DETERMINANTS OF BALL-EXIT VELOCITY IN COLLEGIATE BASEBALL PLAYERS

BY

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THESIS

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Symbols/Abbreviations

EV = Ball-Exit Velocity

VJ = Absolute Vertical Jump Power

VJR = Relative Vertical Jump Power

BS = Back Squat Power

MB = Lying Medicine Ball Chest Pass

BP = Bench Press Power

BA = Batting Average

SLG = Slugging Percentage

Chapter I: Introduction

The baseball swing is a complex movement requiring an abundance of speed and power in order to give the hitter the greatest opportunity to be successful. In the baseball swing, hitters initiate the movement with the hip, followed by the trunk, and finish with their arms (18). This specific skill utilizes the entire kinetic chain from the ground up in order to produce a powerful swing. Success with hitting in baseball has previously been defined as someone who has a batting average of at least .300, a slugging percentage of at least .500, or has hit a superior number of home runs (27). Batting average is commonly measured by the ratio of hits to total at-bats while slugging percentage is commonly measured as total bases divided by at-bats (8).

During the baseball swing, the ball needs to minimally be struck with good contact in the field of play with the objective to maximize ball-exit velocity by exerting as much power as possible with precise impact (7). Bat speed plays a key role in maximizing ball-exit velocity because it allows the hitter to apply more force upon the ball during contact. Beyond increasing one's ball-exit velocity, a faster bat speed will also increase a hitter's decision time, a crucial factor upon considering that a hitter only has 0.4167 seconds to make a decision on a 90 mph fastball or 0.052 more seconds to adjust to an 80 mph change-up (27). The ability to visually track a pitch and accurately make contact with the baseball in fractions of a second plays a major role determining the success of a hitter.

Beyond skill, the best hitters in baseball also generate large amounts of power. The equation for power is force multiplied by velocity, and velocity is further defined as the distance a certain object traverses divided by a certain measure of time. Thus, to yield excellent power an individual must possess a combination of the ability to rapidly generate high levels of force (27). Commonly, athletic performance coaches will work to increase a hitter's power output through various programs of resistance training to maximize an individual's power and hitting potential. Muscular power in the upper and lower extremities has been shown to significantly improve various metrics of the baseball swing including bat speed and ball-exit velocity, both of which are strong determinants of hitting success (18,25). Due to the role of power output throughout a baseball swing, athletic performance coaches often prioritize their assessments towards various power metrics.

Many studies have examined the relationship between muscular power and hitting metrics (11,16,18,25,27). Unfortunately, these investigations have focused on variables such as height, distance, and load resulting in an incomplete model of upper and lower body power. Missing from these studies were measurements of power and velocity that afford investigators a more thorough picture of the key factors impacting hitting metrics such as ball-exit velocity and bat speed. As examples, vertical jump power, back squat power, bench press power, and medicine ball chest pass velocity are all possible power assessments that can offer valuable information that may ultimately correlate more strongly to baseball swing success.

In conclusion, optimizing power production throughout a baseball swing is a key element indicative of baseball swing performance. While previous studies have attempted to identify key variables that link to baseball swing performance, these attempts have focused on variables that do not appropriately portray all aspects of a baseball swing. Convenient, user friendly means to assess an athlete's power production may better define the key variables that can help coaches quickly evaluate effective and ineffective hitting qualities. With the continuous improvements in technology, measuring power production has become easier with devices like linear position transducers, linear velocity transducers, and accelerometers. Linear position transducers are able to measure velocity with a tether that differentiates cable displacement with respect to time while linear velocity transducers can record electrical signals proportional to cable velocity (3). Other popular options to measure speed and power are wearable devices such as accelerometers and gyroscopes, which calculate acceleration data with respect to time (3). The purpose of the proposed study is to investigate the correlation between ball-exit velocity in the baseball swing with vertical jump power, back squat power, lying medicine ball chest pass, and bench press power. It is hypothesized that vertical jump power will exhibit significant correlations to ball-exit velocity in the baseball swing.

<u>Research Question To Be Addressed:</u>

Can vertical jump power, back squat power, bench press power, or lying medicine ball chest pass velocity correlate to ball-exit velocity in the baseball swing?

<u>Purpose:</u>

The purpose of the proposed study is to investigate the correlation between ball-exit velocity in the baseball swing with vertical jump power, back squat power, lying medicine ball chest pass, and bench press power.

<u>Hypothesis:</u>

Vertical jump power will exhibit significant correlations to ball-exit velocity in the baseball swing.

<u>Scope of Study:</u>

This study focuses on the development of a power assessment that can correlate muscular power to ball-exit velocity in the baseball swing. Once determined, this protocol will help athletic performance coaches, baseball coaches, and baseball players to objectively assess who has the most potential power in a baseball swing.

<u>Limitations to the Study:</u>

This study was not without limitations. Even though the PUSH wearable device has been validated with linear transducer metrics, accelerometers are not the most accurate form of power testing for resistance training exercise. With any type of technology, there is always the possibility of a technical error while collecting data. During some of the repetitions, power outputs from the back squat and bench press assessments did not register on the PUSH band due to technical flaws. Launch angles were not taken into consideration while assessing ball-exit velocity. Contact with the ball, spin rates, and swing techniques are all factors that may affect launch angles, which may affect ball-exit velocities for each participant. Failure to standardize the length, weight, and brand of each bat may have affected the ball-exit velocities. Waist height of the tee may have been a little off depending on each subject's batting stance and swing mechanics. The ball-exit velocities were measured outdoors rather than in a controlled indoor batting cage. Although the weather provided good conditions for testing, the outdoor setting may have affected the exit velocities. Lastly, the baseballs used while collecting ball-exit velocity data were all different. The quality of some of the baseballs may have provided inconsistency with the exit velocities.

Significance of the Study:

This study will have a large impact on the performance and training protocols for baseball players at all levels. Findings from this study could greatly enhance all coaches to better understand the keys to hitting success and refine training protocols in athletic performance programs.

Chapter II: Review of the Literature

Importance of Power in Hitting

A powerful swing is a necessary attribute for a hitter in order to increase bat speed, which will directly increase decision time, decrease swing time, and increase ball-exit velocity (18,27). First, if a hitter can increase their swing speed, it will allow them to track the ball longer into the hitting zone before making a decision to swing. For major league hitters, the decision time to swing at a pitch is between 0.26 to 0.35 seconds (27). The increased swing speed for a hitter will allow them to wait a split second longer, which may possibly be the difference between a hit and an out. The longer a hitter can wait before swinging will allow them to identify the type of pitch, the velocity of the pitch, and the location of the pitch, which will theoretically increase their accuracy and timing of the swing (27).

In a similar fashion, if a hitter can increase their decision time, it most likely means that they are decreasing their swing time. Decreased swing times are very similar to increased decision times because it will also allow the hitter to effectively identify the type of pitch, the velocity of the pitch, and the location of the pitch. Major league hitters typically have swing times of 0.19 to 0.28 seconds; therefore, they will have more time to see the ball entering the hitting zone the faster they can swing the bat (27).

Lastly, an increase in bat speed will likely increase ball-exit velocity. This is arguably one of the most important hitting metrics because the faster the ball comes off of the bat, the farther it will travel in the air (depending on launch angle). If a hitter can swing a bat at a faster velocity or swing a heavier bat at the same speed, then ball-exit velocity would increase because of the large transfer of momentum (27). An increased ball-exit velocity gives the hitter the best opportunity to display their true hitting power as long as they can make solid contact and have to optimal launch angle. Athletic performance coaches have the ability to maximize the power potential in each hitter in order to give them the best opportunity to exhibit their true potential on the field.

