completed a rotational and linear plyometric exercise program two times per week for 8 weeks, while the control group had no intervention.

Bat velocity was assessed prior to training, after 4 weeks of training, and after 8 weeks of training. A 2x3 mixed factorial repeated measures design was used to investigate the effects of the rotational and linear training program on bat velocity. Significance was set at alpha ≤ 0.05.

No significant main group effect, time effect, or time and group effect was found.

However practical significance was found, as the plyometric training group had a 9.5% improvement in bat velocity and the control group had a 1.7% improvement in bat velocity at the end of the study. Therefore, the use of normal practice and weight training, and a combination rotational and linear plyometric program had no significant effect on baseball bat velocity, but did account for some positive increases. This study serves as a starting point for further research needed to improve bat velocity in Division I College baseball players.

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CHAPTER 1

INTRODUCTION

Successful hitters are defined as hitters with a batting average greater than 300, or a batting average of at least 275, with more than 220 appearances and superior skills in other hitting statistics such as home runs, total bases, or slugging percentage (Szymanski, DeRenne, & Spaniol, 2009). Bat velocity is one of the most important attributes of a successful hitter in baseball. Assuming each player has the same amount of preparation before each pitch, a fast bat awards the batter more time to react to the pitch and an increased batted ball velocity.

Assuming the hitter maintains a successfully quiet eye, faster reaction time is beneficial because the hitter has additional time to see the ball, determine the type of spin, pitch, and location. A quiet eye refers to one that focuses on a target without distraction. This can lead to more walks and an increase in swinging at pitches in the strike zone, both characteristics of successful hitters (Szymanski et al., 2009). Increased batted ball velocity is beneficial to a hitter because the faster the bat is moving when it makes contact with the ball, the farther the ball will travel (Coburn, 2007).

Batted ball velocity can be achieved by increasing either bat mass or bat velocity while keeping the other variable constant. Coburn (2007) reported that increasing bat velocity has been shown to be much more effective than bat mass, in increasing batted ball velocity. He stated that on a 94-mph fastball, every 1 mph of increased bat velocity extends the distance of a batted ball by 8 ft. This distance could be the difference between an out and a homerun, a crucial outcome in batting performance.

With all of the benefits of increased bat velocity, college coaches and players value bat velocity, yet they have limited practice and conditioning time with a maximum of 132 total team practice days allowed by the NCAA. These days are then further divided between the spring and fall. This works out to an average of 28 days in the fall, and 104 days in the spring. During these fall and spring practice days, the team has a maximum of 20 hours per week in which they must fit both conditioning and actual practice. During a typical 6-day practice schedule, if a team takes 2.5 hours for practice each day, this leaves only 5 hours for conditioning each week.

Therefore, in order to justify training for bat velocity, an exercise routine that provided a practical use of one's resources was needed. In order to determine the optimal type of training, the specific muscles used, the sequence, timing and energy systems of those muscles, and how to apply the overload and underload principles of strength and conditioning were considered, in an attempt to increase bat velocity. Also considered was the amount of time, money, equipment, and facilities needed for the training.

With all of these things considered, baseball strength and conditioning professionals have recommended sport specific plyometric medicine ball training, as it closely mimics the range of motion and velocities encountered in rotational power sports such as baseball, which can lead to a transfer of velocity from training to actual swinging (Earp & Kraemer, 2010). Medicine ball training also allows the training to be done in a short time, with little money, equipment, and facilities. Therefore, due to its potential to efficiently and practically enhance batting performance, it is the focus of this research.

In a previous study by Szymanski, McIntyre et al. (2007), the effect of medicine ball torso rotational strength exercises was examined in relation to various angular joint velocities, three repetition max torso rotational strength, sequential torso hip-torso-arm rotational strength, and linear bat end velocity in high school baseball players. This study compared two groups, one that performed a general resistance training and bat swinging program, and another group that performed the same bat swinging program along with additional medicine ball rotational training.

Szymanski, McIntyre et al. (2007), concluded that performing additional medicine ball rotation exercises two times per week for 12 weeks yielded significant increases beyond the control group, in bat end velocity, angular hip velocity, angular shoulder velocity, three repetition max torso rotational strength, and medicine ball hitters throw distance for high school baseball players. This study suggested that one way to enhance bat swing velocity is to develop sport specific, plyometric torso rotational strength exercises using medicine balls as a supplement to standard training practices.

In order to create a practical training program that adheres to the principles of sport specificity, previous research about the biomechanical and physiological demands of hitting was examined. Adair (2002) concluded that hitting was both a rotational and linear activity. He found that linear motion was emphasized in some hitter's mechanics, whereas rotational motion was emphasized in others. Regardless, he found that a combination of both motions was important for all hitters. To maximize biomechanical specificity in this study, the training program that was used included both linear and rotational plyometric medicine ball exercises.

This study took 12 Division I baseball hitters, and divided them into an experimental and a control group. Both groups performed normal baseball practice and weight lifting sessions. In addition, the experimental group performed seven medicine ball rotational and linear exercises. These exercises were done in three sets of six repetitions with a 10-lb ball, two times per week for the first 4 weeks. This totals a weight of 180 lbs moved during this time. From week 5 to week 8, the same exercises were done in three sets of eight repetitions, two times a week, with a 6-lb ball. This totals a weight of 144 lbs that was moved during this time. The difference in weight between the first and second half of training was done intentionally, as the second phase empasized the velocity of movement. Both groups were tested prior to training, at the end of 4 weeks, and at the end of 8 weeks, to see what effect the exercises had on bat velocity over time. Bat velocity was calculated during maximal swinging efforts while hitting a baseball off a tee, using a Swing Speed Radar, by Sport. Sensor Inc.

Summary

Fast bat velocity is an important characteristic of a good hitter, as it awards batters more time to react to the pitch, and the ball leaves the bat faster. Therefore, many strength and conditioning programs try to do this, yet the optimal intervention has not been determined to date. The purpose of this study was to examine the effect that an 8-week combination rotational and linear plyometric medicine ball training program had on baseball bat velocity.

Significance of Study

A fast baseball bat velocity is an important component of being a successful hitter. This study used an 8-week medicine ball rotational and linear plyometric training program, and examined the changes in bat velocity after 4 weeks and again after 8 weeks. When implementing this program, consideration was given to the practical application so that it could be successful in a realistic college baseball setting. Therefore, we designed a program that could be completed in a short time period, with no special facility, utilizing portable and inexpensive equipment, and in a manner that had a low injury risk.

Training is currently focused on traditional slow resistance training methods and can potentially be enhanced by the use of fast plyometric sports specific exercises. This study may provide data that using a rotational and linear plyometric program would be beneficial in increasing bat velocity. It can also help determine the ideal time needed for such a program, to maximize gains in bat velocity.

Further, this study may help strength and conditioning coaches, baseball coaches, baseball players, and athletic trainers in achieving increased baseball bat velocity, and therefore other batting performance related outcomes.

Research Questions

The following research questions were addressed in this study:

1. Will there be a significant change in bat velocity between a group of NCAA Division I baseball hitters performing normal practice and general strength training, and a group performing the same procedures and an additional combined linear and rotational plyometric program at the end of an 8-week program?

2. Will there be a significantly different change in bat velocity between a group of NCAA Division I baseball hitters performing normal practice and general strength training, and a group performing the same procedures, and an additional combined linear and rotational plyometric program, after 4 weeks or 8 weeks of training?

Hypotheses

The following hypotheses were proposed in this study:

1. Bat velocity will increase for both training programs, but it will increase significantly more for the plyometric group.
2. After 4 weeks, there will be an increase in bat velocity that will be further increased after 8 weeks, and the plyometric group will attain a significantly higher increase in bat velocity at a faster rate, when compared to the control group.

Limitations

The following limitations applied to the study:

1. The study only contains healthy, Division I baseball hitters, which limits the population that the results can be applied to, by excluding anyone who is injured, non-Division I baseball players, and nonhitters.
2. This study was limited to University of Utah students, which limits the generalization of the results to a broad population.
3. This study was limited by not being able to control the player’s ability and willingness to perform with maximal focus and effort at all training and testing sessions, potentially resulting in submaximal effort.

4. This study was limited in controlling any mental effects that the participants were exposed to in performing on testing and training days, potentially giving some athletes a mental advantage.
5. This study did not control the total number of swings taken during the training portion of the study and the practice session. Batters who had less swings could have a potential benefit because of less fatigue.
6. This study was limited in controlling the air temperature during the study, as the testing facility was outside in an unheated building, potentially limiting the velocity of swinging on those days.
7. This study was limited in its ability to control for unrelated and related injuries that prevented athletes from continuing the study, potentially changing the group dynamics.
8. This study was limited in its ability to control for players that quit the team, or transferred and were no longer able to complete the study, potentially changing the group dynamics.

Delimitations

The following delimitations were recognized:

1. This study recruited individuals who were NCAA Division I baseball hitters at the University of Utah, from a narrow age range (18-25 years), and similar level of physical activity in order to create a homogeneous population.
2. None of the participants had injuries that impaired their ability to participate, in order to create a safe environment. Participants who were injured during the course of the study were eliminated from data analysis.

Assumptions

The following assumptions we recognized for this study:

1. All participants were expected to exert maximal effort in all practice and testing sessions.
2. Participants in the experimental group were expected to exert maximal effort in intervention sessions, and adhere to exercise correction instructions.
3. Participants were expected to complete the contact information and participation questionnaire honestly, and to the best of their ability.
4. Participants were expected to follow the rules and restrictions of the study.
5. Participants were expected to use their previous training to maintain consistent swing mechanics for each testing trial.
6. Participants were expected to perform a warm-up that adequately heated their muscles and resembled a normal training warm-up.

Definition of Terms

Batted ball velocity- The velocity of a ball (mph) immediately after it is struck by the bat.

Implement weight training- Training that includes adding or subtracting weight to an actual sport activity, such as swinging weighted baseball bats.

Kinetic link theory- Large proximal base muscles passing momentum or movement to smaller more distal muscles at the extremities (Welch, Banks, Cook, & Draovitch, 1995).

Overload training- Applying a greater stress than the body is normally accustomed to in order to develop muscular strength, power, or endurance (Pretz, 2004).

Plyometric exercise- Quick, power movements that requires a prestretch, activating the stretch shortening cycle (Pretz, 2004).

Power- Force multiplied by the velocity of the force applied, resulting in a combination of strength and speed (Szymanski et al., 2009).

Progression- Approach to resistance training that builds variation in exercise intensity and volume at regular intervals over a specified period of time (Pretz, 2004).

Rotational power sports- All swinging sports such as baseball, softball, hockey, lacrosse, tennis, and golf (Earp & Kraemer, 2010).

SAID principle- (Specific Adaptation to Imposed Demands) When the body attains external stress beyond a certain amount, it responds by building bone and tissue to overcome that potential stress in the future (Pretz, 2004).

Sport specific exercise- Exercise that closely mimics the biomechanical and physiological demands of the sport (Pretz, 2004).

Stretch shortening cycle- This consists of three phases, eccentric phase, amortization phase, and concentric phase (Pretz, 2004).

Successful hitter- All hitters with a batting average greater than 300, or with a batting average of at least 275, with more than 220 appearances, and superior skills in other hitting statistics such as home runs, total bases, or slugging percentage (Szymanski et al., 2009).

Sweet spot- An impact point or a narrow impact zone, where the impact felt by the hands, is reduced enough so that the batter is almost unaware of the collision (Cross, 1998).

Switch hitter- A batter who hits from either the left or right side of the plate.

CHAPTER 2

LITERATURE REVIEW

The purpose of this study was to examine the effect and time course of a combined rotational and linear plyometric exercise program used to supplement a traditional training program on baseball bat swing velocity. Specifically, the researcher's goal was to propose a practical training program that could increase bat velocity and meet the time, portability, and funding needs of collegiate baseball. The Swing Speed Radar, by Sports Sensors Inc., was used to measure baseball bat velocity. The participants were tested at baseline, midpoint, and posttest to see if the program length had any effect on the gains made through training. The organization of the topics in this literature review is: baseball bat swing mechanics, batting musculature, training considerations, and summary.

