CORRELATION OF THROWING VELOCITY TO THE RESULTS OF LOWER BODY FIELD TESTS IN MALE COLLEGE BASEBALL PLAYERS

GRAEME LEHMAN

Correlation of Throwing Velocity to the Results of Lower Body Field Tests in Male College Baseball Players

by

© Graeme Lehman

A Thesis submitted to the

School of Graduate Studies

in partial fulfillment of the requirements for the degree of

Masters of Science (Kinesiology)

School of Human Kinetics and Recreation

Memorial University of Newfoundland

December, 2011

St. John's Newfoundland

ABSTRACT

Baseball specific athleticism, potential and performance have been difficult to predict. Muscle strength and power has shown to help increase throwing velocity through resistance training research however the majority of research has focused on the upper body. The present study sought to determine if bilateral or unilateral lower body field testing correlates with throwing velocity and if so to what extent. Throwing velocity scores were correlated to the following tests; medicine ball scoop toss and squat throw, bilateral and unilateral vertical jumps, single and triple broad jumps, hop and stop in both directions, lateral to medial jumps, 10 and 60 yard dash, and both left and right single leg 10 yard hop for speed in 42 college baseball players. It was hypothesized that the concentric strength of the trail leg and the eccentric strength of the lead leg will correlate positively with throwing velocity. A stepwise multiple regression analysis, assessing the relationship between shuffle and stretch throwing velocities and lower body field test results determined that right handed throwing velocity from the stretch position was significantly predicted by lateral to medial jump right (LMJR) and body weight (BW) R^2 =0.322, whereas lateral to medial jump left (LMJL) $R^2 = 0.688$ significantly predicted left stretch throw. Right handed shuffle throw was significantly related to LMLR and Medicine Ball scoop R^2=0.338; whereas, LMJL, BW and LMJR significantly contributed to left handed shuffle throw R^2=0.950. Overall, this study found that lateral to medial jumps were consistently correlated with high throwing velocity in each of the throwing techniques, in both left and right handed throwers. This is relevant because it is the first

study to our knowledge to correlate throwing velocity with a unilateral jump in the frontal plane, mimicking the action of the throwing stride.

ACKNOWLEDGEMENTS

This thesis could not have been written without the assistance and support of many groups of individuals. I owe a great deal of gratitude to my supervisor Dr. David Behm not only for his patience and guidance but for allowing me the freedom to combine my two passions, baseball and exercise science, into this thesis. I would wish to thank my wife Melissa for her immense support throughout the entire process as both a motivator and editor. I would not have been in this program let alone complete the thesis process if not for her.

The exercise science department at Douglas College provided the testing equipment necessary for this study. The coaching staffs of both the University of British Columbia and Douglas College men's baseball team both deserve recognition for allowing me to use their teams as subjects. I would also like to thank the players of both teams for their effort during the testing session.

Finally a great deal of gratitude goes towards my family for providing me every opportunity to achieve my goals and further my education.

Table of Contents

List of Tables

List of Abbreviations and Symbols

BW – Body Weight

NAIA –National Association of Intercollegiate Athletics

NWACC – Northwest Association of Community Colleges

LMJR – lateral to medial jump right

LMJL - lateral to medial jump left

PAR-Q – physical activity readiness questionnaire

KPH – Kilometers per hour

MB Scoop Throw – Medicine Ball Scoop Throw

M/Sec – Meters per Second

MVIC – Maximal voluntary isometric contraction

Purpose

This study was designed to identify lower body field tests that significantly correlate to throwing velocity. Field tests that require little equipment were selected to allow baseball coaches and athletes to reproduce these tests in order to directly benefit from the results of this study.

The results of this study will provide athletes with performance benchmarks to work towards in order to potentially increase throwing velocity. These results may aid in the selection of exercises by strength and conditioning specialists working with baseball athletes.

Abstract for Review of Literature

Proper kinematics are necessary in order to achieve optimal energy transfer to the ball producing high throwing velocity. However once proper throwing technique is achieved the ability to increase throwing velocity is limited by the amount of energy that can be optimally transferred from the body to the baseball. Research has demonstrated that subjects who produced higher amounts of ground reaction force from the trail leg during the pitching motion in the direction of the target were able to throw with higher velocity. This coupled with information from another study which classified subjects as "high" or "low" velocity throwers based on the actions of the lead leg upon landing demonstrate not only the importance of lower body strength but the differing actions of both the lead and trail leg. Traditional bilateral exercises of the lower body that have been used as a means to increase throwing velocity do not implement the training principle of specificity.

Chapter 1 – Literature Review

1.1 Introduction

The defensive component of baseball places a high degree of importance on any player's ability to throw with high levels of velocity in order to improve defensive performance. Generating maximum ball velocity is an important factor for the success of a baseball pitcher because higher velocities diminish the time offensive hitters have to make the decision of whether or not they make an attempt to strike the ball (Hay 1985). Increased throwing velocity also helps to set up other pitches like the curve ball or change up which disrupt the hitter`s timing. Infielders require high throwing velocity in order to throw out potential base runners who have struck the ball on the ground while outfielders require high throwing velocity to restrict the offense`s ability to advance bases and potentially score runs. The ability to throw with high velocity is a sought after skill that both baseball coaches and scouts look for in order to identify the athletes that are talented enough to play higher levels of baseball.

1.2 Throwing Biomechanics

The act of throwing a baseball can be broken down into six distinct phases: The wind up, stride, arm cock, arm acceleration, arm deceleration and follow through (Fleisig et al. 1996a). Furthermore, throwing has been described as a sequential activation of body parts through a linked segment that begins with the contralateral foot progressing through the trunk to a rapidly accelerating upper extremity (Pappas et al. 1985). Each of these phases and their sequential activation are modifiable variables.

Each baseball player's throwing velocity is the result of kinematics, kinetics and relative timing of segmental interactions that cause a transfer of energy to the momentum of the baseball (Stodden et al. 2005). Throwing is very dynamic and produces extreme levels of joint angular velocities. For example, a joint velocity of 7200^0/s of glenohumeral internal rotation during the arm acceleration phase has been reported as the fastest body action of any sport (Fleisig 1994). Given these complex relationships, optimization of the energy transfer from kinetics to the ball, in order to achieve the highest velocity possible is difficult to address (Fleisig 1994).