Velocity Based Training

Linear Transducers

Linear transducers are devices that display immediate feedback such as velocity and power from resistance training equipment like a barbell (15). These central processing units allow the athletes to easily receive objective feedback that is displayed on a screen from a secondary device (10). A tether from the linear transducer is attached to the barbell, which measures velocity by either differentiating cable displacement with respect to time (linear position transducer) or recording electrical signals proportional to cable velocity (linear velocity transducers) (3). Tendo Units and GymAware are a few examples of linear transducers that are currently available on the market with various price ranges depending on the system (24). With continuous improvement in technology, linear transducers are becoming easier to implement and available for everyone through smart devices like phones and tablets.

Linear transducers have consistently been shown to have high reliability, high validity, and low measurements of error through multiple studies (6,13,14,26). These studies have consistently shown near perfect correlations with mean velocity and percentages of 1RM in the bench press and the back squat. Through these studies, athletic performance coaches can confidently program certain rep ranges, monitor neuromuscular fatigue, and predict 1RM's with velocity based training. Although a meta-analysis is needed in order to gather all the data from these studies, it can be estimated that 100% of a 1RM will be 0.3 meters per second or slower for the squat and bench press movements (2,14,26). The direct measurement of velocity from linear transducers will allow coaches and athletes to monitor velocity based training effectively and incorporate it into specific training programs (15).

PUSH Wearable Device

With linear transducers dominating the velocity based training market, other companies are trying to level the playing field with wearable technology and cheaper price-points. In order to do this, companies are manufacturing wearable devices with accelerometers and gyroscopes that measure the same metrics as linear transducers by calculating the acceleration data with respect to time (3). One of the more popular accelerometers for velocity based training is the PUSH wearable device, which consists of a 3-axis accelerometer and a gyroscope that provides 6 degrees of freedom in its coordinate system (3). The PUSH wearable device is typically worn on the lateral side of the forearm just below the elbow with a PUSH band, which provides comfort and makes the device user-friendly during resistance training exercises.

Although PUSH is a more affordable device using an accelerometer to measure movement velocities, it has still shown a strong relationship with all of the metrics of a linear transducer. Researchers from the University of Madrid in Spain recently compared mean and peak velocities in a study between PUSH and a linear transducer during the back squat exercise in order to validate these correlations. The results from this study showed very strong correlations between mean velocities ($r=0.86$) and peak velocities ($r=0.91$) as well as high levels of agreements between mean velocities (ICC=0.907) and peak velocities (ICC=0.944) (3). With the PUSH band performing up to the standards of a linear transducer, it has become very appealing in the sports performance industry especially for coaches and departments with limited budgets. In today's velocity based training market, the PUSH wearable device can be up to 8 times cheaper than a linear transducer with the same performance standards.

Practical Applications

Velocity based training is a tool that allows coaches to objectively monitor the actual training load an athlete is using (1). By measuring movement velocity, there is now an accurate gauge of how the athlete is feeling and what load the athlete should be using on that particular day. Velocity based training allows the athlete to auto-regulate their training session rather than sticking with percentages that may or may not be accurate. In 2010, Bryan Mann conducted a study that examined the effects of linear periodization versus autoregulation training in collegiate football players (17). At the end of the six week training program, the results showed that the autoregulation group had significant improvements in 1RM squat, 1RM bench press, and repeated 225-lb bench press compared to the linear periodization group (17). Although Mann did not incorporate velocity based training to his study, it was suggested that some sort of auto-regulatory method could be effective for resistance training. Movement velocities would be an excellent tool to use in order to maximize autoregulation training.

Being able to auto-regulate training loads is a crucial factor in order to manage day-to-day stressors. Velocity based training allows a coach to accurately monitor the training loads and modify the training session as needed. One of the key factors that velocity based training allows coaches and athletes to do is monitor neuromuscular fatigue. As neuromuscular fatigue increases, the risk of injury also increases, which is important to manage especially during training sessions. Using submaximal loads with barbell exercises like bench press, squat, and jump squats, velocity based training can determine the readiness and neuromuscular fatigue based upon the load of the barbell and the bar velocities that are demonstrated (23). This feedback from a linear transducer or an accelerometer can quickly tell the coach how the athlete is feeling prior to the training session, but it can also be used to reveal fatigue during the training session in between sets and reps. Velocity loss in various barbell exercises allows coaches and athletes to objectively measure neuromuscular fatigue during resistance training (23).

Velocity based training can also be used to increase muscular strength during resistance training sessions. As mentioned earlier, movement velocities and percentages of 1RM in the bench press and squat have been correlated almost perfectly through numerous studies. Because of this, athletes can work at submaximal loads and know if they are training at their actual percentage of 1RM (1,12,19). If the athlete's mean velocity is slower than it should be, then the coach knows that the load should be decreased. In the same way, if the mean velocity is higher than it should be, then the coach knows that the athlete can add weight to the prescribed training load. Coaches can also use velocity based training to monitor if athletes are going to full exertion. Since we know that maximal effort is around 0.30 meters per second or slower, then the last repetition of each set should be around that speed (2). If the athlete is moving the barbell at speeds greater than 0.30 meters per second on their last repetition, then coaches will know that the athlete is capable of adding load to the barbell depending on how far off they were with their velocity numbers. Velocity based training is a dependable tool that allows the athletes opportunity to maximize their resistance training sessions in order to increase muscular strength.

Since velocity based training can be strategically used to increase muscular strength, it can also be used as a tool to integrate power into a resistance training program. Power cannot be produced unless speed is included throughout the movement. Velocity based training gives the athlete feedback on their bar speed, therefore the athlete can stay at a certain speed in order to increase their power output (20). Velocity based training can also be incorporated with barbell jump squats using peak and mean velocity of the barbell (21). A ballistic movement like a jump squat allows the athlete to train for power and the linear transducer or accelerometer gives the quantitative feedback in order to maximize each repetition. Being able to monitor power output along with strength and neuromuscular fatigue allows velocity based training to be a powerful tool to use in a resistance training program.

Power Assessments

Upper and lower body power is an undeniable aspect for baseball hitters. There have been many different studies looking at baseball-specific power assessments for hitters, but there has yet to be any with strong correlations. Although there have been many studies showing positive correlations between power assessments and hitting metrics, these positive correlations are still inconsistent and show moderate relationships at best (25,27).

Understanding how bodyweight affects power output is also a key aspect to these assessments. Many power assessments look at variables like height or distance, but do not take into account the bodyweight of each individual. Although height and distance measurements may be greater in certain athletes, the amount of power they are generating because of their body weight can make a big difference within the results. Bodyweight has been shown to significantly increase in professional baseball within the different franchise affiliates starting from Rookie Leagues all the way up to the Major Leagues (11). In a similar fashion, mean and peak power outputs identically increase from Rookie Leagues to the Major Leagues likely from the increase in bodyweight (11).

Many studies have also looked at rotational power assessments since hitting a baseball is a rotational skill. This seems reasonable in theory, but it is important to understand that rotation is a skill that may not demonstrate power outputs accurately. Dr. Greg Rose from the Titleist Performance Institute has actually spent a lot of time researching athletic performance for golfers and has continuously found weak relationships between various rotational power assessments and ball speed with the driver (22). The way someone releases a medicine ball and the angle that it is thrown at makes a big difference when measuring rotational power with any lateral toss variation. Another study done by Adam Lewis in 2016 showed positive correlations between club head speed and vertical jump, seated medicine ball throw, and rotational medicine ball throw; however, the rotational medicine ball throw actually had the weakest correlation between the three independent variables (16). Although the rotational medicine ball throw showed a moderate correlation ($r=0.57$) with club head speed, vertical jump ($r=0.817$) and seated medicine ball chest pass (0.706) showed a much stronger correlation, which may suggest that a rotational medicine ball throw may not be the best assessment for rotational power (16).