Baseball Batting Considerations

Batting Decision Time

An average fastball thrown at 90 mph leaves a pitcher's hand at around 55 ft from home plate, and takes only 0.42 seconds to reach the batter at home plate (Coburn, 2007; Szymanski et al., 2009). An average change-up or slow-breaking ball is thrown at 80 mph, and will cross home plate at 0.47 seconds (Coburn, 2007; Szymanski et al., 2009). The difference of 0.05 seconds is a crucial difference when it comes to the timing of the hitter (Coburn, 2007; Szymanski et al., 2009). A timing uncertainty of ± 0.01 seconds is the difference between a hit over second base and a foul ball hit near the first, or third base foul line (Kirpatrick, 1963). Therefore, good timing is very important for the production of fair balls (Kirpatrick, 1963). Good timing also awards the hitter with an advantage in hitting the ball on the "sweet spot," which is the zone of the bat that transfers the maximum energy from the bat to the ball (Adair, 1995).

Within the short amount of time that it takes the ball to get to the plate, hitters must contend with three main variables: identifying the type of pitch thrown, predicting the arrival time of the pitch, and reading the location of the pitch (Szymanski et al., 2009). Specifically the time the hitter has to evaluate the pitched ball and decide if they are going to swing is called the decision time (Szymanski et al., 2009). Major league hitters generally have between 0.26 and 0.35 seconds for their decision time (Szymanski et al., 2009).

After this decision time, it takes the hitter 0.2 seconds to swing (Adair, 1995). This means that the hitter must actually begin their swing when a fastball has traveled only about halfway from the pitcher to the plate (Adair, 1995). The experience is broken down into the batter using 100 milliseconds to see the 3-in ball, and 75 milliseconds to identify the spin, speed, and pitch location (Adair, 1995). The hitter then takes 50 milliseconds to decide if they are going to swing, and where they are going to swing, before they must act (Coburn, 2007). It takes around 25 milliseconds for the brain's signals to move through the body and start the legs in motion, and around 150-190 milliseconds to actually swing (Coburn, 2007). For the first 50 milliseconds, a batter can stop his 2-lb bat in time to check the swing, but after 110 milliseconds the bat, moving at up to 80 mph, carries too much inertia to be stopped in time to check the swing (Coburn, 2007).

The task of hitting is even more difficult because it is done in a hostile environment, as the batter has appreciable personal risk, an intense feeling of individual responsibility, and a high level of acoustic annoyance (Kirpatrick, 1963). In order to overcome this challenge, the experienced hitter uses a plan called his approach. In the approach the hitter attempts to eliminate pitches and locations that are unlikely, based on the scenario of the game, pitchers' strengths, hitter strengths, and pitcher (Coburn, 2007). Hitters ideally want to increase decision time because this allows them to accomplish the two most important goals of successful hitting, being more accurate on contact, and arriving on time (Szymanski et al., 2009). Hitters are taught to let the ball travel as deep as possible before they swing, and focus directly on the ball with a quiet eye, as it will lead to an overall better batting performance (Szymanski et al., 2009).

Batted Ball Velocity

The desire of most power hitters is to hit a home run. Home runs are very important in baseball, as they account for 30% of all runs (Adair, 1995). In order to hit a homerun, the hitter attempts to hit the ball as far and fast as possible. If the hitters do not have enough power to hit a home run, they still want to hit the ball as fast as possible. By hitting the ball fast, the fielders have less time to react to the ball, and are less likely to field it cleanly. This can lead to more running time for the batter, and more errors for the fielder, both of which allow the hitter to get on base more often. Hitters therefore want to increase their batted ball velocity.

Increased batted ball velocity can be created by either increasing the mass of the bat, or the velocity of the bat (Coburn, 2007). Increasing the bat velocity has been shown to affect batted ball velocity more drastically. Research has shown that doubling the weight of a 20-oz. bat can raise batted ball velocity from 68.5 mph to 80.4 mph, a 17.3% increase. In contrast, doubling the speed of a 30-oz. bat can raise batted ball velocity from 62 mph to 83.8 mph, a 35.1% increase. Against a 94-mph fastball this equates to an extended distance of 8 feet for every 1 mile per hour increase in bat velocity. This distance can easily be the difference between an out and a homerun, a crucial difference in batting (Coburn, 2007), and it is therefore essential to increase bat velocity. Also a hitter with a faster bat can see the ball for longer and lay off pitches not in the strike zone, making the pitcher throw more pitches. This increases the pitcher's fatigue and the number of mistakes made.

Summary

Increasing baseball bat velocity is important because it can lead to a longer decision time and increased batted ball velocity. More decision time allows the hitter to see the ball longer, and therefore be more accurate on contact. Increased batted ball velocity increases the distance that the ball travels.

Baseball Batting Motions

Biomechanics of Swinging

Welch et al. (1995) described hitting through quantitative biomechanical data that provides a preliminary account of the activity. Their results were intended to be used for training and rehabilitation purposes. Their data were gathered using right-handed professional baseball players who met a minimum batting average and skills considered to be proficient in hitting. The swing was broken down into three distinct phases, the foot off/stride, foot contact, and ball contact.

Foot Off/Stride

Welch et al. (1995), found that prior to the first phase of foot off/stride, the swing started with a weight shift toward the back leg, and the upper body is rotated counterclockwise on the trunk, which is defined in this study as rotating clockwise for a right-handed hitter. This rotation was initiated by the arms and shoulders, and followed closely by the hips in a coiling process.

According to Welch et al. (1995), following the coil, the foot off/stride phase was underway. The batter started by lifting the front leg, which increases the force applied to the back leg to 102% of the full body weight. At foot off, the back foot applied a shear force in the negative X direction (away from the pitcher) of 146 Newtons (N), and in the positive Y direction (parallel to the ground) of 26 N. At this time the right knee was flexed to 32 degrees, and the center of pressure was at a point 20 cm behind the center of mass. The trunk was also flexed forward to 21 degrees, and laterally, to the left, 6 degrees. The arms rotated 150 degrees and the shoulders 30 degrees clockwise, away from the ball.

According to Welch et al. (1995), as the stride continued toward foot contact, the hips rotated to a maximum of 28 degrees at 0.350 seconds prior to ball contact before they started to rotate in a counterclockwise direction. The shoulders, however, continued in a clockwise direction increasing the coil of the trunk until they reached a maximum of 52 degrees, at 0.265 seconds prior to contact and then changed direction following the lead of the hips in a counterclockwise rotation toward the ball. This is a 24 degree separation between the hips and the shoulders. The arms continued in a clockwise rotation around the trunk, increasing the coil of the upper body against the movement of the hips and shoulders.

Foot Contact

The second phase of the swing is known as foot contact. According to Welch et al. (1995), the left (front) foot contact with the ground at an average stride distance was 33.5 in., or 380% of hip width, with a stride direction of 12 degrees closed, and a foot placement of 67 degrees closed. The arms reached their maximum position of 185 degrees and began a counterclockwise rotation as the body weight shifted forward with the left foot making contact with the ground. At the point the left foot makes contact, it applies a force equal to 123% of body weight to the ground with 292 N of shear force towards the ball and a 280 N force into the ground, while the right foot decreases its force to 58% of the body weight. The center of pressure has now shifted forward to a point 7.9 in ahead of the center of mass.

At this point body segments are accelerated to their maximum velocities, started by the left leg extending at the knee, pushing the left hip backward while the right leg pushes the right hip forward, creating a counterclockwise acceleration of the hips in rotation around the trunk axis. The rotational velocity of the hips reached a maximum of 714 degrees per second, at 0.075 seconds prior to ball contact. The shoulders and arms followed the hips, accelerating at a maximum rotational velocity of 937 degrees per second, and 1160 degrees per second, respectively. This occurred at 0.065 seconds before ball contact. The bat moved away from the body and downward, increasing in both angular and linear velocity. The bat attained a maximal linear velocity of 42.5 mph, and a maximal angular velocity of 35.8 mph, at 0.040 seconds prior to ball contact.

Welch et al. (1995) reported that near impact, the hitter used the last part of angular velocity and reached a maximum value of 1588 degrees per second, at 0.020 seconds before ball contact. The barrel end of the bat reached a maximum linear velocity of 69.3 mph, while the right arm reached a maximum extension velocity of 948 degrees per second, both of these events occurred at 0.015 seconds before ball contact.

Ball Contact

It is stated by Welch et al. (1995), that the final stage of hitting is the ball contact. In this stage, the bat has decelerated to 64.9 mph, with significant velocity now being directed at the ball. The left leg acts as a block, fixed at 15 degrees of flexion, and applying a ground reaction force equal to 84% of the full body weight. The right leg is working as a support, flexed at 45 degrees, and applying 16% of the body weight to the ground. The trunk now becomes an extension of the leg block, and it is positioned at 9 degrees of extension and 20 degrees of right lateral flexion. After contact, the body slows itself through eccentric contractions of the large muscle groups in the legs and core.

Further Swinging Motion Studies

Escamilla et al. (2009a, 2009b) did two other studies on mechanics. Escamilla et al. (2009a) described the difference between age levels on hitting kinematics, whereas in the other article they discussed the effect of bat grip on hitting kinematics. The first study showed some differences between adult and youth hitters, which were mostly due to experience and body development. The second study stated that raising the hands higher on a bat does not improve bat velocity, but rather decreases it. The results of Escamilla et al. (2009a, 2009b) described the same motions and sequencing as the Welch et al. (1995) study. The same mechanics were observed, despite changing the testing methods, to hitting a pitched ball, rather than a ball off a tee, as it was in the Welch et al. (1995) study. Reproducing the same results in these studies strengthens the assessment of batting kinematics by each study.

<u>Rotational and Linear Motion</u>

There has been some controversy over the relative importance of translation or linear motion, and rotational motion in the bat swing (Adair, 2002). The results of Welch et al. (1995) demonstrated that an emphasis on either rotational or linear motion could occur. They determined this could occur because there was a high variation in shear force application and the center of mass/center of pressure was not always consistent. They found that by emphasizing a rotational focus, the center of mass is between both feet and significant shear force by each foot increases the force coupling applied to the hip. In contrast if the linear component is emphasized, the center of pressure stays over the lead foot and center of mass is aligned over the lead leg, commonly known as front foot hitting. In this case the only significant shear force is applied from the lead foot, reducing the force coupling that is applied to the hip segment.

Both rotational and linear motion are important and interrelated, as the energy of translation goes into rotary energy of the bat (Adair, 2002). If a player was not allowed to just rotate, or just step forward, it would be very difficult to hit a ball past second base (Adair, 2002). The relationship between rotational and linear motion is important to understand, because the ability to use both motions creates the power when batting.

Summary

Training in a sports specific manner for increasing baseball bat velocity requires a fundamental understanding of the motions that comprise a biomechanically efficient swing. A right-handed hitter starts the swing with a clockwise rotation of the arms, shoulders, and hip segments, and a weight shift backward in a coiling motion. The batter then strides forward, shifts their weight forward, and accelerates their hips, shoulders, then arms around the axis of the trunk, finally ending with the bat accelerating through the hitting zone. During the swing, the hitter is using both rotational and linear motion as they step, shift weight, and uncoil their body segments. Although there is some variation among swings, the ability to use both rotational and linear motions together creates power when batting. Therefore to maintain sport specificity of motion, it is essential to perform both linear and rotational exercises in training to increase bat velocity.

Batting Musculature

Kinetic Link

Many authors describe the kinetic link as a firing pattern of muscles, in a proximal to distal sequence, that allows the larger more proximal muscles to initiate movement, the trunk to transfer that angular velocity, and the extremities to maintain and fine tune the precision of movement (Earp & Kraemer, 2010; Ebben & Hartz, 2006; Gardner & Schwab, 1998; Szymanski et al., 2009; Szymanski, McIntyre et al., 2007; Szymanski, Szymanski, Bradford, Schade, & Pascoe, 2007; Welch et al., 1995). It is said that in order to improve baseball batting performance, it is essential to improve the amount of momentum transferred and timing of how hitters use their hips, torso, and upper body in the kinetic link (Szymanski, McIntyre et al., 2007).