Matsuo (2001) compared high to low velocity throwers and identified several kinematic differences between groups. The higher throwing velocity group exhibited higher peak knee flexion angular velocity, higher maximum shoulder external rotation, higher lead knee extension angular velocity at instant of ball release, a greater forward trunk tilt at the instant of ball release, a greater time to peak maximum elbow extension angular velocity and a higher time to peak maximum shoulder internal rotation angular velocity. A review of the literature reveals that the majority of studies have focused on the upper body due in part to a study by Toyoshima et al. (1974) who reported that the upper extremities and trunk are responsible for generating 57% of the energy required to throw a baseball. However, the lower body initiates the force required to achieve high throwing velocity through a link segment model, which proceeds from proximal to distal (Putnam 1993).

Although throwing is performed with both legs the majority of the action only has one leg in contact with the ground at any given point during the delivery (Wilk et al. 2000). Thus, in order to examine the role of the lower body in creating throwing velocity one must look at the legs individually since they perform different roles (Fleisig et al. 1996).

1.3 Trail Leg

The trail leg refers to the leg that is ispilateral to the athlete`s throwing arm. In a right handed thrower, the right leg must abduct to initiate the medial to lateral force in the frontal plane towards the intended target, an action referred to as the stride (Fleisig et al. 1998). The pelvis begins to rotate from a side-facing orientation to a more forward-facing orientation relative to the target during the transition from the stride to arm cocking phase. The gluteus maximus and biceps femoris of the trail leg produce the hip extension required to rotate the pelvis which reaches angular velocities of 4000-6000 degrees per second (Stodden et al. 2001). As the throwing motion progresses the trail leg begins to lose contact with the ground as the shoulder reaches its maximal external rotation and beings to accelerate forward.

The muscles of the trail leg demonstrate a "ramping" effect as the arm begins its acceleration phase. When assessed for muscle activity the gastrocnemius, vastus medialis, rectus femoris, gluteus maximus and biceps femoris produced mean values of 172, 138, 48, 141 and 142% of MVIC respectively (Campbell et al. 2010). MacWillams et al. (1996) investigated the ground reaction forces of the trail leg and found that the leg gradually builds force in the direction of the pitch until just before the front foot makes contact with the ground with forces equaling -0.35 body weight (BW). This value is negative because the forces of the trail back leg are being applied in the opposite direction of the ball causing the body to go forward. Higher forces generated towards the target did in fact translate to higher linear wrist velocities (r^2=0.82) which in turn translates to higher throwing velocity (r^2 = 0.97, N =5 trials). Based on their findings, the authors hypothesized that a greater force created in the direction of the pitch generates a faster velocity because there is more kinetic energy transferable from the lower to the upper body and ultimately the ball. Furthermore, the authors stressed the need for generating forward momentum with the back leg and even stated that the pitchers in this study who developed the highest forces relative to their body weight threw the fastest. A study by Fleisig et al. (1999) confirms this theory. His study demonstrated that members of the "high" velocity throwing group had increased pelvic velocities, generated by back leg force, compared to the "low" velocity groups.

1.3.1 *Stride length modification of velocity*

The length of the stride produced by the contraction of the trail leg in the direction of the target enables the thrower to release the ball closer to the intended target. This effectively decreases the distance the ball must travel which diminishes the time the hitter has to determine if they want to attempt to make contact with the pitched ball. Furthermore, the impact of linear velocity can be seen in other throwing activities. For example, Bartlett et al., (1996) demonstrated that top javelin performers exhibit longer strides and higher approach velocities allowing for increased throwing distances. Most coaches advocate a stride length of equal to approximately 90% of a throwers height (House 2006) however pitchers with stride lengths that are 100% or more of their height have been reported (House 2006 & Solesky 2011). One such case is Nolan Ryan who holds the career strikeout record in Major League Baseball (MLB) and is known for being one of the hardest throwers in history. Tim Lincescum another MLB pitcher noted for his ability to achieve high throwing velocities while being smaller than most professional pitchers (180cm & 78kg) has a stride length of 228cm which is 129% of his height and regularly reaches velocities greater than 153 kilometers per hour. (Solesky 2011).

1.3.2 *Pelvis stabilization and alignment*

The hip abductors are required to stabilize the pelvis in order to allow for optimal throwing mechanics (Burkhart et al. 2003). Burkhart et al. (2003) reported that gluteus medius strength in the trail leg is required to prevent the opposite side of the pelvis from dipping inferiorly in the frontal plane during the single leg stance that precedes the stride.

A failure to do so compromises throwing mechanics and results in an increased load to the shoulder potentially leading to injury (Burkhart et al., 2003). Proper pelvic alignment throughout the throwing act have been associated with both increased velocity and decreased injuries (Stodden et al. 2001). Specific amounts of hip internal rotation range of motion are required to create optimal pelvic alignment during lead foot contact with the ground. Restrictions in this range of motion can reduce the amount of energy transferred in turn diminishing throwing velocity. (Robb et al.. 2011)

1.4 Lead Leg

The lead leg is contralateral to the throwing arm (left leg for a right handed pitcher) and is responsible for eccentrically absorbing and redirecting the energy created by the trail leg (MacWillams et al. 1996). When the front foot contacts the ground, at the end of the stride phase, the lead leg applies a braking force in order to decelerate forward momentum. The generated force also functions to dynamically stabilize the hip and knee joints in a single leg stance in order to maintain a standing posture in the trunk and upper extremity in order permit a pivoting action which produces efficient follow through and energy transfer (Dillman, Fleisieg & Andrews – 1993)

When the arm is in maximal external rotation the lead leg applies a force of approximately 1.5 times body weight, while also applying braking forces of nearly 0.75 times that of body weight (MacWilliams et al. 1998). This translates into the muscles of the lead leg producing mean values in excess of 100% of MVIC (gastrocnemius 140%, vastus medialis 166%, rectus femoris 167%, gluteus maximus 108% and biceps femoris 99%) (Campbell et al. 2010).