Lower Body Power

Lower body power is critical in the baseball swing especially since force is generated from the ground up. Many studies have attempted to correlate hitting metrics to lower body power, but often show inconsistent results because they are measuring the wrong data. Power is often measured in watts, which is very important because it accounts for load whether it is an individual's body weight or the weight on a barbell. Vertical jump is a common measurement of lower body power, but by calculating body weight using an equation it is possible to get a more accurate determination of the actual power being generated. The Sayers Power Equation (PAPw (watts) = 60.7 x jump height (cm) + 45.3 x body mass (kg) – 2055) is a simple formula that can be used in order to determine absolute power from the vertical jump assessment (5). Using this equation, the vertical jump assessment can be utilized at a deeper level in order to determine true lower body power.

Another lower body power assessment that can be utilized is a power repetition maximal (PRM) test with the back squat exercise. Using the back squat to determine lower body power is important because it forces the athlete to handle the load both eccentrically and concentrically. The PRM test measures peak mean power in the back squat, which is usually around 65-70% of an individual's one-repetition max. At the University of Kansas, the PRM test is used as a primary assessment with the Men's Basketball team because all athletes who back squatted at least 800 watts ended up on a pro team after their careers at KU (4). Basketball players at KU who ended up on an NBA roster averaged 885 watts of peak mean power while those who did not play professional after their career at KU only averaged 709 watts of peak mean power (4). Although this data is collected from elite basketball players, it magnifies the significance of lower body power that can be calculated with the back squat exercise.

Upper Body Power

Lower body power may be the main factor that increases performance in a baseball hitter, but there is also evidence that upper body power can play a significant role. A 2012 study in Japan compared bench press strength and power to bat swing speed, but only showed moderate correlations between each variable (18). Although these positive correlations are only moderate, it does shed some light on other studies comparing upper body power and swing speed.

Other studies looking at upper body power have used a seated medicine ball chest pass instead of the bench press exercise and have found very significant results. The Titleist Performance Institute incorporates a seated medicine ball chest pass into their power assessments with golfers, which correlated better with club head speed and ball speed better than a rotational medicine ball throw (22). The seated medicine ball chest pass was measured in distance with the athlete seated with their feet flat on the ground and back flat on a chair in an upright position. This power assessment was duplicated in another study that found a strong correlation ($r=0.706$) comparing the seated medicine ball chest pass with a golfer's club head speed (16). Similarly, this study had similar findings to the Titleist Performance Institute showing stronger correlations to club head speed with the seated medicine ball chest pass versus the rotational medicine ball throw.

Although the medicine ball studies are assessing golfers, the results may suggest that upper body power may be useful when evaluating rotational skills regardless of the sport. Comparing power outputs from the bench press and the seated medicine ball chest pass may be a more effective measure of upper body power, but those results are still unknown. Having this data may be a better indicator comparing upper body power and various hitting metrics, but it is still suggested that upper body power assessments may be more effective than rotational power assessments with the results from previous studies.

Conclusion

Hitting is a complex movement that connects the entire kinetic chain from the lower and upper body. Athletic performance is critical in baseball hitters especially pertaining to strength and power. The baseball swing requires an explosive rotational movement that will benefit from upper and lower body power training. The right combination of strength and speed is required in order to maximize power output so it is important to understand this as an athletic performance coach. Incorporating velocity based training may be beneficial for these coaches in order to objectively quantify the exact training zones that their athletes should be in during various resistance exercises. The power outputs from a baseball hitter can be assessed in many different ways, but the most important factor is that body weight is accounted for during these tests in order to get detailed results rather than metrics like load, height, and distance. Lower body power can be properly measured with a vertical jump and the Power Repetition Maximal test with the back squat exercise. In a similar fashion, upper body power can be properly measured in a medicine ball chest pass variation or with the bench press exercise. The upper and lower body assessments are very important for a baseball hitter and it should be understood that rotational power may not be the best measurement for certain hitting metrics. Rotation, especially a baseball swing, is a skill so it is difficult to measure rotational power because skill might be a limiting factor between each individual. Although there are many options to assess upper and body power in the baseball hitters, the bottom line is that the baseball swing is an explosive movement and total body power is vital in order to be successful with this specific skill.

Chapter III: Methods

Experimental Approach to the Problem

The purpose of the proposed study was to investigate the extent to which various power assessments and ball-exit velocity in the baseball swing are related to one another. The primary dependent variable in this study was ball-exit velocity (EV) and the independent variables were vertical jump power (VJ), back squat power repetition max (BS), lying medicine ball chest pass (MB), and bench press power repetition max (BP). Ball-exit velocity was measured with the Stalker Pro II radar gun (Applied Concepts Inc., Plano, TX, USA) while back squat power, lying medicine ball chest pass, and bench press power were measured with the PUSH wearable device (PUSH Inc., Toronto, Canada). All participants performed three repetitions of the vertical jump and lying medicine ball chest pass assessment, fifteen submaximal repetitions of the back squat and bench press assessments, and five repetitions of the hitting assessment on two separate days that were within seven days of each other. Power assessments were tested in the morning between 0600 and 1000 hours and ball-exit velocity was recorded in the afternoon on a separate day with at least 24 hours of rest in between the power assessments and hitting assessments. The four power assessments were conducted in a randomized order with two minutes of rest between each test for every subject. Each participant was blinded from all of their results until completion of their session. Ball-exit was measured in a specific order from subject to subject to keep a consistent rest time of two minutes between each round. The best score was used for each assessment. All testing was supervised by trained research investigators.

Subjects

18 NCAA Division II baseball players from a Midwestern U.S. institution were recruited for this study. One subject was removed from the study due to injury leaving 17 individuals who

completed the entire testing protocol (age, 20.4 ± 0.9; height, 182.43 ± 4.71; weight, 89.32 ± 8.69). This study was approved by the Lindenwood University Institutional Review Board (IRB # 997445-1, approval date: 12/21/2016) prior to any data collection. All subjects provided their signed consent before participating in the study. Each subject had at least three months of consistent (three times per week) resistance training experience relating to each of the prescribed power assessments. All subjects had at least twelve years (15.41 ± 1.37) of baseball experience and were excluded from the study if they were unable to complete each of the four power assessments (e.g., injury, time availability, etc.).

Procedures

Vertical Jump Power

The vertical jump power assessment consists of a countermovement jump on a jump mat using standardized technique (Probotics Inc., Huntsville, AL, USA). Proper landing mechanics were monitored throughout each repetition by trained supervisors that required each subject to land without loss of balance in a power position (greater than 90-degree angle at the knees) with arms back in a loaded position. Each subject first stood on the jump mat before jumping directly up while keeping their legs straight in the air. After takeoff, each subject was required to landed back on the jump mat with both feet using proper landing mechanics. Vertical jump height was calculated, which was then converted to peak power output using the Sayers Power Equation (PAPw (watts) = 60.7 x jump height (cm) + 45.3 x body mass (kg) – 2055) (5). Each subject jumped three times and the highest vertical jump height was used in order to calculate peak power output. Peak power output was then used to determine vertical jump power for each subject.