In batting this refers to the hip segment being maximally accelerated around the axis of the trunk, thereby increasing the velocity of the entire system (Welch et al., 1995). The hip segment is then decelerated, as the trunk transfers this power to the shoulder segment, in order to increase its acceleration (Welch et al., 1995). The shoulders use this kinetic link transfer to apply the built up energy to the hands and bat, which ultimately hit the ball (Welch et al., 1995).

The proximal muscles being referred to include the calves, quadriceps, hamstrings, and glutei (Earp & Kraemer, 2010). The torso muscles being referred to include the external oblique, internal oblique, teres major, rhomboids major, and latissimus dorsi (Earp & Kraemer, 2010). The upper body muscles being referred to include the deltoid, triceps, brachii, internal and external rotators of the arm, and flexors and extensors of the hand (Earp & Kraemer, 2010). The kinetic link concept uses these muscles in segments to complete the bat swing.

Muscle Activation

Shaffer, Jobe, Pink, and Perry (1993) conducted an electromyographic study to examine the muscle firing patterns of 12 muscles through the lower extremity, trunk, and upper extremity during the baseball batting swing. It was their goal to use this information to understand the mechanics that can lead to injury, optimize batting performance, and design training, conditioning, and rehabilitation programs. Eighteen professional baseball player's swings were analyzed and broken down into four phases, the windup (Phase I), preswing (Phase II), swing (Phase III), and the follow-through (Phase IV).

The windup began as the lead heel left the ground and ended when that foot reestablished contact. The preswing was counted as the time between the lead foot contact, and the start of the swing. The swing itself was divided into three subdivisions, early, middle, and late swing. Early swing was considered the time between when the bat started moving forward and lasted until it was perpendicular with the ground. The middle swing was considered the time between early swing and when the bat was parallel with the ground, and late swing was from the start of a parallel bat until ball contact. Lastly, the follow-through started at ball contact and ended as the lead shoulder reached maximum abduction and external rotation.

Shaffer et al. (1993) examined 12 muscles in their study. These muscles included the semimembranosus, biceps femoris, gluteus maximus, vastus medialis oblique, posterior deltoid, triceps, supraspinatus, serratus anterior, erector spinae (lead leg), erector spinae (trail leg), abdominal obliques (lead leg), and abdominal obliques (trail leg). All of these muscles had a significant contribution, except the serratus anterior and the supraspinatus, which did not achieve a significant amount of muscle activation.

The findings of Shaffer et al. (1993) indicate that in the wind-up phase, activity levels were relatively low, except for the hamstring muscle of the trail leg. During single-leg stance, the hamstrings maintained hip extension, as weight shifted in preparation for the swing. In the preswing, there was a high level of activity in the hamstrings and gluteus maximus that indicates their role in hip stabilization and initiation of power. The lead and trail erector spinae and abdominal oblique muscles also had a high level of activity, indicating their role in trunk stabilization and power transmission. The body was lowered during the preswing and early swing, and as a result the posterior deltoid and the triceps activity increased in order to maintain lead shoulder elevation.

During the preswing and early swing, there was increased activity of the vastus medialis oblique, to prevent the collapse of the increasingly flexed trail leg. This enhanced the trail leg push-off force from the ground, creating force that was transferred to the rest of the body. This push-off transfer was a major component of the translational aspect of hitting. It transitioned the majority of the hitter's force, which was transferred to the rotational aspect of the swing. As weight was transferred to the lead leg, the hamstring and gluteus maximus activity in the trail leg declined. The trunk activity remained high in both erector spinae and oblique muscles during the preswing and early swing, and then declined, just before ball contact. This indicated the importance of the trunk for power transmission, as the body uncoils.

There was a relatively high activity of the posterior deltoid and triceps muscles that declined as the swing progressed. The authors concluded that these muscles may contribute slightly to the power generation, but are clearly not the main drivers. They determined that the triceps and posterior deltoid muscles worked in a positional role, to ensure that the bat was in good alignment. During the follow-through, activity levels of the lower and upper extremities were relatively low, except for the vastus medialis oblique. It maintained the extension force on the knee, of the trail leg.

Energy Systems

All swinging sports, such as baseball, softball, hockey, lacrosse, tennis, and golf, can be considered rotational power sports (Earp & Kraemer, 2010). Power is the combination of strength and speed. It is calculated by the amount of force applied, multiplied by the velocity, at which that force is applied (Szymanski et al., 2009). In power sports, athletes use all of their mass to create a maximal force and a maximal velocity, through fast plyometric movements (Gardner & Schwab, 1998). Plyometrics refers to quick powerful movements, which use a countermovement, and involve a stretch shortening cycle to enable a muscle to reach maximal force, in the shortest amount of time possible (Baechle & Earle, 2000).

Using maximal effort in a short period of time primarily requires the utilization of the anaerobic muscle energy system. There are two primary anaerobic energy sources, the phosphagen system and glycolysis (Baechle & Earle, 2000). The phosphagen system uses myosin ATPase, to catalyze the hydrolysis of ATP to form ADP and an inorganic phosphate. This occurs in the absence of oxygen, and provides energy in the form of ATP. This energy is used primarily in short-term, high intensity activities and is active at the start of all exercises.

Baechle and Earle (2000), stated that the other source of energy from the anaerobic energy system is glycolysis. Glycolysis is the breakdown of carbohydrates to produce ATP, which supplements the phosphogen system for high-intensity muscular activity. It can be broken down into fast glycolysis and slow glycolysis. Fast glycolysis takes pyruvate and converts it to lactic acid, providing energy at a fast rate. In slow glycolysis, the pyruvate is transported to the mitochondria, for use at a slower rate by the oxidative system. The phosphagen system and fast glycolysis are both used in swinging a bat, because of the short time and high intensity of activity.

These authors further explain that in order to create power, it is also important to consider the type of muscle fiber needed for anaerobic activity. There are two distinct types of fibers, Type I (slow-twitch) and Type II (fast-twitch). Type I lends itself to aerobic activities, by its ability to resist fatigue with a high density of mitochondria, high aerobic enzyme activity, and dense capillary concentrations. Type II muscle fibers have two subdivisions, Type IIa and Type IIb. Type IIa are fast-twitch oxidative glycolytic muscle fibers that contain many of the fatigue-resistant qualities of Type I fibers, including more mitochondria, greater aerobic enzyme activity, and greater capillary density than Type IIb fibers. Type IIb are fast glycolytic muscle fibers that fatigue rapidly, have relatively few mitochondria, low aerobic enzyme activity, and few capillaries. They also contain greater concentrations of phosphagen, which are needed to fuel the phosphagen energy system. Due to the anaerobic nature of swinging, Type IIb muscle fibers are the most important in powering the phosphagen and fast glycolytic energy systems.

According to Baechle and Earle (2000), these muscle fibers are held together through connective tissue, which combines with dense connective tissue, to attach to bones as tendons. Motor neurons transmit electrochemical signals from the spinal cord to these tendon connections to actively change the muscle length, produce force, and cause limb movement. Motor neurons and the muscle fibers they innervate are known as motor units, and serve as the basis for muscular activity. These motor units are controlled by the neural system. The amount of force achieved in muscles is therefore altered by the frequency and number of motor units recruited. Lastly, proprioceptors such as muscle spindles and golgi tendon organs, are specialized sensory receptors that provide the central nervous system with information to maintain muscle tone and perform complex coordinated movements. For the skillful and powerful motor performance needed to hit a baseball, an optimal amount of motor units, firing at a fast rate, in a well-coordinated sequence is required to be successful.

Summary

It is important to use the same muscles, firing patterns, and energy systems of the bat swing to achieve sports specific training for increasing bat velocity. The muscles of the swing fire in a specific order known as the kinetic link, starting with the larger proximal muscles, and ending with the smaller distal muscles. Specifically, it begins with the hamstrings, gluteus maximus, and vastus medialis oblique of the legs, initiating the power, the erector spinae and oblique abdominal muscles transferring that force, and the triceps and posterior deltoid muscles working in a positional role to maintain precise bat alignment for solid contact.

The muscles described above are used in a fast motion, with maximal effort during the swing. This maximal effort, fast motion requires the utilization of anaerobic energy sources, the phosphagen system and glycolysis. It also requires primarily Type IIb fast-twitch muscle fibers, as they power the phosphagen, and fast glycolytic energy systems. To be successful, hitting requires an optimal amount of motor units, firing at a rapid rate, in a well-coordinated sequence. This knowledge was used to establish a training protocol for bat velocity that focused on training the appropriate hip, trunk, and upper extremity musculature in a fast and intense manner, with the goal of stressing the same body systems as the swing.

Training Considerations

History of Training Methods

Over the past 100 years, physical conditioning for the game of baseball has evolved greatly (Rhea & Bunker, 2009). Throughout history little importance has been placed on physical conditioning, other than practicing sport activities such as fielding, hitting, and throwing (Rhea & Bunker, 2009). Widely renowned as the greatest player in the 1920s and 30s, Babe Ruth was well known for his unhealthy eating habits and lack of exercise routine (Rhea & Bunker, 2009). The success of baseball players like Babe Ruth, who were visibly and apparently unfit, contributed to the lack of emphasis on physical training (Rhea & Bunker, 2009). It was actually believed that lifting weights would hinder a baseball player's ability to pitch, throw, and hit, as players would get too bulky, decreasing their range of motion, and thereby leading to a decreased performance and potential injury (Gardner & Schwab, 1998).

Over the past 30 years, baseball coaches, players, and sports and conditioning professionals have altered physical conditioning practices, because research has shown that resistance training is not detrimental, but rather beneficial (Gardner & Schwab, 1998; Rhea & Bunker, 2009). Although this is known, the optimal training parameters for increasing baseball bat velocity are still unknown.

Current Baseball Training Methods

Ebben, Hintz, and Simenz (2005) surveyed current major league baseball strength and conditioning coaches to find out what type of strength/power development teams are currently using. This study provides insight into the types of traditional weight lifting or plyometric training programs that professional teams are doing to see if it is similar to what is being proposed by this research.

According to Ebben et al. (2005), when asked about strength and power development, 6 coaches out of 21 who responded to the survey reported using some form of Olympic weightlifting techniques, and all coaches indicated using some form of machines. When asked to rate the five most important exercises for strength and power development, the coaches rated squats, lunges, lat pulldowns, rows, step ups, and rotator cuff/shoulder stabilization among their most important exercises. Other coaches indicated additional exercises were important that targeted hamstrings, chest, and core stabilization (Ebben et al., 2005). In addition, all 21 teams reported using plyometrics, including 17 that used them for the lower body, 11 that used them for total body training, and 10 that used them for upper body training.

Summary

Throughout history little importance has been placed on physical conditioning, but over the past 30 years, formal conditioning has been used to improve baseball performance. Professional baseball players use a plyometric and the general strength training program that is very similar to the suggested research. The general resistance training program that was performed in this study was similar to what is being done in the major leagues. The recommendations of this study incorporate lower body, upper body, and total body plyometric exercises.

Current Research on Bat Velocity Training

Warm-Up Effects on Bat Velocity

Several studies looked at different types of warm-up protocols and their effect on bat velocity. These studies examined the effect of warm-up technique on bat velocity. These warm-up programs may serve as a basis for creating training programs, and also give us insight into how to effectively warm-up prior to batting.

These warm-up programs consisted of swinging either an underweighted or overweighted bat in the on-deck circle, before swinging a normal bat. This was done in an attempt to see the effect of using various weighted bat warm-ups, on the subsequent velocity of the normal bat. The normal game bats used in these studies varied between 30 oz. (DeRenne, Ho, Hetzler, & Chai, 1992), 31.5 oz. (Montoya, Brown, Coburn, & Zinder, 2009), and 34 oz. (Southard & Groomer, 2003). Some of the overweight bats used various implements added to a normal bat, including a donut ring at both 16 ¾-oz, 28 oz., and a 32 oz.-power sleeve (DeRenne et al., 1992). In addition, a wooden bat that weighed 48 oz., and aluminum bats that weighed 42, 45, 48, 51, 55.2, and 56 oz. were used as overweight bats (DeRenne, Buxton, Hetzler, & Kwok 1995; Montoya et al. 2009; Southard & Groomer, 2003). Underweight bats weighed 9.6, 12, 23, 25, 27, and 29 oz. (DeRenne et al., 1995; Montoya et al., 2009; Southard & Groomer, 2003).