When comparing and contrasting high velocity throwers versus low velocity throwers the action of the lead leg varied between the groups demonstrating its importance. Matsuo et al. (2001) identified four common lead knee movement patterns in the subjects who were classified as either "high" or "low" velocity groups based on their throwing capabilities. The four patterns which were classified by the amount of flexion or extension between the time the lead leg touched the ground and the time the ball was released were categorized as either A, B, C or D. Eighty three percent of the high velocity versus 35% of the low velocity throwing group displayed either the "A" or "B" patterns with enhanced knee extension when compared to lower velocity throwers, most of whom displayed "C" or "D" patterns which displayed knee flexion upon landing. More specifically, 69% of the high velocity group was categorized in the "A" pattern which showed small amounts of both knee flexion and extension (50-60 degrees) during the initial 60% of the time interval between front foot contact (0%) and instant of ball release (100%). From the 60% to the 100% interval time mark the knee extended from approximately 55 to 30 degrees. Only 9% of the low velocity group was classified as having the "A" pattern. Low velocity throwers displayed the "D" pattern of throwing, whereby their front knee continued to flex from approximately 20 to 50 degrees throughout the entire pitching motion 0-100% time interval. Seventeen percent of the low velocity group demonstrated the "D" pattern while none of the high velocity group fell into this category.

The information provided by Matsuo et al. (2001) supports the data presented by Escamilla et al. (1998) which reported that collegiate pitchers demonstrated knee extension just prior to maximum external rotation of the glenohurmeral (GH) joint during a fastball pitch. The lead knee continued to extend throughout the throwing motion as the trunk moves forward and rotates towards the intended target during which time the arm accelerates. This ability to brace the lead knee allowing for optimal forward trunk tilt and rotation was identified as a characteristic of high velocity pitchers by Elliott et al. (1998).

Similar knee movement patterns are also seen in elite level javelin throwers who display the ability to produce a clear double flexion -extension pattern which were described by Matsuo as the "A" pattern of lead knee movement. During the javelin throw, the role of the lead knee is to brace the body in order to aid in the transfer of energy from the ground up the kinetic chain to the trunk and upper extremity, which are accelerating forward. (Whiting et al.1991) High velocity cricket bowlers exhibit similar lead knee movement patterns with greater lead knee extension at ball release (Wormgoor et al. 2010).

1.5 Effects of Resistance Training on Throwing Velocity

A review by Behm and Sale (1993b) concluded that ballistic movements such as jumping and throwing are preprogrammed and maximal limb velocity is determined primarily by rate of force development and overall force output. In theory, resistance training aims at increasing the contractile capabilities of the muscle by increasing cross sectional area and/or increasing the rate of contraction. High levels of strength are beneficial to baseball players due to the games anaerobic nature (Bonnette et al. 2008) and increases in strength levels may serve as a means of improving on field performance. Historically, players have been cautioned by baseball coaches to avoid resistance training in fear of excessive hypertrophy, which was thought to restrict the player's ability to throw and swing; this theory is not supported by any research. However, review of the literature that has assessed resistance training as it pertains to throwing velocity demonstrates that 22 of 26 studies report an increase in throwing velocity from resistance training, even when confounding variables such as changes to throwing technique are controlled (DeRenne et al. 2001).

The ongoing search for variables that improve throwing velocity has led coaches and athletes to implement resistance training in many different shapes and forms. Research has shown that variables such as increased lean body mass, lower body power, increased speed and increased agility are all factors related to a player's levels of competition and their baseball related athletic performance (Hoffman et al. 2009). Newton & McEnvoy (1994) noted however that the correlation between strength and throwing velocity is low suggesting that other factors were responsible for throwing velocity. The authors came to this conclusion following their study, which reported a 22% increase in strength and only a 4% increase in throwing velocity.

The majority of the literature that has assessed resistance training and its modulation of throwing velocity have been largely focused on the upper body. Pioneer work by Toyoshima et al. (1973) demonstrated that the muscles of the upper body that induce trunk and shoulder rotation produced 53.1% of the energy used to throw a baseball. However the focus on the upper body within the literature is contrary to the current popular implementations from strength and conditioning coaches in Major League Baseball who are focused on lower body development and state that it is more important. In a recent survey of strength and conditioning coaches within the major league of baseball; 15 of 21 coaches stated that lower body exercises are the "most" important for player performance, specifically stating that squats were the exercises most commonly used (Ebben et al. 2005).

1.5.1 *General Resistance Training*

van der Tillar (2004) reviewed different training programs and their effect on throwing velocity and ascertained that general resistance training, focused on exercises for the upper body with loads of 6-12 repetition maximum (RM) positively influence throwing velocity. His work was supportive of the studies done by Bagonzi (1973), Newton & McEvoy (1994), Popescue (1975), which demonstrated that upper body, open chain, free weight isotonic exercises increase throwing velocity. Recently, Prokopy et al.

(2008) demonstrated a 3.4% increase in throwing velocity with closed kinetic chain upper body exercises. The addition of lower body exercises to fitness regimes has also been reported to increase throwing velocity, Potteirger et al. (1992) reported a 2.3 mph increase in throwing velocity when isotonic open chain exercises like pullover, bench press, squat, leg curl and leg extension were implemented. While more recently Saeterbakken et al. (2011) demonstrated closed chain core stability exercises along with a pushup and single leg squat exercise in female hand ball player's increased throwing velocity by 4.9% in just 12 training sessions over the course of 6 weeks.

While not as numerous, some studies have reported no increases in throwing velocity with isotonic exercises (Jackson (1994), Edwards (1991), Shenk (1990)). The designs of these studies might explain the absence of increased throwing velocity, as both Edwards and Jackson exclusively used exercises that targeted the shoulder with single joint exercises (supraspinatus raise, internal rotation, external rotation, shoulder flexion and shoulder abduction), while Shenk used college aged men who were non-baseball players.

1.5.2 *Special and Specific Resistance Training*

The use of lighter loads coupled with higher velocities, which better approximate the speeds required during the act of throwing a baseball have also been shown to improve throwing velocity (Newton & McEvoy, DeRenne 1990, Lachowetz 1998). Many strength and conditioning coaches believe that movement patterns closer to the sport specific action required and speeds that are more closely related to those seen in the sport have an increased transfer of training effects to the field of competition (NSCA Roundtable 1985).

Implementation of ballistic weight training was shown to increase the throwing velocity of professional baseball players. All of the subjects had experience with general resistance training and demonstrated a 2% increase in throwing velocity over a ten-week period with ballistic training (McEvoy and Newton 1994). The authors concluded that the increase in throwing velocity from exercises such as jump squats and bench press throws were due to a training induced, velocity specific increase in strength, accompanied by an enhancement in rate of force development.