Back Squat Power Repetition Max

The back squat power repetition max assessment evaluated maximal mean power output in each subject. Each repetition required a squat depth resulting in 90 degrees of knee flexion. All repetitions were supervised and were completed in a Laser Double Rack Station with a 20 kilogram barbell (Wilder Fitness Equipment, Pontotoc, MS). On a separate day before the power repetition max testing, 1RMs were estimated with each individual's 3RM using a Prilepin relative intensity chart (9).

Subjects performed three repetitions at 30% 1RM, three repetitions at 40% 1RM, three repetitions at 50% 1RM, two repetitions at 60% 1RM, two repetitions at 70% 1RM, one repetition at 80% 1RM, and one repetition at 90% 1RM with average power outputs recorded during each repetition throughout the entire assessment. Maximal mean power output with the back squat will be around 65 – 70% of each subject's 1RM (4). Rest periods of two minutes were followed between each set of back squats throughout the protocol. Power outputs were calculated with a PUSH wearable device (PUSH Inc., Toronto, Canada) (3). The PUSH wearable device consists of a triaxial accelerometer and a gyroscope that provides six degrees of freedom in its coordinate system and has been shown to have very strong relationships with all of the metrics of a linear transducer (3,5,14,20,25). The PUSH band was worn on the radius of the right forearm, 1-2 centimeters distal to the elbow.

Lying Medicine Ball Chest Pass

Peak velocity for the lying medicine ball chest pass was measured to assess upper body power. Each subject laid flat on their back with their legs fully extended with a three-kilogram medicine ball resting on their chest and the PUSH device attached to their right forearm. From this initial position, each participant was instructed to throw the ball towards the ceiling as quickly and forcefully as possible. Upon releasing the ball, the participant was required to hold their arms in an extended position while one test supervisor catches the medicine ball before landing and another test supervisor measures peak velocity. Each subject completed three trials of the lying medicine ball chest pass with the highest velocity being recorded. Peak velocity was calculated with a PUSH wearable device, which was worn on the radius of the right forearm, 1-2 centimeters distal to the elbow with a PUSH band (PUSH Inc., Toronto, Canada) (3).

Bench Press Power Repetition Max

The bench press power repetition max assessment was performed in a Laser Double Rack Station with a 20-kilogram barbell (Wilder Fitness Equipment, Pontotoc, MS). Each subject was required to maintain five points of contact (head, back, tailbone, and both feet) while performing the bench press exercise. Arms were abducted at approximately 45 degrees from the subject's torso while bench pressing and the bar was required to touch the chest with each repetition. On a separate day before the power repetition max testing, 1RMs were estimated with each individual's 3RM using a Prilepin relative intensity chart (9).

Subjects performed three repetitions at 30% 1RM, three repetitions at 40% 1RM, three repetitions at 50% 1RM, two repetitions at 60% 1RM, two repetitions at 70% 1RM, one repetition at 80% 1RM, and one repetition at 90% 1RM with average power outputs recorded during each repetition throughout the entire assessment. Maximal mean power bench press output will be achieved around 65 – 70% of each subject's 1RM (4). All subjects observed rest periods of two minutes between each set of bench press. As before, power outputs were calculated with a PUSH wearable device as described previously (3).

Ball-Exit Velocity

Ball-exit velocity was calculated using the Stalker Pro II radar gun (Applied Concepts Inc., Plano, TX, USA). Every swing occurred with the baseball placed on a tee at waist height

(83.3 ± 3.8). Waist height was determined to be the distance between the floor and the top of a subject's pant zipper while standing in a baseball "swing-ready" position. Waist height was measured prior to the first testing session by the same investigator. Each recorded swing was conducted outdoor on a synthetic turf field with similar weather conditions. Ball-exit velocity was measured directly behind the tee with the out-bound reading of the radar gun giving a consistent measure of each batted ball. All hitting data was collected on the same day between 1200 and 1500 hours and each subject used their own baseball bat, footwear, and gloves for all assessments. Each participant completed a warm up round of five swings followed by a second round of five swings where the highest ball-exit velocity was recorded as the participant's score. Two minutes of rest was given to each participant between the first and second round of swings.

Statistical Analysis

Pearson correlations were used to determine the relationships between each variable using Microsoft Excel (Microsoft Corp., Seattle, WA, USA) and IBM SPSS version 23 for Windows (International Business Machines Corp., Armonk, NY, USA). A p-value of 0.05 was used to determine statistical significance. Correlations were deemed a weak correlation if the corresponding r-values fell between $-0.4 < r < 0.4$, a moderate correlation if the correlation value was between -0.4 to -0.7 or 0.4 to 0.7, and a strong correlation was considered if calculated correlation values were between -0.7 to -1.0 and 0.7 to 1.0. Z-scores for ball-exit velocity were calculated and separated into the upper third and lower third before using independent t-tests to determine if differences existed between players with a low or high ball-exist velocity relative to power assessments and hitting metrics. Subjects with a ball-exit velocity lower than 83.67 miles per hour were placed in the low ball-exit velocity group ($n = 4$) and subjects with a ball-exit velocity higher than 87.33 miles per hour were placed in the high ball-exit velocity group ($n = 5$).

Chapter IV: Research Manuscript

This chapter presents a complete manuscript that describes the study in traditional journal article form including a title page, abstract, introduction, methods, results, discussion, acknowledgements, references, figures, and tables. The manuscript, entitled "Determinants of Hitting Metrics in Collegiate Baseball Players" will be submitted to the *Journal of Strength and Conditioning Research* when all data collection and analysis is completed. It is currently authored by Ross Hasegawa and Chad Kerksick. The final manuscript will follow the formatting and style guidelines of the *Journal of Strength and Conditioning Research* (http://edmgr.ovid.com/jscr/accounts/ifauth.htm). The references cited are provided at the end of the manuscript.

Running head: Ball-exit velocity in baseball players

Determinants of Ball-Exit Velocity in Collegiate Baseball Players

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ABSTRACT

Ball-exit velocity has been a major metric of the baseball swing that hitters have focused on in hopes of improving performance at the plate. While the importance of strength and power development in baseball hitters is understood, an objective assessment of absolute power has yet to be determined to understand the strongest relationships between ball-exit velocity and athletic performance. The purpose of this study is to investigate the correlation between ball-exit velocity in the baseball swing with vertical jump power, back squat power, lying medicine ball chest pass, and bench press power. 17 NCAA Division II baseball players participated in this study (age, 20.4 ± 0.9; height, 182.43 ± 4.71; weight, 89.32 ± 8.69) and Pearson correlations were used to determine relationships between each variable. A positive correlation was determined between ball-exit velocity and back squat power ($r = 0.777$) while absolute power in the vertical jump demonstrated a moderate correlation ($r = 0.533$) to ball-exit velocity. Findings from the current study suggest the importance of lower body power for increased ball-exit velocity, which can be beneficial to athletes, coaches, and performance professionals looking to improve hitting abilities at the NCAA Division II level.

INTRODUCTION

The baseball swing is a complex movement requiring the coordination of speed and power across multiple parts of the body. This integrated transfer of force and power throughout the baseball swing is initiated with movement in the hips, followed by the trunk, before finishing with the arms (18). This specific skill utilizes the entire kinetic chain from the ground up to effectively yield a powerful swing. Success with hitting in baseball has previously been defined as someone who has a batting average of at least .300, a slugging percentage of at least .500, or has hit a superior number of home runs (27). Batting average is commonly measured by the ratio of hits to total at-bats while slugging percentage is commonly measured as total bases divided by at-bats (8).