The results of DeRenne et al. (1992) concluded that swinging a bat at ± 12% (27-34 oz.) of normal game bats increased subsequent normal game bat velocity. Therefore, it was recommended to warm up and train using bats that were ± 12% (27-34 oz.) of normal game bats. DeRenne et al. (1992) believed that the reason for heavier bats increasing subsequent normal bat velocity was that when you remove the heavy weight, additional motor units may continue to function. He also believed that slightly lighter bats that are well balanced may help elicit firing of high-threshold motor units, which can only be fired during rapid motions, and could supplement force production.

It was also found that heavier or lighter implements outside this range had adverse effects on bat velocity (DeRenne et al., 1992). Therefore, it was not recommended to use these bats to warm up or train with. The benefits of warming up with certain bat weights could transcend to training with weighted bats.

Weighted Bat's Effect on Bat Velocity

The weight of the bat, along with the volume and frequency of swinging that is used for training in practice must be considered as it may affect how much bat velocity is gained. Therefore, previous research that has examined various weighted bat swinging programs, provides insight into what bat velocity gains could be expected from a swinging program.

Two college baseball swinging programs were examined that used either underweighted or overweighted bats to see the effect that training with the specific weight had on bat velocity (DeRenne et al., 1995; Sergo & Boatwright, 1993). In addition, one study used college female softball players who swung on either dry land, or in shoulder-deep water (Stuempfle, Crawford, Petrie, & Kirpatrick, 2004). The bats used in the studies varied between heavy bats at 62 oz. (Sergo & Boatwright, 1993), and 31-34 oz. (DeRenne et al., 1995), a standard game bat at 30 oz. (DeRenne et al. 1995), a light fungo bat with an unspecified weight (Sergo & Boatwright, 1993), and other lightweight bats weighing 27-29 oz. (DeRenne et al., 1995). The number of swings in these studies ranged from 300-600 per week. The two baseball studies both found significance, and the softball study did not.

The highest percent increase was found by DeRenne et al. (1995), as they used 600 swings per week, either during batting practice, or dry swinging, while they used heavy bats at 31-43 oz., standard bats at 30 oz., and lightweight bats at 27-29 oz. for a 12-week program. They achieved a 10% increase with the hitters who underwent batting practice training, a 6% increase with the weighted bat dry-swinging group, and a 1% increase with the control group that used standard game bats. In contrast, Sergo and

Boatwright's (1993) study took 300 swings with either only a 62-oz. bat, a 62 oz. and a light fungo bat, and a 31-oz. normal bat for 6 weeks. The normal bat group achieved an 8.8% increase, the 62-oz. bat accounted for an 8.0% increase, and the 62-oz. bat with a fungo bat accounted for an 8.2% increase. Stuemfle et al. (2004) found a decrease in bat velocity with 150 swings per week for 8 weeks in both dry land, and underwater groups that also performed general resistance training programs. The actual bat velocity was not reported in the research of Stuemfle et al. (2004), so the percent change was not compared to the current study.

These studies suggest that swinging a normal bat, an overweighted bat, or swinging both an overweighted and underweighted bat, 240-600 times a week, for 6-12 weeks, produced increases in bat velocity. It was also suggested that an underwater or dry land swinging program may decrease bat velocity if combined with a resistance training program for softball players. These are important factors to consider when accounting for the increase in bat velocity that is seen from the swinging portion of the training program.

Resistance Training Effects on Bat Velocity

Another method for bat velocity training that has been used is general training. General training has focused on increasing overall strength through traditional resistance training methods, that focus on exercises, such as squats, bench press, and rows (Szymanski et al., 2009). It is important to look at the type of increases that occur with general resistance training to know what type of changes to expect from general resistance training.

Two studies were examined that used various types of general resistance training programs to increase bat velocity (Hughes, Lyons, & Mayo, 2004; Szymanski et al., 2006). One study examined if there was any correlation among bat velocity and squat press strength (Basile, Otto, & Wygand, 2007), and one study looked at both general and power training exercises (Scwendel & Thorland, 1992). The two general resistance training studies were performed on both high school and college athletes, whereas the correlation study used untrained college students and the study looking at power versus traditional exercises looked at untrained college students.

The general resistance program by Hughes et al. (2004), found no significant increase with either a control group performing eight full body exercises or an experimental group doing the same program with an additional six forearm and grip exercises for 6 weeks. In addition, a study by Basile et al. (2007) found no significant correlations between bat velocity and strength in the squat press exercise.

In contrast, a resistance training program by Szymanski et al. (2006), which examined a control group that performed general resistance exercises and an experimental group that performed the same general resistance training, with additional forearm and wrist exercises for 12 weeks, found significant increases. This study found significant increases (3.2%) in the control group and in the experimental group (3.5%), with the difference between both groups not being significant. Using the data from Szymanski et al. (2006), and the formula (Score2-Score1)/Score1)*100 = Percent Change, I calculated their control group's percent increase to be 3.4%, not 3.2%.

In comparison, Schwendel and Thorland (1992) found a 7.9% increase in power trained men, and no significant increase in females who were power trained, or males or females who were general resistance trained. They examined the difference in baseball bat velocity, between traditional and power resistance training in untrained men and women. Both groups performed the same exercises, but they distinguished between power training and general resistance training by the speed of the exercises.

These studies show that the largest gains were made with power training and in inexperienced populations. General resistance training provided some information to consider when determining the effect of resistance training on bat velocity.

Rotational Plyometrics Studies

Another category of training exercises that have been used to increase bat velocity is special training. Special training can be done in a sport specific manner, and in this case it consists of developing power through explosive exercises such as throwing medicine balls in a rotational manner.

Szymanski, McIntyre et al. (2007) examined the effect of torso rotational strength on angular hip velocity, angular shoulder velocity, hand velocity, linear bat velocity, and medicine ball distance throws, of high school baseball players. They took 49 participants and assigned them to either an experimental group or control group. Both groups performed a stepwise periodized resistance exercise program and took 100 swings with a normal game bat, 3 days a week, for 12 weeks. In addition, the experimental group also performed rotational and full body medicine ball exercises 2 days a week, for 12 weeks.

The results of this study showed that both groups increased bat end velocity with a self-reported 6.4% increase in the experimental group in comparison to a 3.6% increase in the control group. Again using their data I calculated their percent increase, and concluded there to be a 12.1% increase in the experimental group's bat velocity, and a

3.5% increase in the control group's bat velocity, according to the formula (Score2-Score1)/Score1)*100 = Percent Change. I do not know what caused this large of a discrepancy in percent change. Szymanski, McIntyre et al. (2007) also found that the experimental group significantly increased their angular hip velocity and angular shoulder velocity. The experimental group also showed greater improvements than the control group in angular hip velocity, angular shoulder velocity, three repetition max torso rotational strength, and distance of their medicine ball throws. This study concluded that performing additional rotational medicine ball exercises 2 days a week for 12 weeks statistically improved baseball performance variables, and could lead to better success in hitting.

Another study by Fletcher and Hartwell (2004) examined the effectiveness of an 8- week combined weights and rotational plyometric training program on golf drive performance. The experimental group consisted of six male golfers, who performed a 90-minute workout, two times per week, consisting of traditional resistance training exercises and sport specific medicine ball plyometrics. The control group consisted of five male golfers who did not perform either of these activities. The results of the study found that the experimental group increased by 1.5% in club head speed, and 4.3% in drive distance, when compared to the control group, who increased by 0.5% in club head speed and decreased drive distance 0.7%. Therefore, the authors recommended traditional resistance training and sport specific plyometrics, to increase drive distance and club head speed. They attributed the improvements to increased muscular force, and faster sequential acceleration of body parts, that led to a greater final velocity applied to the ball.

Summary

Previous studies that significantly increased baseball bat swing velocity provide insight into what factors to consider when designing a successful program to increase bat swing velocity. Research has shown that the type of bat used in warm-ups can increase subsequent game bat velocity if that bat is within 27-34 oz. However, a heavy bat (>34 oz.), or very light (<27 oz.) bat, is not recommended as it may have a negative impact on swing velocity (Szymanski et al., 2009). Swinging programs by DeRenne et al. (1995), achieved the highest increase of 10% by swinging bats within ± 12% of normal game bats during batting practice for 12 weeks, and a 6% increase for dry-swinging, whereas Sergo and Boatwright's study (1993) took 300 swings and found an 8.8% increase with normal bats.

Bat swing velocity was increased on average by 3.4%, while performing a general resistance training program, and 7.9% while performing a power resistance training program in untrained individuals. Performing additional rotational medicine ball exercises explosively two times per week in a manner that mimics bat swing motion improved bat velocity for high school baseball players by 6.4%. Rotational medicine ball plyometrics also significantly increased club head speed in golfers. Performing additional forearm and grip exercises, swinging bats underwater, wearing overweight forearm devices, have not contributed to improvements in bat velocity (Szymanski et al., 2009).

College Baseball Practical Considerations

The NCAA limits the total amount of days and times in which teams are allowed to practice and condition. Each team is limited to a maximum of 132 total team practice days for the entire year. This generally works out to an average of 28 days in the fall, and 104 days in the spring. During these fall and spring practice days, the team can condition and hold team practice for a maximum of 20 hours per week. This means that during a typical 6-day practice schedule, if a team practices for 2.5 hours each day, they only have 5 hours for conditioning each week. If there are four conditioning sessions each week, this leaves only 1 hour and 15 minutes for conditioning at each session. Therefore, it is essential to be as efficient with this time as possible.

Literature Review Summary

Increasing baseball bat velocity is important because it can lead to an increased decision time and increased batted ball velocity. Increased decision time allows a player to be more accurate on contact, and a faster batted ball velocity increases the distance that the ball travels (Szymanski et al., 2009).

Although increasing bat velocity through training is important, throughout history little importance has been placed on physical conditioning, as coaches and players believed physical conditioning would lead to decreased performance and potential injury (Gardner & Schwab, 1998; Rhea & Bunker, 2009). However, over the past 30 years, baseball coaches, players, and sports conditioning professionals have altered physical conditioning practices, because research has shown that resistance training is beneficial (Gardner & Schwab, 1998; Rhea & Bunker, 2009).

One must consider swing biomechanics, muscles, energy systems, training principles, and practical time use for improving bat velocity. Biomechanically, both rotational and linear motions are important in batting, as the player strides forward, and then accelerate the hips, shoulders, and arms around the axis of the trunk, and transfers the body's momentum to the bat as it accelerates through the hitting zone (Welch et al., 1995). The muscles are fired in a kinetic link, as the larger, more proximal hamstrings, gluteus maximus, and the vastus medialis oblique muscles initiated movement, the trunk transferred that angular velocity, and the triceps and posterior deltoid muscles maintained, and fine tuned the precision of movement (Earp & Kraemer, 2010; Ebben & Hartz, 2006; Gardner & Schwab, 1998; Shaffer et al., 1993; Szymanski et al., 2009; Szymanski, McIntyre et al., 2007; Szymanski, Syzmanski et al., 2007; Welch et al., 1995). These muscles used the anaerobic energy system, Type IIb muscle fibers, and it operated with an optimal amount of motor units, firing at a fast rate, in a well-coordinated sequence (Baechle & Earle, 2000).

Current strength and conditioning practices of major league baseball teams consist of lower body plyometrics, and strength and power development. Research into bat swing training concludes that a hitter should warm up with a specific weighted bat that is identical or very close to the same weight as his standard bat (Szymanski et al., 2009). For untrained individuals, swinging a standard game bat 100 times a day, three times a week, for 6 to 8 weeks increased swing velocity by 8.8%, whereas trained individuals increased bat swing velocity by a maximum of 10% by using specific resistance training with underweighted and overweighted bats (± 12%), for 150 swings, four times a week, for 12 weeks in batting practice (Szymanski, et al., 2009). Bat swing velocity increased by 3.4% while resistance training for at least three times per week, for 6 weeks and performing additional rotational medicine ball exercises explosively, two times per week, in a sport specific manner caused a 6.4% increase. Lastly, it is important to realize that college baseball players have a limited amount of practice and conditioning time, so one last factor to consider when creating a training program is to make sure that it is efficient.