Medicine ball training is a popular form of upper body training since it emphasizes both high velocity movements and the stretch shortening cycle (Newton and McEvoy 1994). However the only study to compare the effects of upper body weight training to upper body plyometric training with the use of medicine ball demonstrated superior increases in throwing velocity with weight training (Newton & McEnvoy 1994). The authors concluded that the movements selected for the medicine ball training (chest pass & two handed overhead throw) did not mimic the throwing action and were only chosen to be comparable to the resistance training movements (bench press & pullover). The increase in throwing velocity seen in the weight training group can be linked to research from Behm and Sale (1993a) that stated in may be the intention to move quickly or explosively that determines the velocity-specific response despite the use of heavy loads with the weight training group.

The implementation of under and overweight baseballs have also produced positive adaptations in throwing velocity (DeRenne 1994). The theory behind the use of baseballs of varying weights is that they produce an overload effect. The underweight balls produce a velocity overload effect while the overweight balls cause a force overload. Training programs that have exclusively used underweight balls, with balls 20-25% lighter than traditional 5oz baseballs, have produced increased throwing velocity (DeRenne 1985, 1990, 1993).

Overweight ball training has also produced increases in throwing velocity (DeRenne 1985, 1990) but not unanimously, Straub et al. (1966) reported no increase in throwing velocity with overweight ball throwing. It should be noted that the studies that did not show any increase in velocity used baseballs that were more than double the weight of a normal baseball whereas those that did produce positive effects on throwing velocity where only 20% greater (DeRenne et al. 2001).

1.6 Physical Characteristics of Increased Throwing Velocity

Physical tests are used by coaches in many sports to help identify athletic talent, prevent physical injury, and to plan a course of action for future training (Kohmura et al. 2008). Physical test scores have a higher correlation to sporting success when performance is measured by tangible variables such as time or distance (Arrese et al. 2006). Baseball performance is difficult to express in terms of physical performance due to the complexities of the game such as the combination of throwing velocity coupled with accuracy. Kohmura et al. (2008) conducted a study that compared the results of physical capabilities with a baseball coach implemented performance evaluation that assessed batting, running and fielding. Although the performance ranking of the coaches is quite subjective the results of the 6 physical performances tests did correlate highly with one another. The skill of throwing with high velocity conversely is easily measured without bias and the numerical measure of pitching velocity has been observed and used as an indicator of talent by coaches and scouts in order to facilitate their selection of players for teams of higher levels of competition.

The ability to predict throwing velocity based on physical characteristics will help identify those individuals who are likely to succeed at baseball. These predictors can also identify limiting factors that may or may not be inhibiting one's ability to reach their throwing velocity potential.

1.6.1 *Anthropometrics*

One physical characteristic that baseball coaches and scouts assess is height which can be seen with the fact that from the year 1990 to 2000 over 93% of major league pitchers were above 183cm tall while nearly 14% of those were 195cm or taller (Swift 2001). High velocity throwers have been noted to be taller and have a greater radial and humeral length when compared to low velocity throwers (Matsuo et al. 2001). Similar findings can be seen when examining the bowler position in the sport of cricket, which also places an emphasis on throwing velocity (Stockill et al. 1994). Long levers seen in taller players allows for higher limb velocities, which can be translated into higher throwing velocities when compared to short players exhibiting shorter levers.

Higher body weight is also positively correlated with greater throwing velocity. The increased body mass provides a direct source of potential energy that can be transferred into kinetic energy on the ball, allowing for increased throwing velocity (Werner et al. 2008). This trend of athletes with more mass being able to create more velocity can be seen in cricket bowlers (Pyne et al. 2006) as well as javelin throwers (Van Der Tillar et al. 2004).

Spaniol (2009) assessed physical and physiological characteristics of baseball players at three different levels of competition. He observed high school players (HS), National Association of Intercollegiate Athletics (NAIA) players and National Collegiate Athletic Association (NCAA) players. Although his findings did not demonstrate a significant correlation between throwing velocity and any of physical or physiological characteristic he measured.

1.6.2 *Range of Motion*

A greater amount of shoulder external rotation during the arm-cocking phase of throwing has been shown to generate higher throwing velocities (Matsuo et al. 2001).

Edwards (1991) found that baseball players were able to increase throwing velocity when they applied proprioceptive neuromuscular facilitation stretching to increase ranges of motion of the upper body, arms and shoulder. Furthermore, an additional group in this study performed isotonic resistance training for the shoulder and demonstrated a decrease in throwing velocity.

A larger range of motion allows the athlete to create a greater impulse, which in turn can increase velocity (Neal et al. 1991) while also improving the efficiency of the stretch shortening cycle (Wilson et al. 1992). Baseball players frequently display significantly larger amounts of shoulder external rotation due to morphological adaptations such as humeral head retroversion, rotator cuff weakness, capsular laxity and osseous adaptations from the repetitive and highly asymmetrical act of throwing. These modifications are especially common and prominent when baseball begins at a young age prior to growth plate fusion and closure. (Wilk & Andrews 2002, Chant et al. 2007). An increase in external rotation is often accompanied by a restriction in internal rotation, which produces a condition called glenohurmeral internal rotation deficit (GIRD) in the throwing arm when compared to the non-throwing arm (Crochkett & Wilk 2002). The lower extremity is also affected by the repetitive asymmetrical action of throwing; the acetabular-femoral joint of the lead leg often displays less range of motion resulting in a femoracetabular deficit when compared to the trail leg. The lead leg is exposed to additional trauma and excessive force that it must absorb with each throw, thus a deficit ensues (Robb et al. 2011).

Lower extremity range of motion also influences throwing velocity (Robb et al. 2011). Subjects with less external and internal range of motion of the lead leg demonstrated lower throwing velocities. This is potentially due to the restricted hip range of motion in the lead leg, not allowing for proper foot contact, hindering proper alignment in the pelvis and preventing it from generating kinetic force from the trail leg.

1.6.3 *Muscular Power*

Powerful motor performance in movements such as throwing relies on the rate and sequence of motor unit activation (Brooks et al. 2000). Increased levels of physical power in athletic movements like running speed, jumping ability, power and agility are highly desirable skills for a baseball player to possess since they allow the athletes to cope and react to the unpredictable and anaerobic nature of baseball (Kohmura et al. 2008). Performance rating and ranking amongst baseball players by their coaches is correlated to a combination of athletic skills and various anaerobic field tests such as throwing distance, back strength, medicine ball throwing, standing long jump, T-test, and base running suggesting that improvements in these physical characteristics serve as an advantage to the baseball player wishing to improve their playing ability (Kohmura et al. 2008).