During the baseball swing, the ball needs to minimally be struck with good contact in the field of play with the objective to maximize ball-exit velocity by exerting as much power as possible with precise impact (7). Bat speed plays a key role in maximizing ball-exit velocity because it allows the hitter to apply more force upon the ball during contact. Beyond increasing ones ball-exit velocity, a faster bat speed will also increase a hitter's decision time, a crucial factor upon considering that a hitter, on average, only has 0.4167 seconds to make a decision on a 90-mph fastball or 0.052 more seconds to adjust to an 80-mph change-up (27). The ability to visually track a pitch and accurately make contact with the baseball in fractions of a second plays a major role determining the success of a hitter.

Beyond skill, the best hitters in baseball also generate large amounts of power. The equation for power is force multiplied by velocity, and velocity is further defined as the distance a certain object traverses divided by a certain measure of time. Thus, to yield excellent power an individual must possess a combination of the ability to rapidly generate high levels of force (27).

Commonly, athletic performance coaches will work to increase a hitter's power output through various programs of resistance training to maximize an individual's power and thus their hitting potential. Muscular power in the upper and lower extremities has been shown to significantly improve various metrics of the baseball swing including bat speed and ball-exit velocity, both of which are strong determinants of hitting success (18,25). Due to the role of power output throughout a baseball swing, athletic performance coaches often prioritize their assessments towards various power metrics.

Many studies have examined the relationship between muscular power and hitting metrics (11,16,18,25,27). Unfortunately, these investigations have focused on variables such as height, distance, and load resulting in an incomplete model of upper and lower body power. Missing from these studies were measurements of power and velocity that afford investigators a more thorough picture of the key factors impacting hitting metrics such as ball-exit velocity and bat speed. As examples, vertical jump power, back squat power, bench press power, and medicine ball chest pass velocity are all possible power assessments that can offer valuable information that may ultimately correlate strongly to baseball swing success.

During the baseball swing, force is produced from the ground up, which suggests that lower body power is necessary with all baseball hitters. Previous studies have shown positive relationships between lower body power and various hitting metrics like bat speed and ball-exit velocity in hitters across multiple playing levels (25,27). In 2016, Lewis et al. (16) also examined the relationship of lower body power with the club head speed of PGA golfers. A strong positive correlation between the vertical jump and club head speed ($r = 0.817$) was shown at the conclusion of this study, which suggests the importance of lower body power in skills requiring force from the ground up.

Although lower body power is accepted as an important variable in the baseball swing, upper body power has also shown relationships with swing speed in baseball hitters (18,27). Miyaguchi was able to demonstrate a moderate correlation between bench press power and bat swing speed (r = 0.408) in his 2012 study suggesting that upper body power may play an important role along with lower body power in baseball hitters (18).

In conclusion, optimizing power production throughout a baseball swing is a key element indicative of baseball swing performance (7,18,27). While previous studies have attempted to identify key variables that link to baseball swing performance, these attempts have focused on variables that do not appropriately portray all aspects of a baseball swing. Convenient, user friendly means to assess an athlete's power production may better define the key variables that can help coaches quickly evaluate effective and ineffective hitting qualities. With the continuous improvements in technology, measuring power production has become easier with devices like linear position transducers, linear velocity transducers, and accelerometers. Linear position transducers are able to measure velocity with a tether that differentiates cable displacement with respect to time while linear velocity transducers can record electrical signals proportional to cable velocity (3). Other popular options to measure speed and power are wearable devices such as accelerometers and gyroscopes, which calculate acceleration data with respect to time (3). The purpose of the proposed study is to investigate the correlation between ball-exit velocity in the baseball swing with vertical jump power, back squat power, lying medicine ball chest pass, and bench press power. It is hypothesized that vertical jump power will exhibit significant correlations to ball-exit velocity in the baseball swing.

METHODS

Experimental Approach to the Problem

The purpose of the proposed study was to investigate the extent to which various power assessments and ball-exit velocity in the baseball swing are related to one another. The primary dependent variable in this study was ball-exit velocity (EV) and the independent variables were vertical jump power (VJ), back squat power repetition max (BS), lying medicine ball chest pass (MB), and bench press power repetition max (BP). Ball-exit velocity was measured with the Stalker Pro II radar gun (Applied Concepts Inc., Plano, TX, USA) while back squat power, lying medicine ball chest pass, and bench press power were measured with the PUSH wearable device (PUSH Inc., Toronto, Canada). All participants performed three repetitions of the vertical jump and lying medicine ball chest pass assessment, fifteen submaximal repetitions of the back squat and bench press assessments, and five repetitions of the hitting assessment on two separate days that were within seven days of each other. Power assessments were tested in the morning between 0600 and 1000 hours and ball-exit velocity was recorded in the afternoon on a separate day with at least 24 hours of rest in between the power assessments and hitting assessments. The four power assessments were conducted in a randomized order with two minutes of rest between each test for every subject. Each participant was blinded from all of their results until completion of their session. Ball-exit was measured in a specific order from subject to subject to keep a consistent rest time of two minutes between each round. The best score was used for each assessment. All testing was supervised by trained research investigators.

Subjects

18 NCAA Division II baseball players from a Midwestern U.S. institution were recruited for this study. One subject was removed from the study due to injury leaving 17 individuals who completed the entire testing protocol (age, 20.4 ± 0.9; height, 182.43 ± 4.71; weight, 89.32 ± 8.69). This study was approved by the Lindenwood University Institutional Review Board (IRB

997445-1, approval date: 12/21/2016) prior to any data collection. All subjects provided their signed consent before participating in the study. Each subject had at least three months of consistent (three times per week) resistance training experience relating to each of the prescribed power assessments. All subjects had at least twelve years (15.41 ± 1.37) of baseball experience and were excluded from the study if they were unable to complete each of the four power assessments (e.g., injury, time availability, etc.).

Procedures

Vertical Jump Power

The vertical jump power assessment consists of a countermovement jump on a jump mat using standardized technique (Probotics Inc., Huntsville, AL, USA). Proper landing mechanics were monitored throughout each repetition by trained supervisors that required each subject to land without loss of balance in a power position (greater than 90-degree angle at the knees) with arms back in a loaded position. Each subject first stood on the jump mat before jumping directly up while keeping their legs straight in the air. After takeoff, each subject was required to landed back on the jump mat with both feet using proper landing mechanics. Vertical jump height was calculated, which was then converted to peak power output using the Sayers Power Equation (PAPw (watts) = 60.7 x jump height (cm) + 45.3 x body mass (kg) – 2055) (5). Each subject jumped three times and the highest vertical jump height was used in order to calculate peak power output. Peak power output was then used to determine vertical jump power for each subject.

Back Squat Power Repetition Max

The back squat power repetition max assessment evaluated maximal mean power output in each subject. Each repetition required a squat depth resulting in 90 degrees of knee flexion.

All repetitions were supervised and were completed in a Laser Double Rack Station with a 20 kilogram barbell (Wilder Fitness Equipment, Pontotoc, MS). On a separate day before the power repetition max testing, 1RMs were estimated with each individual's 3RM using a Prilepin relative intensity chart (9).

Subjects performed three repetitions at 30% 1RM, three repetitions at 40% 1RM, three repetitions at 50% 1RM, two repetitions at 60% 1RM, two repetitions at 70% 1RM, one repetition at 80% 1RM, and one repetition at 90% 1RM with average power outputs recorded during each repetition throughout the entire assessment. Maximal mean power output with the back squat will be around 65 – 70% of each subject's 1RM (4). Rest periods of two minutes were followed between each set of back squats throughout the protocol. Power outputs were calculated with a PUSH wearable device (PUSH Inc., Toronto, Canada) (3). The PUSH wearable device consists of a triaxial accelerometer and a gyroscope that provides six degrees of freedom in its coordinate system and has been shown to have very strong relationships with all of the metrics of a linear transducer (3,5,14,20,25). The PUSH band was worn on the radius of the right forearm, 1-2 centimeters distal to the elbow.