CHAPTER 3

METHODS

The purpose of this study was to examine the effect and time course of a combined rotational and linear plyometric exercise program used to supplement a traditional training program on baseball bat swing velocity. Specifically, the researcher's goal was to propose a practical training program that could increase bat velocity and meet the time, portability, and funding needs of collegiate baseball. This section outlines the steps that were taken to test the hypothesis. The organization of this chapter includes: participant selection criteria and forms used, testing procedures, instrumentation, training program used, and research design and statistical analysis.

Participant Selection Criteria and Forms

Fifteen healthy current Division I baseball hitters between the ages of 18-25 years were recruited for this study. All participants qualified as hitters if they were on the official baseball team roster, and were currently undergoing all practices, including hitting and lifting sessions without exceptions.

In order to participate in the study, each athlete had to have no self-reported sicknesses, mental illnesses, neurological problems, current physical injuries, or significant past injuries that would place them at risk in performing maximal plyometric medicine ball exercises, or swinging a baseball bat. They were also required to follow all normal team-training procedures, and not to train on their own outside of the prescribed training program. Participants were excluded from the study if they did not meet the inclusion criteria, if they were injured during the study, or if they missed two training sessions, or one testing session during the study.

After obtaining the University of Utah IRB approval, participants were recruited through talking with coaches and players at informal meetings. Participants were invited to attend an informational meeting, and with the permission of the University of Utah baseball coaching staff, the players completed and signed the informed consent form. The purpose and protocol of the study were explained to the participants, and all questions were answered. The participants were assured that participation was voluntary and they had the opportunity to drop out of the study at any time if needed. After the introduction, a participation questionnaire was administered, filled out and signed. Participants who checked each box of the questionnaire were accepted as participants in the study. A contact information sheet containing demographic information was then filled out and signed, to obtain information on all participants. The contact information sheet and participation questionnaire, are included in Appendices A and B.

Participants were then randomly assigned to the experimental or control group, by an independent uninvolved person drawing names from a hat. Due to uneven numbers, the experimental group had 8 participants, whereas the control group had 7 participants. All participants were instructed to undergo normal practice procedures, and all participants followed a set timeline.

Testing Procedures

Participants reported to the University of Utah baseball indoor hitting facility, in Salt Lake City, UT, at 2 pm on the first day of testing. They were informed of their group at this time. Bat size and dominant batting side were recorded for each participant, and were used in all testing for consistency during the study. Tee height was measured with a tape measure and set at 4 inches below the athlete's bellybutton, with this position representing the center of the strike zone (Hughes et al., 2004). The same heavy-duty tee was used for all participants, with an extra 10-lb weight set on it to prevent movement of the tee. One participant was too short for this tee, so he used a shorter tee of the same style. The height of the tee was recorded, and kept constant for all testing.

The radar gun (Sports Sensors Inc) was set up on the tripod, which was leveled using a carpenter's level. The tripod was set at the recommended distance of 4 ft behind the tee, so that it was not in danger of being hit by a swing. The sensor on the radar was set to read in MPH, and the height of the radar sensor was set so that it lined up directly with the center of the baseball. This was determined by measuring the height of the ball, and the height of the tripod with a tape measure. The tee and radar position were marked by tape for each participant's test to maintain consistency throughout testing. The bat was marked with a 4-in reflective sticker, at 2 in from the end of the bat, as measured by a tape measure. This distance was determined by using a hammer to find the node of least vibration, in an attempt to have the sticker represent the sweet spot of the bat (Cross, 1998).

Due to stance variation, foot placement was not measured. Each player was instructed to swing as fast as possible, while keeping the same stance and same mechanics. They were also instructed to stay in control during each swing, to make the swing realistic. The participants were reminded to maintain consistency, as needed. Encouragement to focus on the external environment, rather than movements of the body was given, in an attempt to elicit optimal performance (Gray, 2009). Participants were encouraged to take a breath if they had more than two mistrials, or seemed to be rushing.

For testing, each athlete performed a warm-up as needed. This consisted of any stretching they needed, and no more than five dry-swings, with the same bat they used for testing. The velocity of 10 swings with good mechanics were recorded on the first day, and used as a baseline. A swing was considered to have good mechanics if the ball represented a line drive. This was determined by the ball hitting the back netting of the cage on a fly, without hitting the floor, left side, right side, or the top of the cage (Hughes et al., 2004). Any velocity that was ± 10 mph from the other scores was determined to be a faulty reading by the Swing Speed Radar, and therefore was not counted as part of the study. In addition, if the participant missed the ball, the attempt was also not counted.

Day 2 of testing consisted of participants reporting to the University of Utah baseball indoor hitting facility between 2 pm and 4 pm. This was done only 24 hours after the first testing day. Each participant repeated the same test procedures as test day one. Velocities were recorded as measurements for the reliability of the Swing Speed Radar.

Test Day 3 consisted of the participants reporting to the University of Utah baseball indoor hitting facility between 2 pm and 4 pm; 4 weeks after Test Day 1. Each participant repeated the same test procedures as Day 1 and 2, and the midpoint of the study bat velocities were recorded.

Test Day 4 consisted of participants reporting to the University of Utah baseball practice field between 2 pm and 4 pm; 8 weeks after test Day 1. Each participant repeated the same test procedures, and posttest bat velocities were recorded.

Instrumentation

A Swing Speed Radar by Sport Sensors Inc., measured bat velocity in this study as seen in Appendix C. Previous studies examining bat velocity have used motion capture labs, photo sensing computer timers, a Quick Bat, an electric eye infrared timing device, and a SETPRO Rookie (Basile et al., 2007; Dabbs, et al. 2010; DeRenne, 1987; DeRenne et al., 1995; DeRenne et al., 1992; Hughes et al., 2004; Montoya et al., 2009; Scwendel & Thorland, 1992; Southard & Groomer, 2003; Stuempfle et al., 2004; Szymanski et al., 2009; Szymanski, McIntyre et al., 2007; Szymanski et al., 2006).

The Swing Speed Pro used in this study was similar to the SETPRO Rookie, which was used in the Hughes et al. (2004) study, because they both give immediate results for bat velocity as seen in Appendix C. The Swing Speed radar uses a microwave Doppler radar to measure the velocity of the bat in mph or kmh (Sport Sensors Inc.). According to the manufacturer, this device measured bat velocity in the hitting zone, as the bat made contact with the ball. It measured the velocity of the barrel of the bat, not the end or tip (Sport Sensors Inc). The manufacturer claims it is accurate within a 1% of error, yet this error value is undefined. Along with the manufacturer claims, the reliability of the radar was tested using a test, re-test method 24 hours after the first testing period.

Training Program Used

Hitting Practice

Participants of both groups were instructed to maintain normal fall practice procedures. This included practice on Monday through Friday each week. Each practice consisted of warming up, throwing, fielding, base running, and hitting. The hitting completed in practice consisted of swinging with their normal aluminum game bats and composite bats. The hitting consisted of dry swings, batting tee work, soft toss, batting practice off live pitching, and game scenario hitting. The coaches estimated that the players take an average of 35-50 live swings a day (hitting baseballs), and around another 20-50 dry swings, for a total of around 220-400 swings per week.

The amount of practice and interaction with coaches was similar for each group and all participants. The coaches were not aware of which group each player was in, and were instructed to give the same attention to each player, as they would during normal practice procedures.

Weight Lifting and Conditioning

All participants lifted weights in their normal prescribed weight lifting sessions, on Monday, Tuesday, Thursday, and Friday each week during their fall practice schedule. All participants followed the same lifting routine. This program was relatively consistent throughout the 8 weeks of this study as it was timed with the fall in-season lifting program. The general cycle of exercises in the fall start out light, then level off for the entire fall in-season time, and then ramp up at the end of the fall season.

The weight lifting sessions consisted of alternate lower and upper body lifting days, with core work each day, done in a traditional resistance-training program. Lower body lifting focused on squats, Romanian dead lifts, step-ups, lunges, and calf raises. Upper body lifting focused on bench press, rows, lat pulldown, bicep curls, and tricep extensions. Core work focused on 2 days of static core, such as shoulder and elbow bridges, and 2 days of core focused on dynamic motions such as bicycles, v-ups, suitcase crunches, and Russian twists. The strength coach was not aware of which group each player was in, and was instructed to give the same amount of attention to each player, as he would with normal weight lifting procedures.

Plyometric Exercise Intervention

The intervention of this study was a specialized exercise program. Only the experimental group participated in the plyometric program, which consisted of full body rotational and linear plyometric medicine ball exercises. The plyometric training was performed after normal lower body team weight lifting sessions, in the HPER building, at the University of Utah, in Salt Lake City, UT. The program took place two times per week, on Monday and Thursday, with a makeup day on Friday. Class schedules and unforeseen events were worked around to make sure that each participant attended two sessions each week. Rest in between training sessions was set at a minimum of 24 hours, to allow for muscle recovery time (DeMichele et al., 1997; Earp & Kraemer, 2010; Rhea, Alvar, Burkett & Ball, 2003; Saez-Saez de Villarreal, Requena, & Newton, 2010).

The program itself consisted of seven combination rotational and/or linear plyometric exercises. Pictures of the start and end of each exercise can be found in Appendix D. The baseball specific rotational and linear plyometric exercise program was created from previous research recommendations (Crotin, 2009; DeMichele et al., 1997; Dodd & Alvar, 2007; Earp & Kraemer, 2010; Ebben & Hartz, 2006; Ebben et al., 2005;

Gardner & Schwab, 1998; O'Connor, 1999; Pretz, 2004; Rhea, & Bunker, 2009; Scwendel & Thorland, 1992; Szymanski, Szymanski, et al., 2007) and the University of Utah's baseball strength and conditioning coach's input and experience.

The first exercise was called standing rotational throws. In this exercise the athlete faced a wall straight on, and slightly rotated back, and then threw a medicine ball in a shovel pass from the hip in a forward motion, and caught it on the same side. This exercise was done on both the left and right sides.

The second exercise was called skater jumps, where the athlete jumped off of their outside foot as far as possible sideways, while landing on both feet and quickly jumped back off of their other outside foot as far as possible sideways towards the starting poisition. The third exercise was called skater jump with rotation, as the athlete did a skater jump as described above, but held a medicine ball and rotated that ball in the same direction that they are jumping with their elbows bent to 45 degrees and the ball held in a comfortable position. The fourth exercise was called skater step side throw, and in this exercise the athlete stood sideways facing the wall and took a fast and hard sidestep toward the wall, cocked the ball backwards towards their ear and threw it into the wall. This exercise was done on both sides.

The fifth exercise was called high to low woodchoppers. This exercise consisted of the athlete throwing the ball from one ear towards the ground and catching it by their opposite ear and repeating this motion until all repetitions were done . The sixth exercise was low to high woodchoppers. In this exercise the athlete faced a wall straight on and slightly rotated back, and then threw a medicine ball in a shovel pass from the hip in a forward motion, and caught it on the opposite side. The ball was thrown between each side without resting until all repetitions were done. The seventh exercise was called hitting immitation. In this exercise the athlete stood in their hitting stance and stepped as they would in a batting scenario and then threw the medicine ball into the wall as if they were hitting a baseball. This exercise was only completed on their dominant batting side.

Before the program started, all instructions and proper execution for each exercise were explained. To ensure that high velocity ballistic training occurred, these exercises were done as fast as possible. The athletes were constantly encouraged to give maximal effort on each repetition, and they were also encouraged to rest as often as needed, so that they performed each repetition with maximal intensity. In addition, proper technique was stressed throughout all of the training sessions. Encouragement was given, that focused on the external environment, rather than movements of the body, to elicit optimal performance.

During the first phase of training from week 0 to week 4, each participant performed each exercise in three sets of six repetitions, using a 10-pound medicine ball. This was done in order to build strength, because research has shown that 10 pounds was a heavy enough weight for strength gains, but not heavy enough to drastically alter the mechanics of the exercise (Earp & Kraemer, 2010; Rhea et al., 2003; Saez-Saez de Villareal et al., 2010). During this training, the participants were encouraged to perform each exercise with emphasis first on maximal strength, and second on velocity.