Athletes participating in team handball, a sport which also considers throwing velocity to be a valuable skill, elite level players with significantly higher throwing velocities had higher values of absolute power in their lower body during a half squat and vertical jump power. While elite and novice groups of handball players both demonstrated similar results in vertical jump test, elite level players had significantly more total and fat free body mass which would produce higher power outputs (Gorostelaga et al. 2004).

In a 2 year long study of professional baseball players Hoffman et al. (2009) tested nearly 350 players from the Texas Rangers baseball organization and observed that performance variables during field tests differentiated and predicted what level of competition each player was participating in. The players at the major league level produced much higher score of lower body power, measured by vertical jump and lean body mass. Physical ability in the form of field test scores have been correlated to success, such as amount of playing time, in college basketball (Hoffman et al. 1996), college football (Garstecki et al. 2004) and professional football (Sierer et al. 2008).

In a meta-analysis Spaniol (2009) reported that 60 yard dash time (60 yard), vertical jump (VJ) and broad jump (BJ) scores differed along with throwing velocity (TV) when he compared baseball players of various levels and calibers (HS, NAIA and NCAA playing levels). Mean 60-yard dash times were 7.71 sec in the HS group, 7.61 in the NAIA group and 7.25 in the NCAA players. Vertical jump scores were 18.9 in the HS players, 23.7 in those of the NAIA and 27 inches in NCAA players and broad jump scores were 90.2 in the HS players 95 in those playing in the NAIA and 96.3 inches NCAA players. While there was no direct correlation with throwing velocity and the ability to jump vertically or horizontally within each level, the average throwing velocities were

72.8 (HS), 76.7 (NAIA) and 78.2 mph (NCAA), which suggest that higher levels of baseball require, increased lower body power. Although Spaniol reported no positive correlation between the free weight squat or vertical jump and throwing velocity, he noted that leg power is positively correlated with throwing speed (Spaniol et al. 1997). This theory is supported by Pyne et al. (2006) who reported that a static one-legged jump is a moderate predictor of peak bowling speed in first class senior cricket bowlers (r=0.74).

1.6.4 *Muscular Strength*

The contribution of muscular strength to throwing velocity has been well documented. In a study by Flesig et al. (1999) adult pitchers demonstrated similar limb movement and temporal movement patterns compared to younger elite pitchers suggesting that the observed increases in pitching velocity in the adult group was a result of increased levels of strength and muscle mass.

Katsumata et al. (2006) reported that in younger baseball players (14 years) pitching velocity was correlated with elbow extension strength, measured by maximum voluntary isometric contraction, and that college aged baseball players exhibited a similar correlation whereby throwing velocity was correlated with knee extension strength. Review of the literature surrounding other throwing sports demonstrates that both squat and bench press power are correlated with superior throwing performance in track and field athletes (Bourdin et al. 2010). This theory however was contradicted by Newton & McEnvoy (1994) who noted that the correlation between strength and throwing velocity was low suggesting that other factors were responsible for throwing velocity with baseball players.

Spaniol et al. (1997) conducted a study measuring several athletic qualities in order to predict throwing velocity in college baseball players. Of the tests assessed. (1RM bench press, 1RM squat, 1 min sit-up test, vertical jump, sit and reach, 60 yard dash, handgrip, skin fold) only handgrip scores showed were significantly correlated to throwing velocity.

Fleck (1992) studied team handball and demonstrated a relationship between handball throwing velocity and upper extremity isokinetic torque. Furthermore, Gorstiaga et al. (2005) reported a positive correlation between throwing velocity in handball players and the strength and power scores of a concentric only bench press. In another study of elite handball players, Chelly et al. (2010) demonstrated that throwing velocity was strongly correlated with peak power output in a free weight bench press as was maximal force created using a an upper body ergometer for a 7 second sprint.

1.7 Conclusion

Research has clearly pointed out the importance of the lower limb strength and power for both the trail leg (MacWilliams et al. 1996) and the lead leg (Matsuo et al. 2001) during the act of throwing. Despite these findings, the majority of the research focused on improving muscular strength and power as a means to increase throwing velocity has focused on the upper body. Research on the effects of lower body resistance training and throwing velocity has also focused on bilateral movements in the sagittal which do not meet principal of specificity. Despite the number of studies that focus on upper body strength a survey of Major League Baseball strength and conditioning coaches reported that 15 out of 21 respondents believe that a lower body exercise is the most important exercise for the sport of baseball (Ebben et al. 2005).

In an attempt to predict throwing velocity through common field tests such as sprint and various jumps Spaniol (1997) was unable to show any significant correlation to throwing velocity. These field tests that focused on the lower body were bilateral and were performed in the sagittal plane. Throwing a baseball is bilateral in the sense that both legs are contribution however they are performing drastically different actions from left to right and is predominantly executed in the frontal plane.

Knowledge of how much strength and power elite level baseball players can produce from each of their lower limbs in various plane of movement may perhaps allow those who aspire to become elite or those who coach them to better navigate their training approach

References

Arrese, LA, Izquierdo, DM, and Galindo, JRS. Physiological measures associated with marathon running performance in high-level male and female homogeneous groups. *Int J Sports Med* 27:289–295. 2006.

Bagonzi, JA. The effects of graded weighted baseballs, free weight training, and simulative isometric exercise on the velocity of a thrown baseball. Master's thesis, Indiana University, 1978.

Bartlelt, R, Muller, E, Lindinger, S, Brunner, F, and Morris, C. Three-dimensional evaluation of the kinematic release parameters for javelin throwers of different skill levels. *J Appl Biomechanics* 12: 58-71. 1996.

Bartlett RM, Stockill NP, Elliott BC, and Burnett AF. The biomechanics of fast bowling in men's cricket: a review. *J Sports Sci* 5: 403-424, 1996.

Behm, DG, and Sale DG. Intended rather than actual movement velocity determines velocity-specific training response. *J. Appl. Phsyiol.* 74: 359-368. 1993a.

Behm, DG, and Sale DG. Velocity specificity of resistance training. *J of Sports Med.* 15: 374-388. 1993b.

Bourdin, M, Rambaud, O, Dorel, S, Lacour, JR, Moyen, B, and Rahmani, A. Throwing performance is associated with muscular power. *Int J Sports Med.* 31(7):505-510. 2010.

Brooks, GA, Fahey, TD, White, TG and Baldwin, K. *Exercise physiology: Human bioenergetics and its applications* (3rd ed). Mountain View, CA: Mayfield Publishing Company. 2000.