Lying Medicine Ball Chest Pass

Peak velocity for the lying medicine ball chest pass was measured to assess upper body power. Each subject laid flat on their back with their legs fully extended with a three-kilogram medicine ball resting on their chest and the PUSH device attached to their right forearm. From this initial position, each participant was instructed to throw the ball towards the ceiling as quickly and forcefully as possible. Upon releasing the ball, the participant was required to hold their arms in an extended position while one test supervisor catches the medicine ball before landing and another test supervisor measures peak velocity. Each subject completed three trials of the lying medicine ball chest pass with the highest velocity being recorded. Peak velocity was calculated with a PUSH wearable device, which was worn on the radius of the right forearm, 1-2 centimeters distal to the elbow with a PUSH band (PUSH Inc., Toronto, Canada) (3).

Bench Press Power Repetition Max

The bench press power repetition max assessment was performed in a Laser Double Rack Station with a 20-kilogram barbell (Wilder Fitness Equipment, Pontotoc, MS). Each subject was required to maintain five points of contact (head, back, tailbone, and both feet) while performing the bench press exercise. Arms were abducted at approximately 45 degrees from the subject's torso while bench pressing and the bar was required to touch the chest with each repetition. On a separate day before the power repetition max testing, 1RMs were estimated with each individual's 3RM using a Prilepin relative intensity chart (9).

Subjects performed three repetitions at 30% 1RM, three repetitions at 40% 1RM, three repetitions at 50% 1RM, two repetitions at 60% 1RM, two repetitions at 70% 1RM, one repetition at 80% 1RM, and one repetition at 90% 1RM with average power outputs recorded during each repetition throughout the entire assessment. Maximal mean power bench press output will be achieved around 65 – 70% of each subject's 1RM (4). All subjects observed rest periods of two minutes between each set of bench press. As before, power outputs were calculated with a PUSH wearable device as described previously (3).

Ball-Exit Velocity

Ball-exit velocity was calculated using the Stalker Pro II radar gun (Applied Concepts Inc., Plano, TX, USA). Every swing occurred with the baseball placed on a tee at waist height (83.3 ± 3.8). Waist height was determined to be the distance between the floor and the top of a subject's pant zipper while standing in a baseball "swing-ready" position. Waist height was measured prior to the first testing session by the same investigator. Each recorded swing was conducted outdoor on a synthetic turf field with similar weather conditions. Ball-exit velocity was measured directly behind the tee with the out-bound reading of the radar gun giving a consistent measure of each batted ball. All hitting data was collected on the same day between 1200 and 1500 hours and each subject used their own baseball bat, footwear, and gloves for all assessments. Each participant completed a warm up round of five swings followed by a second round of five swings where the highest ball-exit velocity was recorded as the participant's score. Two minutes of rest was given to each participant between the first and second round of swings.

Statistical Analysis

Pearson correlations were used to determine the relationships between each variable using Microsoft Excel (Microsoft Corp., Seattle, WA, USA) and IBM SPSS version 23 for Windows (International Business Machines Corp., Armonk, NY, USA). A p-value of 0.05 was used to determine statistical significance. Correlations were deemed a weak correlation if the corresponding r-values fell between $-0.4 < r < 0.4$, a moderate correlation if the correlation value was between -0.4 to -0.7 or 0.4 to 0.7, and a strong correlation was considered if calculated correlation values were between -0.7 to -1.0 and 0.7 to 1.0. Z-scores for ball-exit velocity were calculated and separated into the upper third and lower third before using independent t-tests to determine if differences existed between players with a low or high ball-exist velocity relative to power assessments and hitting metrics. Subjects with a ball-exit velocity lower than 83.67 miles per hour were placed in the low ball-exit velocity group ($n = 4$) and subjects with a ball-exit velocity higher than 87.33 miles per hour were placed in the high ball-exit velocity group ($n = 5$).

RESULTS

Results from the Pearson correlations can be found in Table 1 for all power assessments and Table 2 for all other performance variables. Correlations between ball-exit velocity and the power assessments indicated that back squat power ($r = 0.777$, $p < 0.01$) was the strongest correlate (Figure 1), followed by vertical jump power ($r = 0.533$, $p < 0.05$) (Figure 2). When comparing ball-exit velocity to all other performance variables, slugging percentage (SLG) ($r = 0.485$, $p < 0.05$) was moderately correlated to ball-exit velocity (Figure 3).

<<< Insert Figures 1, 2 and 3 about here >>>

Lying medicine ball chest pass ($r = 0.158$) and bench press power ($r = 0.118$) showed no significant correlations ($p > 0.05$) with ball-exit velocity (Table 1). Other performance variables including relative vertical jump power (VJR) ($r = 0.370$) and batting average (BA) ($r = 0.216$) also showed weak ($p > 0.05$) relationships with ball-exit velocity (Table 2). Slugging percentage had a moderate correlation ($r = 0.485$) with ball-exit velocity while lying medicine ball chest pass had moderate correlations with batting average ($r = 0.697$) and slugging percentage ($r = 0.542$).

Independent t-tests were computed to determine if performance characteristics were significantly different between individuals who generated high and low levels of ball exit-velocity. Significant differences in back squat power production ($p = 0.001$), absolute vertical jump power ($p = 0.048$) and slugging percentage ($p = 0.025$) between subjects who generated high and low levels of ball exit-velocity were identified. No other differences were noted ($p > 0.05$).

DISCUSSION

The purpose of this investigation was to examine the presence of any relationship between ball-exit velocity with various performance metrics and to identify if any variables could operate as significant predictors of ball-exit velocity. Previous studies have indicated that ball-exit velocity is strongly correlated to hitting power (7,18,27), but limited work is available to identify what performance variables may predict or explain levels of ball-exit velocity. The primary findings from this study suggest that back squat power (Figure 1 and Table 1) operates as the strongest correlate and predictor of ball exit velocity in NCAA Division II baseball players while absolute vertical jump power (Figure 1 and Table 1) also exhibited a statistically significant relationship with ball-exit velocity.

Previous research has indicated that certain assessments of power as what were used in the present study directly impact the ball-exit velocity produced (18,27). The specific skill of hitting a baseball and in particular producing higher ball-exit velocity utilizes the entire kinetic chain. Biomechanically, this places a certain level of importance on the need to develop as well as the ability to produce lower body power as hitters initiate the movement with the hips, followed by the trunk, and finish with their arms throughout each swing (18). With this understanding, it was hypothesized that lower body power would be a significant determinant of ball-exit velocity. For example, previous studies from Spaniol (25) and Szymanski (27) have determined the presence of a positive relationship between lower body power and various hitting metrics. In conjunction, results from the present study identified that back squat power ($r = 0.777$) had the strongest correlation with ball-exit velocity. Although back squat strength has been evaluated with positive results while comparing it to various hitting metrics (27), back squat power seems to be the better assessment in relation to the baseball swing. Furthermore, an independent t-test between high and low ball-exit velocity producers also revealed that those athletes determined to have high ball-exit velocity produced significantly more back squat power than low ball-exit velocity producers. From these results, performance in the back squat may translate into improved levels of ball-exit velocity and for some might be viewed to be the optimal exercise selection for lower body power. In this respect, the ability to demonstrate efficient loading and driving through both concentric and eccentric muscle actions during the back squat in a powerful manner seemingly translates well to the ballistic movement of the baseball swing.