Week 5 to week 8 of the program consisted of the same exercises, done in three sets of eight repetitions each, and performed with a 6-pound medicine ball. This was done in an attempt to emphasize velocity gains through overspeed training. During this part of the program, the encouragement placed emphasis on the velocity of movement first, and strength second.

Research Design and Statistical Analysis

Descriptive statistics were calculated to describe the demographic characteristics of the sample. This information was taken from the initial contact information form. One dependent variable (DV), maximal baseball bat velocity, was tested at three periods of time: baseline, midpoint (after 4 weeks), and posttest (after 8 weeks). Baseline was counted as a combination of scores from both Day 1 and Day 2. This testing was completed by two groups. The two groups were the experimental (plyometric) group, and the control group. Therefore, a 2x3 mixed factorial repeated measures design was used. The assumptions of parametric statistics were tested to see if the data were normally distributed, there was homogeneity of group variance, and sphericity existed. Next, data cleaning took place to account for any missing values and outliers. Missing values or outliers were accounted for by owning the subjects' scores in this study. Significance was then tested against an alpha = .05.

One of the statistical tests looked for a main effect across time, to see if all groups had a statistically significant increase in bat velocity during the study. Secondly, the effect of the length of the program on all participants bat velocity was examined for significance. This specifically aimed to see if there was a significant increase at midpoint, or final testing for all groups as a whole. If significance existed, a Tukey's post hoc test was performed to calculate significance for both groups over time. Next, the interaction effect of time by group was examined. This comparison looked at the differences between groups and times, and a simple main effects post hoc test was used.

A pairwise *t*-test was also performed to examine if the experimental group improved significantly from the pretest to the posttest, in bat velocity.

Further calculations included effect size and power analysis. Reliability of the Swing Speed Radar was tested through a test- retest reliability measure, using Cronbach's alpha technique. The test was determined to be reliable if $r_{tt} \geq .70$ (Nunnally, 1978). Finally practical significance was calculated to see if recommendations could be made to use this training method for increasing bat velocity. The study was assumed to be practically significant if the supplemental training condition accounted for greater than 10% (Tolson, 1980) of the difference between groups.

CHAPTER 4

RESULTS

The purpose of this study was to examine the effect and time course of a combined rotational and linear plyometric exercise program used to supplement a traditional training program on baseball bat swing velocity. The first section of the chapter includes the demographics of the participants. The second section includes descriptive and inferential statistics related to the hypotheses of this study.

Demographic Information

Demographic data that described the age, year in school, years of baseball experience, activity last year, height, weight, and dominant hand are found in Table 1. The control group consisted of 5 male participants, with an average grade between freshman and sophomore. The experimental group consisted of 7 male participants, with an average grade between junior and senior. According to a two tailed *t*-test, no statistically significant differences existed between the groups for experience, dominant hand, weight, height, previous year activity or pretraining bat velocity. Their grade was statistically significant at $p = .013$. This indicates that there were more upperclassmen in the experimental group, and underclassmen in the control group.

Initially, 15 individuals were recruited, and three dropped out after starting the program, due to injuries that required surgery. Two of these individuals dropped out of

Table 1

Control Group and Experimental Group Descriptive Statistics

	Control Group (*n*= 5)		Experimental Group (*n*= 7)			
	Mean	*SD*	Mean	*SD*	*t*-value	*p*-value
Grade	1.800	1.010	3.429	0.787	3.014	0.013
Experience (Yrs)	14.80	0.837	14.60	4.791	0.104	0.919
Last Year	1.000	0.0	0.857	0.378	0.833	0.424
Dominant Hand	1.000	0.0	0.571	0.535	1.768	0.108
Height (Inches)	71.40	3.050	72.29	1.500	0.672	0.517
Weight (Pounds)	188.6	27.70	188.0	6.928	0.056	0.957
Bat Velocity	82.07	6.162	75.62	10.15	1.255	0.238

Note.
Dominant Hand: 1 = right, 0 = left
Grade: 1 = freshman, 2 = sophomore, 3 = junior, 4 = senior
Last Year: 1 = played baseball, 0 = did not play baseball
Bat Velocity: represents the average of pretraining scores from day 1 and 2

the control group, and one dropped out of the experimental group. These injuries were attained during practice, and were seemingly unrelated to the medicine ball training. All data discussed in this paper represent the 12 participants who completed the entire study

Hypothesis Testing

An a priori power analysis revealed that 15 subjects per group were needed to achieve a power of .80 or above. Next, the data sets were examined for missing values, and none were found. Q-Q plots and box plots were also examined to look for any outliers and to determine if the data were normally distributed. Two potential outliers were found in box plots for the midtest scores, and one potential outlier was found for the posttest scores. These potential outliers were not removed as the data were believed to accurately represent the population. This was based on visual observation of the participant's swings in comparison to other subjects. No significant difference was found between bat velocities of each group prior to testing, as the experimental group had a mean of 75.62 mph, and the control group had a mean of 82.07mph. The scores were examined and found to have a p value of $p = .24$.

Upon analyzing the test-retest data for the Swing Speed Radar testing device, the device was found to be adequately reliable because the Cronbach's alpha score was above .70, at .95. Therefore, the radar measurements were a reliable means of measuring bat velocity. The individual scores had an acceptable level of precision or repeatability as indicated by the coefficient of variation. The subjects varied between 2.91% to 18.83%, with the majority falling between 2% and 6%. Thus, the data were considered stable.

Means and standard deviations for bat velocity in the experimental and control groups were calculated at baseline, after 4 weeks, and after 8 weeks. These means and percent changes indicated that bat velocity increased in both groups throughout the program as seen in Table 2 and Figure 1.

The results for the 2x3 mixed factorial RMANOVA did not show statistical significance for any main or interaction effects. The first hypothesis of this study stated that bat velocity will increase for all athletes, but it will increase significantly more for the experimental group. An additional assumption for a repeated measures analysis includes the Mauchly's Test of Sphericity, which resulted in a Mauchly's $W = .52$, with an approximate chi square of 5.83, and a $p = .054$, with two degrees of freedom. Given the *p*-value for the Mauchly test, the Huynh-Feldt was examined, which was .82. Due to a Huynh-Felt score above .7, the univariate statistics were the best determinant of significance. With sphericity assumed, the time main effect had an $F(2,20) = 2.58$, $p = .10$, with an observed power equal to .46 as seen in Table 3. Therefore, this study did not produce a significant difference in bat velocity across time. Thus, the hypothesis was not supported and no post hoc tests were performed. The two-tailed pairwise *t*-test that examined the experimental group to see if there was a significant change between pretest and posttest, that there was not a significant change as the $t(6) = 1.80$ and $p = .12$. A 95% confidence interval about bat velocity change in the experimental group from pretest to posttest was (-2.46, 16.11).

The second hypothesis suggested that after 4 weeks, there would be an increase in bat velocity that would increase again up to 8 weeks, and the experimental group would attain a significantly higher increase in bat velocity, compared to the control group.

Table 2

Experimental, Control, and Combined Group Bat Velocity, and Percent Changes Scores for Pretest, Midtest, and Posttest

	Pre Bat Velocity	Pre-Mid % Change	Mid Bat Velocity	Mid-Post % Change	Post Bat Velocity	Pre-Post % Change
Control (*n*=5)	82.07	-2.55	79.98	4.35	83.46	1.69
Experimental (*n*=7)	75.64	9.39	82.74	-0.33	82.47	9.03
Both	78.32	4.18	81.59	1.69	82.97	5.94

Note.

Bat velocity is in mph

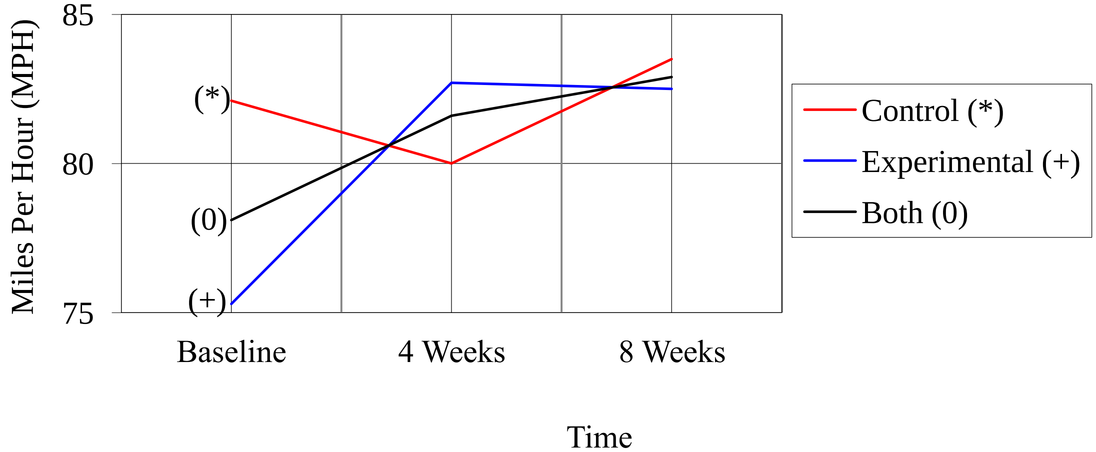

Figure 1: Bat Velocity Graph Over Time.

Table 3

Two-Way RMANOVA Posttest Values of Bat Velocity

Source	*SS*	*DF*	*MS*	*F*	Sig.	PEta²	Power
Between-subjects							
Group	24.33	1	24.33	0.20	0.60	0.02	0.07
Error	1042.76	10	104.30				
Within-subjects							
Time	109.32	2	54.66	2.60	0.10	0.21	0.46
G x T	134.74	2	67.37	3.20	0.06	0.24	0.54
Error	423.23	20	21.16				

Note.
G x T = Group by time
SS = Sum of squares
DF = Degrees of freedom
MS = Mean square
Sig. = Significance
Eta² = Partial eta²

Significance was examined again through the use of univariate statistics as described above. With sphericity assumed, we found an $F(2,20) = 3.18$, $p = .063$ for the group by time interaction with an observed power equal to .54 as seen in Table 3. Therefore, no significant difference was found, and this hypothesis was also not supported.

Although no statistically significant differences were found, practical significance was noted as both the main effect for time and the group by time interaction had low power. The plyometric training group started with a slower bat velocity than the traditional training group and improved by 7.45 mph or 9.39% in 4 weeks, whereas the traditional group decreased bat velocity by nearly 2.09 mph or 2.55%. Over the last 4 weeks of the study the traditional group improved bat velocity by 3.48 mph or 4.40% and the plyometric group remained essentially the same by decreasing by 0.29%. By the end of the study the traditional group had a bat velocity that was 1 mph faster than the plyometric group, after starting nearly 6.5 mph faster.

CHAPTER 5

DISCUSSION

The purpose of this study was to examine the effect that an 8-week combined rotational and linear plyometric medicine ball training program had on baseball bat velocity. A pretest-midpoint-posttest control group design was used for this study, and is discussed in this chapter. In the first section, the effects that the team resistance training, team practice, and medicine ball training had on bat velocity are discussed. In the second section the focus is on the effect that the training program had on bat velocity, with respect to the length of the study. Finally, in the third and fourth sections, the limitations and future directions are presented and I conclude with possible implications from the study, and a short summary.

Effects of Training on Bat Velocity

The first hypothesis in this study stated that bat velocity would significantly increase for all participants from baseline to posttest, but it would increase significantly more for the experimental group in this time. The mean values for the data showed an increase in bat velocity for both groups from pretest means to posttest means, and a greater increase in the experimental group in comparison to the control group; however, statistical significance was not achieved. Therefore, the first hypothesis was not supported.

<u>Control Group's Effect on Bat Velocity</u>

Previous research has shown that the control group has significantly increased its bat velocity from pretest to posttest. The lack of statistical significance found by the control group in this study contradicts the findings of two previous studies that were mentioned in the literature review (Hughes et al., 2004; Szymanski, McIntyre, et al., 2007).