Burkhart, S, Morgan, C, and Kibler, WB. The disabled throwing shoulder: spectrum of pathology. Part I, pathoanatomy and biomechanics. *J Arthroscopy.* 19: 404-420. 2003.

Campbell, BM, Stodden, DF, and Nixon, MK. Lower extremity muscle activation during baseball pitching. *J Strength Cond Res.*24(4): 964-971. 2010.

Chant, C, Litchfield, R, Griffen, S, and Thain L. Humeral head retroversion in competitive baseball players and its relationship to glenohumeral rotation range of motion. *J Orthop Sports Phys Therpy* 37: 514-520. 2007.

Chelly, MS, Hermassi, S, and Shephard, RJ. Relationships between power and strength of the upper and lower limb muscles and throwing velocity in male handball players. *J Strength Cond Re.s* 24(6):1480-1487. 2010.

Crockett, H, Gross, L, and Wilk, K. Osseous adaptations and range of motion at the glenohumeral joint in professional baseball pitchers. *Am J Sports Med.* 30:20-26. 2002.

Derenne, C, Ho, KW, and Murphy, JC. Effects of general, special and specific resistance training on throwing velocity in baseball: a brief review. *J Strength Cond Res.* 15(1):148-156. 2001.

Derenne, C, Buxton, BP, Hetzler, RK, and Ho, KW. Effects of under-and over-weighted implement training on pitching velocity. *J. Strength Cond. Res.* 8:247–250. 1994.

Derenne, C. Ho, CK. and Blitzblau, A. Effects of weighted implement training on throwing velocity. *J. Appl. Sport Sci. Res* 4:16–19. 1990.

Derenne, C. Increasing throwing velocity. *Athlet. J* 65(9):36–39. 1985.

Dillman, CJ, Fleisig, GS, and Andrews, JR. Biomechanics of pitching with emphasis upon shoulder kinematics. *J of Ortho and Sports Phys Thera* 18: 402-408. 1993.

Ebben, WP, Hintz, MJ, and Simenz CJ. Strength and conditioning practices of Major League Baseball strength and conditioning coaches. *Strength Cond Res* 19(3):538-546. 2005.

Edwards, DE. Comparing proprioceptive neuromuscular facilitation and isotonic weight exercises to the pitching velocity of college baseball pitchers. Master's thesis, University of Nevada at Reno, 1991.

Elliot, B, Grove, R, and Gibson, B. Timing of the lower limb drive and throwing limb movement in baseball pitching. *Int J Sports Biomech.* 4: 59-67. 1988.

Escamilla, RF, Fleisig, GS, Yamashiro, K, Mikla, T, Dunning, R, Paulos, L, and Andrews, JR. Effects of a 4-week youth baseball conditioning program on throwing velocity. *J Strength Cond Res.* 24(12): 3247–3254, 2010.

Escamilla, RF, Fleisig, GS, Barrentine, SW, Zheng, N, and Andrews, JR. Kinematic comparisons of throwing different types of baseball pitches. *J of Appl Biomechanics* 14: 1-23. 1998.

Fleck, SJ, Smith, SL, Craib, MW, Denahan, T, Snow, RE, and Mitchell, MR. Upper extremity isokinetic torque and throwing velocity in team handball. *J Appl Sport Sci Res* 6: 120–124. 1992.

Fleisig, G, Escamilla, R, Andrews, JR, Matsuo, T, Satterwhite, Y, and Barrentine, S. Kinematic and kinetic comparison between pitching and football passing. *J Appl Biomech* 12: 207-224. 1996a.

Fleisig, GS, Barrentine, SW, Escamilla, RF, and Andrews, JR. Biomechanics of overhand throwing with implications for injuries. *J Sports Med* 21: 421-437. 1996b.

Fleisig, GS, Dillman, CJ, and Andrews, JR. Biomechanics of the shoulder during throwing. In: Andrews JR, Wilk KE, eds. *The Athlete's Shoulder*. New York: Churchill Livingstone, pp: 360-365. 1994.

Fleisig, GS, Escamilla, RF, Andrews, JR. Biomechanics of throwing. In Zachazewski JE, Magee DJ, Quillen WS (eds), *Athletic Injuries and Rehabilitation*, W.B. Saunders, Philadelphia, pp: 332-353, 1996.

Fleisig, G, Barrentine, S, Zheng , N, Escamilla, R, and Andrews, JR. Kinematic and kinetic comparison of baseball pitching among various levels of development. *J Biomech* 32: 1371-1375, 1999.

Garstecki, MA, Latin, RW, Cuppett, MM. Comparison of selected physical fitness and performance variables between NCAA Division I and II football players. *J Strength Cond Res* 18(2): 292-297. 2004.

Gorostiaga, EM, Granados, C, Ibáñez, J, and Izquierdo, M. Differences in physical fitness and throwing velocity among elite and amateur male handball players. *Int J Sports Med* 26(3): 225-232. 2005.

Hay, JG. Baseball. In: *Biomechanics of Sports Technique* (3rd ed.). Englewood Cliffs, NJ: Prentice-Hall, Inc. pp. 188–213. 1985.

Hoffman, JR, Vazquez, J, Pichardo, N, and Tenenbaum, G. Anthropometric and performance comparisons in professional baseball players. *J Strength Cond Res* 23(8): 2173-2178. 2009.

Hoffman, JR, Tennenbaum, G, Maresh, CM, and Kraemer, WJ. Relationship between athletic performance tests and playing time in elite college basketball players. *J Strength Cond Res* 10: 67–71, 1996.

House, T, Heil, G, and Johnson, S. *The Art and Science of Pitching.* Monteray, CA: Coaches Choice. 2006.

Jackson, JB. The effects of weight training on the velocity of a thrown baseball. Master's thesis, Central Michigan University, 1994.

Katsumata, Y, Kawakami, Y, and Fukunaga T. Relationships Between Throwing Velocity and Muscle Strength Measures in Japanese Baseball Players *(Abstract)-NSCA 2006* Abstracts e40. 2006.

King, JA and Cipriani, DJ. Comparing preseason frontal and sagittal plane plyometric programs on vertical jump height in high-school basketball players. *J Strength Cond Res* 24(8): 2109–2114, 2010.

Kohmura, Y, Aoki, K, Yoshigi, H, Sakuraba, K, and Yanagiya, T. Development of a baseball-specific battery of tests and a testing protocol for college baseball players. *J Strength Cond Res* 22(4):1051-1058. 2008.