An independent t-test was also used to evaluate any significant differences between the subjects when they were separated into high and low ball-exit velocity groups. Z-scores for ball-exit velocity were calculated before separating the subjects into low and high ball-exit velocity groups. A significant difference in back squat power ($p = 0.001$) was shown after separating the subjects into low and high ball-exit velocity groups. The significance shown through the independent t-test support the strong correlations found in all the subjects when measuring ball-exit velocity to back squat power. The independent t-test demonstrates that individuals who hit the ball harder produce more power in the back squat compared to those who have the lowest ball-exit velocities.

Absolute vertical jump power ($r = 0.533$) also showed a moderate positive correlation with ball-exit velocity in the present study. Hoffman et al. (11) previously examined the correlation between peak vertical jump power (VJPP) and mean vertical jump power (VJMP) with various hitting statistics. Although he did not examine ball-exit velocity like the current study, he did report that vertical jump peak power and vertical jump mean power were moderately correlated with slugging percentage (VJPP: $r = 0.471$, VJMP: 0.465) and home runs (VJPP: $r = 0.481$, VJMP: 0.476), key statistics for baseball power hitters. In a similar fashion while investigating the golf swing, Lewis et al. (16) reported strong correlations with the vertical jump ($r = 0.817$) while comparing it to club head speed in the golf swing. Although that study used vertical jump height rather than vertical jump power, it still suggests the importance of lower body power with the vertical jump assessment.

Significant differences were also shown with absolute vertical jump power ($p = 0.048$) and slugging percentage ($p = 0.025$) when subjects were divided into high and low ball-exit velocity groups. Just like back squat power, the individuals who had higher ball-exit velocities produced more absolute power during the vertical jump compared to the individuals who had lower ball-exit velocities. Respectively, the same individuals had significantly different slugging percentages, which suggests that players with better power hitting statistics are hitting the ball much harder than those with poor power hitting statistics.

It is also important to note the differences in agreement with ball-exit velocity between absolute and relative. The values from absolute vertical jump power and relative vertical jump power were taken from the same jump, but absolute vertical jump power showed a moderate positive correlation ($r=0.533$) with ball-exit velocity while relative vertical jump power showed a weak positive correlation ($r=0.370$) with ball-exit velocity. The baseball swing is a powerful movement and power equals force times velocity with force equaling mass times acceleration. The component of body mass in the baseball swing plays a vital role with ball-exit velocity, which goes to suggest that relative vertical jump power may not be as valuable as absolute vertical jump power with baseball hitters when it comes to predicting key baseball swing metrics.

Upper body power did not correlate well with ball-exit velocity in this current study. The weak correlations of the lying medicine ball chest pass ($r = 0.158$) and BP ($r = 0.118$) suggest that upper body power likely does not operate as an important contributor to ball-exit velocity, particularly in comparison to measurements of lower body power. Contrary to the results of this study, Miyaguchi (18) previously reported moderate correlations when comparing bat swing speed with bench press strength (r = 0.588) and bench press power (r = 0.408). The measurement techniques of upper body power from Miyaguchi (18) were different from the current study, but the cause of these results could also be linked to the dependent variable of bat swing speed compared to the dependent variable of ball-exit velocity that was used in this current study. Although Szymanski (27) discusses the positive relationship between bat swing speed and ball-exit velocity, he does mention the importance of the ball striking the barrel of the bat at the center of percussion in order to measure ball-exit velocity more precisely, which may explain the differences between the results of the current study and the research by Miyaguchi in 2012.

Lewis et al. (16) has also previously reported that upper body power may have a positive impact on club head speed with PGA golfers. The results from this study showed significant correlations between the seated medicine ball chest pass and club head speed (r = 0.706) even when separating the PGA players based on age where one group was under the age of 30 (r = 0.643) and the other group was over the age of 30 (r = 0.881). Although the biomechanics of the golf swing are different from the baseball swing, it can still be categorized as a rotational skill requiring force and power through the entire kinetic chain starting from the ground up (16,19). In line with the current study, previous research consistently demonstrates the importance of lower body power in rotational skills even with the biomechanical differences in the golf swing and the baseball swing (11,16,25,27). Based off the results of the current study and the research from Lewis et al. (16), it does not seem like upper body power plays as much of a significant role for a hitter in baseball like it does for a golfer.

Other performance variables like batting average and slugging percentage were also evaluated during the current study, but only slugging percentage ($r = 0.485$) showed a moderate relationship with ball-exit velocity. This moderate correlation is consistent with the Lewis et al. (16) study suggesting the possible advantages of upper body power in the golf swing. Slugging percentage ($r = 0.542$) and batting average ($r = 0.697$) also showed moderate correlations with the lying medicine ball chest pass during the current study. Although the lying medicine ball chest pass did not correlate in a significant fashion to ball-exit velocity, they can still be something to consider when implementing upper body power for baseball hitters because of the importance of on-field performance. Slugging percentage is a greater power hitting metric compared to batting average, but both are required in order for a baseball player to be successful (8).

This study was not without limitations. For starters, our sample size was small and a larger sample size will help to bolster the statistical power behind our assessments. While the PUSH wearable device has been previously validated with linear transducer metrics (3), shortcomings exist regarding the collection of data using accelerometer based technology. Launch angles were not taken into consideration while assessing ball-exit velocity, which is important because contact with the ball, spin rates, and swing techniques are all factors that may influence ball-exit velocities for each participant. Lastly, the baseballs used while collecting ball-exit velocity data were all different, which means that the quality of some of the baseballs may have provided inconsistency with the exit velocities.

Strengths from this study include a tightly controlled testing setting with all tests performed by the same people. The ability to objectively measure the lying medicine ball chest pass, bench press, vertical jump, and back squat for power rather than strength also created strong variables for the current study. The results from the present study suggest that lower body power was a critical determinant of ball-exit velocity; therefore, future research should be aimed towards the identification of optimal collection methods of lower body power to potentially include front squat PRM, broad jump power, as well as the integration of force plate technology with the vertical jump assessment.

PRACTICAL APPLICATION

In conclusion, the results from this study reinforce the necessity of lower body power in baseball hitters. Ball-exit velocity showed significant relationships with back squat power and absolute vertical jump power suggesting that importance of lower body power in the baseball swing. Furthermore, this study also highlighted that those athletes who produced the highest levels of ball-exit velocity produced significantly higher amounts of back squat power and absolute vertical jump power when compared to those athletes who produced the lowest ball-exit velocity. Furthermore, these results suggest that improvements in ball-exit velocity may be achieved through an emphasis on increasing lower body power. Athletes, coaches, and sports performance professionals should consider this when prescribing and implementing programs for collegiate baseball players.

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Figure 1. Correlation between ball-exit velocity and back squat power.