In Hughes et al. (2004), the 12 Division II baseball players in their control group found a statistically significant improvement in bat velocity, after 6 weeks of normal practice and team weight lifting, 3 days per week. Although the total number of swings taken during practice were not counted in either study, it would be reasonable to assume that the number of swings per practice would be similar, as the athletes compete at a similar level. The resistance-training program that was used by Hughes et al. (2004) was also similar to the one that was used in this study. This indicates that the swinging, and resistance programs were likely not a contributing factor to the lack of significance found in this study. The only substantial difference in the Hughes et al. (2004) study was that they used only 6 weeks for training, whereas 8 weeks were used in this study.

The testing apparatus and methods used in this study were similar to Hughes et al. (2004) research. Not only were the testing methods similar, but the pretest and posttest bat velocities were also similar. Their control group mean pretest bat velocity for the control group was 81 mph, and their mean posttest bat velocity was 82.7 mph (Hughes et al., 2004). Our control group had a mean pretest bat velocity of 82.1 mph, and a mean posttest bat velocity of 83.5 mph. This indicates that an increase of 1.7 mph, or 2.1% was found in their study, whereas an increase of 1.4 mph, or 1.7% was found in this study.

This similarity between bat velocities makes it unlikely that the testing measures, or skill level of the players, had a large effect on the lack of significance found in our study.

Instead, the most likely difference between the studies that affected the findings was the sample size. In Hughes et al. (2004) research, they had a total of 23 participants, whereas this study had only 12 participants. With 12 participants, the study was underpowered, making it challenging to find significance because a large effect size would be needed. Because this study's power was only .54, when .80 or above is generally considered to be adequate power, it is clear that this study was underpowered.

In Syzmanski, McIntyre et al. (2007), the control group performed a general resistance training exercise program similar to this study, and took 300 swings per week with a standard game bat, and they found statistically significant increases in bat velocity. Although the swings in our study were not counted, the coaches estimated that the players took an average of 35-50 live swings a day, and around another 20-50 dry swings, for a total of around 220-400 swings per week. Therefore, the total swings and training protocols were similar among studies, indicating that it would be an unlikely cause for the lack of significance found in our study. One difference among these studies could be the length of the study, as that of Syzmanski, McIntyre et al. (2007) lasted for 12 weeks, whereas this study was only done for 8 weeks. If this study lasted an extra 4 weeks, and continued to increase at a constant rate, a 2.6% increase would be seen. This highlights that the effect of the total time of the program should be investigated, to see what the optimal length of the program would be.

The testing methods that were used in the study by Syzmanski, McIntyre et al. (2007) were different from the testing methods performed in our study, which potentially accounts for some differences in findings between the studies. The control group in Syzmanski McIntyre et al. (2007) had a mean pretest bat velocity of 64.9 MPH, and finished with a mean posttest bat velocity of 67.1 mph, a 3.4% increase. In our study, the control group had a mean pretest bat velocity of 82.1 mph, and a mean posttest bat velocity of 83.5 mph, for an increase of 1.7%.

One theory for this difference could be that there may be a greater possibility for improvement for the less trained high school athletes in Syzmanski, McIntyre et al. (2007) study, to increase their bat velocity than there is for college athletes, with a weight training and swinging program. Another reason for the difference between the findings of Syzmanski, McIntyre et al. (2007), and the current study could be due to the different sample sizes. In Syzmanski, McIntyre et al. (2007), a total of 49 participants were used, whereas this study had only 12 participants. This means that Syzmanski, McIntyre et al. (2007) had over four times as many athletes.

Several other studies showed a significant increase in batted ball velocity with only a bat-swinging program or only a resistance-training program. These studies included Sergo and Boatwright (1993) and DeRenne et al. (1995), who found that training by swinging a standard game bat similar to how it was used in this study, 100 times a day, three times week, for 6 to 8 weeks, significantly increased swing velocity, especially when hitting live baseballs. Syzmanski et al. (2006), found that a general resistance-training program similar to the one used in this study significantly increased bat velocity. These studies and others provide further evidence that it is deemed unlikely that the general strengthening and swinging in practice caused the lack of statistical significance that was found in this study.

Although there is substantial evidence supporting significant bat velocity gains made through combined resistance training and swinging programs, one study by Stuemfle et al. (2004) contradicted this study, as they found a statistically significant decrease in bat velocity in their dry swinging group. Stuemfle et al., studied collegiate softball players who performed a similar resistance training, and dry swinging program. Stuemfle et al. (2004) attributed the decrease in bat velocity to the general resistance-training program. They believed that the slow resistance training program could have led to hypertrophy of slow twitch Type I muscle fibers, and a transition of fast twitch Type IIb fibers to the slower Type IIa fibers, which may prove to be detrimental to bat velocity. Although the reason for differing results is unknown between the two studies, one could argue that using female softball players, a different testing apparatus, and a different bat weight (26 oz. vs. 30 oz.) could have contributed to the different trend between Stuemfle et al. study, and this study.

No significant main group effect, time effect, or time by group effect was found in the current study. However, practical significance was found, as the plyometric training group had a 9.03% improvement in bat velocity and the control group had a 1.7% improvement in bat velocity. Therefore, the use of normal practice and weight training, and a combination rotational and linear plyometric program had no statistically significant effect on baseball bat velocity, but did account for some positive increases. This study serves as a starting point for further research needed to improve bat velocity in Division I College baseball players.

Experimental Group's Effect on Bat Velocity

According to previous research, the experimental group's bat velocity was likely going to increase significantly from pretest to posttest. In this experiment, the pairwise *t*-test revealed a $p = .12$, and was therefore not significant even though there was a 9.03% increase. The experimental group's lack of a statistically significant increase in bat velocity in this study contradicts the finding of two previous studies mentioned in the literature review (Fletcher & Hartwell, 2004; Szymanski, McIntyre, et al., 2007).

In Fletcher and Hartwell (2004), 8 weeks of a combined weights and plyometric exercise program significantly increased golf club head speed and driving distance. Fletcher and Hartwell's (2004), training program consisted of training two times per week, with eight general resistance exercises done in three sets of six to eight repetitions. Their plyometric program consisted of training two times per week, using four medicine ball plyometric exercises, done with a 6.6-lb ball, in three sets of eight repetitions. The experimental group in Fletcher and Hartwell's (2004), study performed these medicine ball plyometric exercises in a sports specific manner, mimicking the golf swing by emphasizing sequential acceleration in the kinetic chain.

The general resistance training and plyometric medicine ball training procedures in Fletcher and Hartwell's (2004) study were very similar to what was done in this study, which makes it unclear why this study did not find a significant increase in bat velocity. One difference could be that they only had four exercises, whereas this program had seven. The combination of the resistance training, swinging in practice, and weight lifting done in this study may have overworked the participants, and their muscles may not have had adequate time to recover. This could lead to a lack in muscle gains, and potentially bat velocity, as the muscle is not adequately rebuilding. Also supercompensation may have not occurred yet, as it sometimes takes a week or more to appear (Baechle & Earle, 2000). Another difference among the studies was the training level of the participants, as their participants were unaccustomed to any weight lifting or plyometric medicine ball exercises, whereas the athletes in this study were highly trained. Therefore, their golfers should show greater gains, and a greater lack of recovery.

The club head velocity of Fletcher and Hartwell's (2004) experimental group increased from a pretest value of 111.7mph, to a posttest value of 113.5mph, a 1.8 mph, or 1.6% increase. Our study had an experimental group pretest bat velocity of 75.64 mph, and a posttest value of 82.47, indicating a 6.83 mph, or 9.03% increase. In addition, their sample size was slightly smaller than the one in our study, with only 11 golfers, as compared to our 12 baseball hitters. Therefore, it is unclear why their study found a statistically significant increase, but none was seen in a paired *t* test on the data. One speculative reason could be due to error variance.

In Szymanski, McIntyre et al. (2007), the experimental group used a general resistance training, swinging, and plyometric exercise program to study the effect of such a program on bat swing velocity. Their plyometric exercises were similar to this study's, but they focused on the rotational aspect of hitting. This study differed because we focused on both rotational and linear plyometric exercises. They performed their rotational medicine ball exercises two times per week, and on 1 additional day, they performed whole body medicine ball plyometric exercises in a nonsports specific manner. Szymanski, McIntyre et al. (2007), progressed from a heavier medicine ball at 11 lbs, to a lighter ball at 8.8 lbs, and finally finished with a 6.6 lbs ball. They also performed two sets during each progression, and they started with six repetitions, and then progressed to eight repetitions, before finishing with 10 repetitions. Their total program lasted 12 weeks, whereas this one lasted only 8 weeks. The length of the program, or the fewer number of repetitions per day could have accounted for the lack of significance in this study in comparison to Szymanski, McIntyre et al. (2007). Again it is possible that my program could have overworked the athletes, and they did not recover in time.

Although not statistically significant, we found similar increases in bat velocity as Szymanski, McIntyre et al. (2007) study. Their experimental group's raw data for pretest bat velocity was 64.9mph, and their posttest bat velocity was 72.7mph, a 7.8mph, or 12.0% increase. My study had an increase of 9.03% suggesting a lower increase in bat velocity. The 95% confidence interval suggests a range of (-2.46,16.12).

Further reasons for the lack of statistical significance in our study could be due to Szymanski, McIntyre et al. (2007) using less trained high school athletes, who may have a greater potential to increase bat velocity. It may also be due to Szymanski, McIntyre et al. (2007), having a larger sample size at 49, in comparison to 12 participants. By having a larger sample size, the power of their study was increased and therefore a smaller effect size was needed to show significance.

Another factor to consider is the change in program style. The program in the current study decreased total workload, and changed emphasis from mass to velocity, for the second half of the training period. This is an unknown factor, as the optimal protocol has yet to be established. Further investigation will provide details about the optimal workload, velocity for rotational plyometric training, and periodization within a program.

Overall, the results of this study show no significant effect of training on bat velocity in the experimental group. The data show a nonsignificant tendency for bat velocity to increase within the experimental group from pretest to posttest results. The potential causes for a lack of significance could be length of time for training, over working muscles without proper rest, and a small sample size.

Group by Time Effect on Bat Velocity

The second hypothesis stated that after 4 weeks, there would be an increase in bat velocity in both groups, indicating a main effect of time. Also it states that a further increase would occur up to 8 weeks, and the experimental group would attain a significantly higher increase in bat velocity, when compared to the control group, indicating a group by time effect. Raw data show a large increase in bat velocity for the experimental group, and a moderate decrease in bat velocity for the control group from baseline to midtest. However, no statistically significant difference between the groups was found. From the midtest to the posttest, the control group had a large increase in bat velocity, while the experimental group had a slight decrease. However, no statistical difference between the groups was found. Therefore, the second hypothesis was not supported.

The control group's bat velocity began at a pretest value of 82.1 mph, and decreased to a midtest value of 80.0 mph, and finished with a posttest value of 83.5 mph. This trend shows a decrease of 2.55% from pretest to midtest, and an increase of 4.4% from midtest to posttest. To the author's knowledge, no study has examined this effect, and it is largely unknown why a decrease in bat velocity occurred from pretest to midtest, with an increase in bat velocity occurring from midtest to posttest. This may indicate that the control group's training was most effective from week's 5 to 8. One reason for this could be that hitting practice, or both the hitting practice, and the training program took 4 weeks to get accustomed to, before actual gains could be made.

The experimental group's bat velocity began at a pretest value of 75.64 mph, went to a midtest value of 82.7 mph, and finished with a posttest value of 82.5 mph. This trend showed an increase of 9.39% from pretest to midtest, and a decrease of -0.29% from midtest to posttest. To the author's knowledge, no study has examined this effect, and it is largely unknown why bat velocity would increase for the first 4 weeks, before dropping slightly after the second 4 weeks. One possible reason is that the medicine ball training program was most effective for the first 4 weeks, and then decreased .29% for the second 4 weeks. These data suggest that the plyometric exercises were the most valuable for the first 4 weeks, and there may be a ceiling effect after this time, where increases in bat velocity were not supported by the data. Although this is suggested by the data, it may be misleading as the protocol workload changed, between the first and second half of the training, creating an unknown effect on bat velocity. Future studies that indicate the optimal program may provide clarity into this situation.