Lachowetz, T, Evon, J, and Pastiglione, J. The effects of an upper-body strength program on intercollegiate baseball throwing velocity. *J. Strength Cond. Res* 12:116–119. 1998.

Logan, GA, McKinney, WC, and Rowe, W. Effect of resistance through a throwing range of motion on the velocity of a baseball. *Percept Motor Skills* 25:55–58. 1966.

MacWilliams, B, Choi, T, Perezous, M, Chao, E, and McFarland, E. Characteristic ground-reaction forces in baseball pitches. *Am J Sports Med* 26: 66-71, 1998.

Matsuo, T, Escamilla, R, Fleisig, G, Barrentine, S, and Andrews, J. Comparison of kinematic and temporal parameters between different pitch velocity groups. *J Appl Biomech* 17:1-13, 2001.

Mcevoy, KP, and Newton, RU. Baseball throwing speed and base running speed: The effects of ballistic resistance training. *J. Strength Cond. Res*. 12(4):216–221. 1998.

Myers, JB, Laudner, KG, Pasquale, MR, Bradley, JP, and Lephart, SM. Glenohumeral range of motion deficits and posterior shoulder tightness in throwers with pathologic internal impingement. *Am J Sports Med*. 34:385-391. 2006.

National Strength and Conditioning Association Roundtable. Determining factors of strength—Part 1. *Nat Strength Cond J*. 7(1):10–19, 22–23. 1985.

Neal, RJ, Snyder, CW, and Kroonenberg, PM. Individual differences and segment interactions in throwing. *Human Movement Science*, 10, 653-676. 1991.

Newton, RU, and McEvoy, KP. Baseball throwing velocity: A comparison of medicine ball training and weight training. *J.Strength Cond. Res* 8:198–203. 1994.

Pappas, AM, Zawacki, RM, and Sullivan, TJ. Biomechanics of baseball pitching. A preliminary report. *Am J Sports Med* 13: 216–222, 1985.

Popescue, MG. Weight training and the velocity of a baseball. *Athlet J* 55:74–106. 1975.

Potteiger, JA, Williford, HN, Blessing, DL, and Smidt, J. Effect of two training methods on improving baseball performance variables. *J. Appl. Sport Sc. Res*. 6:2–6. 1992.

Prokopy, MP, Ingersoll, CD, Nordenschild, E, Katch, FI, Gaesser, GA, and Weltman A. Closed-kinetic chain upper-body training improves throwing performance of NCAA Division I softball players. *J Strength Cond Res* 22(6):1790-1798. 2008.

Putnam, CA. Sequential motions of body segments in striking and throwing skills: description and explanations. *J Biomech* 26:125-135. 1993.

Pyne, DB, Duthie, GM, Saunders, PU, Petersen, CA, and Portus MR. Anthropometric and strength correlates of fast bowling speed in junior and senior cricketers. *J Strength Cond Res* 20(3):620-626. 2006.

Robb, AJ, Fleisig, G, Wilk, K, Macrina, L, Bolt, B, and Pajaczkowski J. Passive ranges of motion of the hips and their relationship with pitching biomechanics and ball velocity in professional baseball pitchers. *Am J Sports Med* 38(12):2487-2493. 2010.

Saeterbakken, AH, van den Tillaar, R, and Seiler S. Effect of core stability training on throwing velocity in female handball players. *J Strength Cond Res* 25(3):712-718. 2011.

Salter, CW, Sinclair, PJ, and Portus, MR. The associations between fast bowling technique and ball release speed: A pilot study of the within-bowler and between-bowler approaches. *J of Sports Sci*, 25(11): 1279 – 1285. 2007.

Shenk, BS. Effect of two strength training programs on throwing velocity. Doctoral dissertation, University of Virginia, 1990.

Sierer, SP, Battaglini, CL, Mihalik, JP, Shields, EW, and Tomasini, NT. The National Football League Combine: performance differences between drafted and nondrafted players entering the 2004 and 2005 drafts. *J Strength Cond Res* 22: 6–12. 2008.

Solesky, L, Cain, JT, and Meacham, R. *The Physics of Pitching.* Minneapolis, MN: MVP Books. 2011.

Spaniol, FJ. Predicting throwing velocity in college baseball players. (Abstract) *J Strength Cond Res* 11: 286. 1997.

Spaniol, FJ. Baseball athletic test: a baseball-specific test battery. *J Strength Cond Res* 31: 26–29. 2009.

Stodden, D, Fleisig, G, McLean, S, Lyman, S, and Andrews, JR. Relationship pelvis and upper torso kinematics to pitched baseball velocity. *J Appl Biomech* 17:164-172. 2001.

Stodden, DF, Langeddorfer, SJ, and Fleisig, GS. Kinematic constraints associated with the acquisition of overarm throwing part I: Step and trunk actions. *Research Quarterly for Exercise and Sport* 77: 417-427, 2006.

Stodden, DF; Fleisig, GS, McLean, SP, and Andrews, JR. Relationship of biomechanical factors to baseball pitching velocity: Within pitcher variation. *Journal of Applied Biomechanics* 21; 44-56. 2005.

Swift, E.M. The Height Report (13, Aug., 2001) http://sportsillustrated.cnn.com/vault/article/magazine/MAG1023164/index.htm (visited 8, Aug., 2011). 2001.

Thomas, S, Reading, J and Shephard, RJ. Revision of the Physical Readiness Questionnaire (PAR-Q). *Can J Sport Sci*; 17 (4): 338-345. 1992.

Tippett, SR. Lower extremity strength and active range of motion in college baseball pitchers: A comparison between stance leg and kick leg. *Journal of Orthopaedic and Sports Physical Therapy* 8: 10-14, 1986.

Toyoshima, S, and Miyashita, M. Force-velocity relation in throwing. *Res Q* 44(1): 86-95. 1973.

Toyoshima, S, Hoshikawa, T, and Miyashita, M. Contributions of the body parts to throwing performance. In: *Biomechanics IV*. R.C. Nelson and C.A. Morehouse, eds. Baltimore: University Park Press. pp. 169–174. 1974.

van den Tillaar, R. Effect of different training programs on the velocity of overarm throwing: a brief review. *J Strength Cond Res* 18(2): 388-396. 2004.

Werner, SL, Suri, M, Guido Jr, JA, Meister, K, and Jones, DG. Relationships between ball velocity and throwing mechanics in collegiate baseball pitchers. *J Shoulder Elbow Surg* 17 (6): 905-908. 2008.