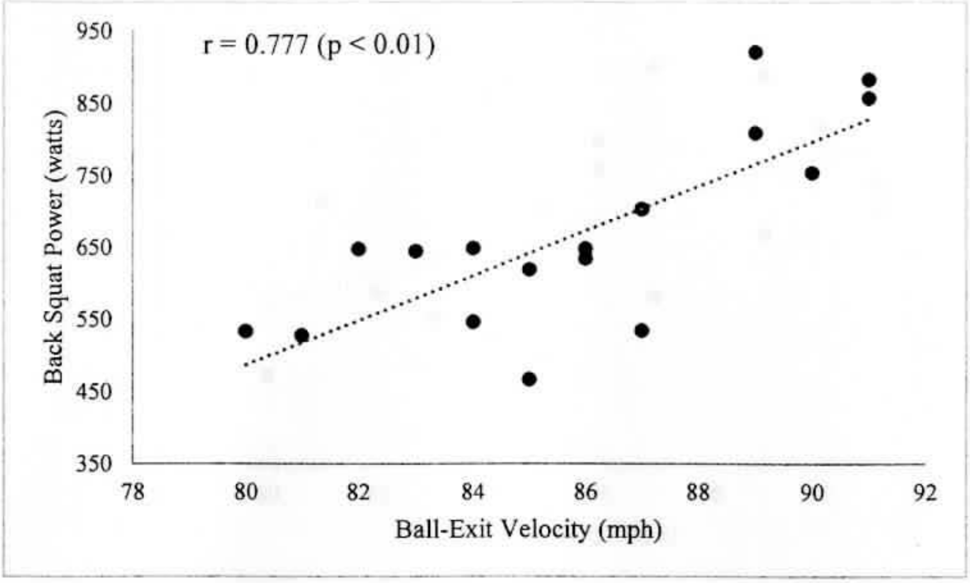

Figure 2. Correlation between ball-exit velocity and absolute vertical jump power.

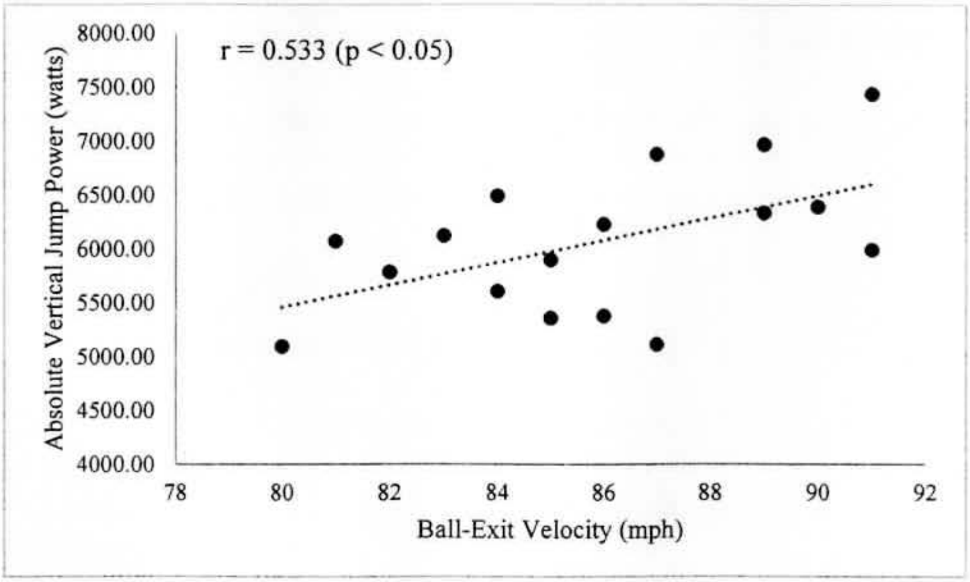

Figure 3. Correlation between ball-exit velocity and slugging percentage.

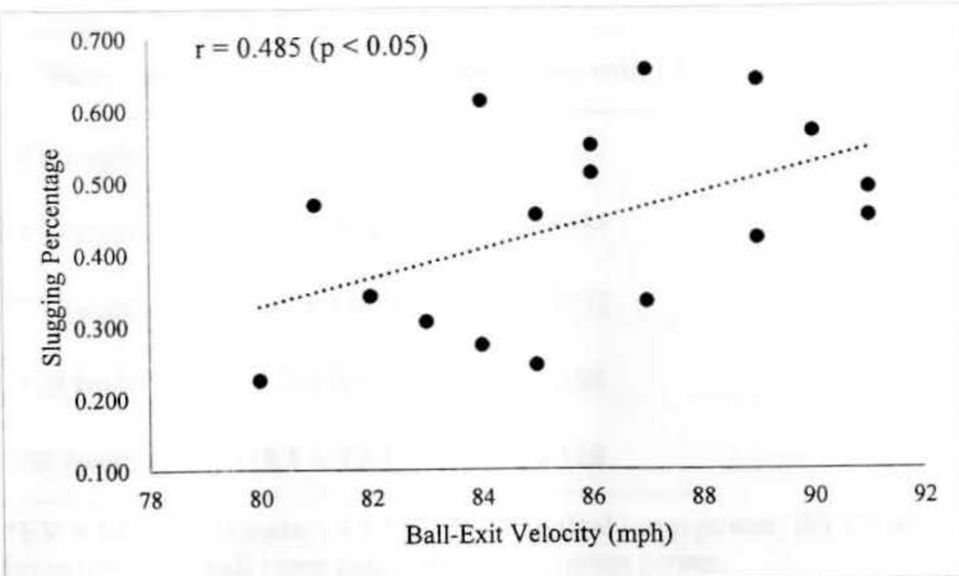

Table 1. Descriptive statistics and correlations between EV and power assessments.*

Field-Test	Mean (±SD)	Correlation with EV
EV (mph)	85.9 ± 3.4	
VJ (watts)	6069.7 ± 656.2	0.533†
BS (watts)	669.4 ± 134.7	0.777‡
MB (m/s)	2.2 ± 0.4	0.158
BP (watts)	418.8 ± 75.4	0.118

*EV = ball-exit velocity; VJ = absolute vertical jump power; BS = back squat power; MB = lying medicine ball chest pass; BP = bench press power.
†Correlation is significant at the 0.05 level.
‡Correlation is significant at the 0.01 level.

Table 2. Descriptive statistics and correlations between EV and other performance variables.*

Field-Test	Mean (±SD)	Correlation with EV
EV (mph)	85.9 ± 3.4	
VJR (watts/kg)	68.3 ± 8.0	0.370
BA	0.306 ± 0.078	0.216
SLG	0.443 ± 0.138	0.485†

*EV = ball-exit velocity; VJR = relative vertical jump power; BA = batting average; SLG = slugging percentage.
†Correlation is significant at the 0.05 level (2-tailed).

Chapter 5: Future Research and Recommendations

Summary of Findings

The primary findings revealed that lower body power played a significant role with ball-exit velocity in collegiate baseball players. Pearson correlations were used to analyze the relationships between hitting and power metrics. Subjects were also separated into a high ball-exit velocity and a low ball-exit velocity group based off of z-scores. An independent t-test was used to examine significant differences between high and low ball-exit velocity groups.

Ball-exit velocity had a strong correlation with back squat power and a moderate correlation with vertical jump power and slugging percentage. Independent t-tests also revealed that there were significant differences in back squat power, vertical jump power, and slugging percentage when separated into a high velocity and low velocity groups.

Future Research

The purpose of the proposed study is to investigate the correlation between ball-exit velocity in the baseball swing with vertical jump power, back squat power, lying medicine ball chest pass, and bench press power. Although the current study found positive correlations between ball-exit velocity and various power metrics, future research should be recreated with a larger subject pool of collegiate baseball players in order to increase the power of the study.

The results from the present study suggest that lower body power was a critical determinant of ball-exit velocity; therefore, future research should be aimed towards the correlation of other lower body power assessments with ball-exit velocity including front squat PRM, broad jump power, and the use of a force plate. Force plate data from Fortenbaugh et al. (7) has been used with the baseball swing and using it in the weight room could produce more in-depth analysis for certain lower body power assessments that correlate with ball-exit velocity.

Recommendations

The primary recommendation for this research is to collect more data on lower body power metrics and ball-exit velocity in an effort to better understand what translates from the weight room to the field for baseball hitters. If accomplished, athletes, coaches, and performance professionals will understand the importance of lower body power development and programming for training sessions can be geared more specifically towards the advancement of baseball hitters.