When combining the groups, it is evident that bat velocity started at a pretest value of 78.1 mph, went to a midtest value of 81.6 mph, and finished with a posttest value of 82.9 mph. This trend shows an increase of 4.18% from pretest to midtest, and an increase of 1.61% from midtest to posttest. This trend needs to be further explored in order to better understand the effects of timing. Overall, the results of this study show no significant effect of the length of the program on bat velocity in the control, experimental, or both groups. However, the data show a larger although statistically nonsignificant tendency for bat velocity to increase across time from pretest to midtest, and a lesser increase from midtest to posttest results, although a group by time interaction was neaarly significant.

Limitations

Although the testing measures were similar to those used in other studies that found statistical significance, certain limitations in this study need to be addressed (Hughes et al., 2004). First, the actual Swing Speed Radar frequently came up with scores that were ± 10 mph, so they were not counted. Visually some of these swings that were ± 10 mph, looked like good swings, whereas others did not. In addition, some participants often hit the ball into the side netting, floor, or ceiling of the cage, making it an invalid trial. This made certain participants swing many more times than others. The variation in the number of swings could have led to a fatigue effect. It could have also frustrated the participants who took many swings, potentially causing them to rush their swings. The total number of swings taken was not recorded. This could lead to lower scores from fatigue as certain players swung more than others.

A further source of variation with the testing was the lack of temperature control in the hitting facility. The final test was done with the temperature around freezing, where the first two tests were done with a higher temperature. If the muscles were colder, because of the cold temperature, it could potentially create lower bat velocities.

The testing schedule was another area for potential variation, as it was impossible to maintain consistency with training and testing dates. Due to the value of the participants to their athletic team, it was difficult to control their schedule. This could have affected the results, as the last testing day was done after a holiday weekend in which players went home. They did not practice for a few days, and therefore could have been unprepared to test, leading to lower bat velocities.

Furthermore, the participants were college students, so scheduling had to work around their school requirements. This meant that not all participants could be trained on the same day for the medicine ball exercises, potentially altering the group dynamics. Also their schedules for baseball practice changed, and were made to fit around class schedules. Every effort was made to nullify this factor by having makeup days and scheduling training when the majority of the participants could be present yet this could lead to more variability.

Mental state also played an important role in this study. Because testing was done during and before practice time, athletes may have been rushing their testing so they could get back to practice. They were instructed to remain calm and swing as hard as possible, but some athletes may have been upset with missing practice time, as they were competing for playing time. This could lead to submaximal performance and increase variability.

Potential variation in this study could occur from the Hawthorne Effect. The Hawthorne Effect refers to the tendency for people to act differently when they know they are being studied (Chiesa & Hobbs, 2008). Although the control group could not be made to do a sham exercise, because of the coach's demands on their time, evidence is not conclusive that this effect occurs. Although this may be a commonly believed theory, evidence tells us that due to the complexity of the issues revolving around this theory, it has been determined that this term adds nothing to our understanding of the problems of empirical research with human participants (Chiesa & Hobbs, 2008). It may actually be a hindrance if the assumed familiarity of this nebulous process discourages the author from looking more analytically at the procedures involved (Chiesa & Hobbs, 2008). Chiesa and Hobbs (2008), believe that the Hawthorne Effect could show either a social facilitation effect as the athletes think they should be better, or a social inhibition effect as the athletes feel pressured, based on how each person responds, or to simplify it by claiming this effect is a misrepresentation of what could be occurring. Therefore, without further testing it cannot be determined if this effect created any variance in this study.

Swing mechanics were also not assessed in this study, but they could play a significant role in bat velocity. If a player had bad mechanics, the hitting coach would work with them to create more fundamental mechanics. This could lead to an increase in gains for these players. The only way to be certain is to perform motion analysis testing on the participants. Unfortunately, motion capture analysis was not available at the time of this study, so it was not used.

Another potential limitation was the instructions given to the participants to change their focus from strength in the first half of the training to speed in the 2nd half of the training. This could have disrupted potential gains in the last 4 weeks of the study, as the players may have been trying to shift their focus. Although the hitters were trying to throw the ball faster during the last 4 weeks, it is possible that they were not actually doing so. Further studies would need to see if there actually was a change in the players efforts.

Future Directions

Many suggestions can be made for future studies in this area, as no known program has found the definitive way to increase baseball bat velocity. Further studies in this area should consider participant selection methods, testing procedures, and various specifics of training programs.

The first recommendation for future studies would be to obtain more participants. Twelve athletes were not enough participants for the study. It is challenging, however, to attain players at the Division I collegiate level, because of their rigorous demands of their season, and other requirements, as they are playing baseball year round. Future studies may consider using high school athletes during their off-season. Ideally, a location that has multiple baseball teams close by that are willing to participate would allow for larger participant pools and therefore an increased power. Further, studies should attempt to find participants that they can train in the off-season, so that there are fewer interruptions or missed training sessions.

A further recommendation is to try and find a more consistent way of measuring baseball bat velocity than the Swing Speed Radar. Many of the scores seemed to be either ± 10 MPH away from the other scores. If the Swing Speed Radar was utilized, my recommendation would be to place it 4 feet behind, and also on the side of the athlete. Reliability studies should then be conducted on the different positions, to see which way is the most accurate. My recommendation would be to use both places, and record all data. Additionally, when testing, hitting baseballs off of a tee and dry swings should both be used. This allows the examiner more data if participants have difficulty hitting balls off of a tee. Furthermore, all swings should be counted, and their outcomes as well. This means that the number of balls hit into the side netting, top, floor, and any scores ± 10 mph should be counted, along with successful trials. These changes would eliminate some of the variation seen with recording scores and help factor in any fatigue factors.

In addition, data on the biomechanics of the bat hitting the ball should be analyzed. This can be done through breaking down the swing in a biomechanics laboratory. This would provide information on how different bat angles affected velocity of the swing. It could further explain variability among scores, if there is great variability among swings. The greatest challenge with this method is to find a motion capture lab that would be large enough, and safe to hit baseballs in. If this is impossible, using dry swings, or hitting a whiffle ball would be the best alternative to live hitting.

The testing should be done in a temperature controlled facility, and each player should be required to complete a short bike ride for warm-up, along with the five practice swings. This will ensure that each player's muscles are appropriately heated before activity. Each player should also be given the same verbal cues, and all verbal cues should be recorded. The participants should not know how many swings they have left, or have to complete in total. This would ensure that maximal effort was attained on each trial.

All lifts and swinging should be recorded and dated during the training and swinging program. Future studies should focus on determining the best strength, speed, and exercise relationship. They should examine the ideal weight of medicine balls, progression of the program, type of exercises, number of exercises, number of sets, number of repetitions, amount of rest, number of days per week, appropriate warm-up, and how to integrate all of this within the current swinging and lifting programs. To examine the best exercises, motion capture labs and EMG systems should be used to examine the kinematics of swinging and see which exercises most closely resemble the swing. Scientifically planned trials should be used that attempt various ball weights, exercises, warm-ups, repetitions, and sets. The order of swinging, resistance training and plyometric training should be examined to find out what type of a program maximizes gains.

It would be beneficial to control the lifting and swinging procedures. This can be challenging as the population used in this study is very structured in their training, establishing a good rapport and working closely with coaches and strength and conditioning professionals may lead to a greater amount of control. Further recommendations would be to educate the coaches on the benefits of such a program, and try to get them to integrate this training into their team's daily routine. This will enhance compliance and participant effort.

Future studies in this area should also have a survey for each participant to find out their mental status during the study. This survey should assess if the participants feel pressured by coaches, teammates or the research team to perform. It is nearly impossible to prevent all talking about the training program among members of a team, but my suggestion is to try and limit the talking. This talking may affect mental status, and therefore, how each group performs on their testing.

Future studies in bat velocity should set a time course, and determine if strength or speed is the appropriate emphasis. They could use lower body plyometrics for the control group and see if the rotational plan had a greater increase than the lower body plyometric exercises did. Then one could determine if strength or speed is the best emphasis, and for how many weeks.

My future recommendations also include examining the effect of new types of training. This includes sport specific, complex training, or using resistance training and plyometric training together right after each other. This method could be very beneficial to bat velocity increases as it has been shown to increase strength gains in other areas (Ebben & Watts, 1998). Other recommendations would include focusing on training lower body musculature, as it seems to produce the majority of the power (Dodd & Alvar, 2007; Scwendel & Thorland, 1992). The periodization, amount of total work, and emphasis of training should be targeted as factors to consider when planning future studies. Determining the optimal periodization, mass of implement, velocity of movement and total work should be the focus of future studies in this area. It would also be beneficial to determine the optimal time for the program, and to try and integrate this program into a daily routine, instead of making it an additional workout.

Implications and Summary

Increasing baseball bat velocity has been proven to be an important performance outcome in baseball batting. Increasing bat velocity has been shown to promote successful hitting. Therefore, strength and conditioning coaches desire to increase their baseball teams' bat velocity. The findings of this study can help shape the way that strength and conditioning professionals, athletic trainers, and coaches view bat velocity training.

Training with a combined rotational and linear plyometric program, as well as general team resistance training and hitting practice did not statistically increase bat velocity. Also the length of the program did not have any statistically significant effects on the outcome. The results of this study suggest that this type of a training program did not statistically create an effective increasing in bat velocity. However, a major factor to consider is that it was underpowered and a future study would need to be conducted with more subjects to determine if significance would occur.

The raw data supported a practically significant increase in bat velocity for both groups that increased more rapidly from 0 to 4 weeks, and increased less from 5 to 8 weeks. Because no statistical significance was found, these results need to be interpreted with caution, but they point towards the experimental group training being most beneficial from zero to 4 weeks. This increased bat velocoity indicated that it would be beneficial for strength and conditioning coaches to incorporate this training with their hitters for at least 4 weeks. Future studies could help determine if there are any additional benefits after 4 weeks depending on the program.

A third implication is that this study serves as groundwork for future research. Further investigation is needed to fully understand the optimal type of training to increase bat velocity. This study provides a first insight into these questions, and can be used as a baseline to build upon.

As a summary, baseball bat swing velocity is imporatant, but requires an optimal training program. Often people do not train for bat velocity, or they use ineffective methods. As a strength and conditoning coach, the goal should be to implement appropriate practices to increase bat velocity. It is important to create these programs so that they are sport specific, and utilize the appropriate muscles and energy systems. Although more research is needed, knowing that plyometric training, resistance training and swinging can increase bat velocity gives hope that certain training programs will help to increase bat velocity. With further research, this intervention option can be investigated and developed into a possible strength and conditioning practice to be used during baseball bat velocity training.

APPENDIX A

CONTACT INFORMATION AND DEMOGRAPHICS

Name:____

Address:____

Phone #: ____

Grade: ____

Age: ____

Height: ____

Weight: ____

Baseball Experience (Years): ____

Place You Played Before This Season: __________________________________

APPENDIX B

PARTICIPATION QUESTIONNAIRE

Check each of the boxes if they are true for you.

Name______________________

- ❑ **Are you at least 18 years of age?**

- ❑ **Are you a Division I collegiate baseball player?**

- ❑ **You do not have any current injury, sickness or mental illness within the last month?**

- ❑ **You have not had any injuries in the past that would put you at risk by participating in this study?**

- ❑ **You do not have any neurological problems, or contraindications to plyometric exercise?**

- ❑ **Can you perform maximal bat swing exercises?**

- ❑ **Can you undergo your normal lifting program, and not increase any squatting, power cleaning, snatching, or plyometric exercises?**

- ❑ **Can you undergo normal practice procedures?**

Note. If the subjects have checked each box, they will be eligible for this study.

APPENDIX C

SWING SPEED RADAR

Figure 2: Swing Speed Radar.

APPENDIX D

TRAINING PROGRAM PLYOMETRIC EXERCISES

START POSITION

END POSITION

Figure 3: Standing Rotational Throws.

START POSITION

END POSITION

Figure 4: Skater Jumps.

START POSITION

END POSITION

Figure 5: Skater Jump with Rotation.

START POSITION

MIDDLE POSITION

END POSITION

Figure 6: Skater Side Step Throw.

START POSITION

MIDDLE POSITION

END POSITION

Figure 7: Woodchoppers High to Low.

START POSITION

END POSITION

Figure 8: Woodchoppers Low to High.

START POSITION

END POSITION

Figure 9: Hitting Imitation.

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