Whiting, WC. Gregor, RJ, and Halushka, M. Body segment and release parameter contributions to new-rules javelin throwing. *Int J of Sport Biom* 7: 111-124. 1991.

Wilk, K, Meister, K, and Andrews, JR. Current concepts in rehabilitation of the overhead throwing athlete. *Am J Sports Med* 30: 136-151. 2002.

Wilk, KE, Meister, K, and Fleisig, G. Biomechanics of the overhead throwing motion *Sports Med and Arthro Re* 8; 124-134. 2000.

Wilson, GJ, Elliott, BC, and Wood, GA. Stretch shorten cycle performance enhancement through flexibility training. *Med and Sci in Sports and Exer* 24, 116-123. 1992.

Wooden, MJ, Greenfield, B, Johanson, M, Litzelman, L, Mundrane, M, and Donatelli, RA. Effects of strength training on throwing velocity and shoulder muscle performance in teenage baseball players. *J. Orthop. Sports Phys. Ther* 15:223–228. 1992.

Wormgoor, S, Harden, L, and Mckinon, W. Biomechanical and isokinetic strength predictors of ball release speed in high-performance cricket fast bowlers. *J Sports Sci* 28(9): 957-965. 2010.

Young, WB, McDowell, MH, and Scarlett, BJ. Specificity of sprint and agility training methods. *J Strength Cond Res* 15: 315–319, 2001

Co-Authorship Statement

Graeme Lehman was the primary individual for the development of the idea for this thesis, collection and analysis/interpretation of the data, and writing of the paper. Dr. David Behm helped with the idea generation, analysis/interpretation of the data and writing revisions.

Correlation of Throwing Velocity to the Results of Lower Body Field Tests in Male College Baseball Players

by

© Graeme Lehman

Chapter 2 - Introduction

Throwing velocity is an important factor in deciding success in the game of baseball (Kohurara et al. 2008). Position players require high throwing velocities to restrict the offense's ability to advance bases and potentially score runs. Pitchers benefit from increased throwing velocity by diminishing the hitter's decision time of whether or not to strike the ball, increasing a pitcher's chance at success (Hay 1985). High velocity pitches also help set up other pitches such as curve balls or change ups to disrupt the hitters timing.

Increasing throwing velocity would benefit any baseball player in a quest to improve their ability to play and to be noticed by coaches and scouts for higher levels of competition. Enhancing throwing mechanics (technique) through proper kinematics and kinetics can optimize the athlete's ability to transfer energy from the ground to upper extremities then ultimately to the ball leading to higher throwing velocity (Pappas et al. 1985). While proper throwing mechanics help maximize performance research has shown players at youth levels, despite lower throwing velocities, can demonstrate similar mechanics as professional players (Stodden et al. 1999). The difference seen in throwing velocities between these two groups is a result of increased amounts of strength and muscle mass (Fleisig et al. 1999). This statement is in agreement with DeRenne (2001) who stated that throwing velocity could be increased through the improvement in throwing technique or through the use of resistance training (DeRenne et al. 2001) stressing the importance of strength to throwing velocity.

The implementation of resistance training with the goal of increasing throwing velocity has been successfully studied for many years with the use of several different methods (DeRenne et al. 2001). Resistance training in the form of free weight (Popescue 1975), band training (Escamilla et al. 2010), medicine balls (Newton and McEvoy 1994) and isokinetic machines (Wooden et al. 1992) have all shown positive effects on throwing velocity as well as special resistance training of throwing over-weight and under-weight balls (DeRenne et al. 1994). The majority of the research has focused on the upper body due in part to studies that show the trunk and shoulder generates much of the energy needed to display high throwing velocities (Toyoshima et al. 1974). Despite the number of studies that focus on upper body strength a survey of Major League Baseball strength and conditioning coaches reported that 15 out of 21 respondents believe that a lower body exercise is the most important exercise for the sport of baseball (Ebben et al. 2005). This creates a gap between the research of exercise scientists' and the application of strength and conditioning practices. The causes of which may be a result of the failure of previous studies to consistently demonstrate correlations between lower body strength and throwing velocity.

Katasumata (2006) reported that knee extension maximum voluntary isometric contraction (MVIC) of college aged pitchers correlated highly with throwing velocity however this same relationship was not present in younger pitchers. While Spaniol

(2009) demonstrated higher mean scores in 60 yard dash, horizontal jump, broad jump and throwing velocity with higher levels of competition but no correlation is seen with a lower body test and throwing velocity within any level. The author did however report a significant relationship between throwing velocity and grip strength.

This lack of a correlation between lower body strength and throwing velocity is perplexing due to some research that demonstrates that increased lower body force production during the act of throwing allow for higher throwing velocities. MacWilliams et al. (1998) demonstrated that increases in force production of the trail leg in the direction of the intended target in the frontal plane correlated with higher throwing velocity leading the authors to suggest that this allowed for more potential energy to be transferred to the ball. The strength of the lead leg was identified as a difference between high and low velocity throwing groups by Matsuo (2001) who reported that the ability to demonstrate knee extension upon landing was a common characteristic among high velocity throwers. Members of the slow velocity group continued further into knee flexion. The authors concluded that the lead leg provides both a stable base while also redirecting energy superiorly towards the upper extremities. This is congruent with Pappas et al. (1985) description of throwing as a sequential activation of body parts through a link segment beginning with the contralateral foot progressing through the trunk to a rapidly accelerating upper extremity

The act of throwing while bilateral in nature requires different actions during the throwing cycle from both lower extremities. The trail leg performs a concentric action

(MacWilliams et al. 1998) in the frontal plane while the lead leg eccentrically absorbs the energy created by the trail leg then concentrically redirect kinetic energy up the kinetic chain via a concentric contraction (Matsuo et al. 2001). The difference between the lower extremities was noted by Tippett et al. (1986) who reported differences in strength and range of motion in the lower extremities of college baseball pitchers. This study did not however correlate any of their findings with throwing velocity. Other studies have exclusively used bilateral lower body movements in an attempt to correlate with throwing velocity (Spaniol et al.1997) with the exception of running which is a cyclical action unlike throwing. Based on the research that describes the dynamic and independent actions of the lower extremities one can hypothesize that tests like isometric contractions, maximum strength, bilateral movements or actions in sagittal plane would poorly correlate with throwing velocity.

There is no research examining frontal, unilateral and non-lab based tests to predict throwing velocity. Thus the purpose of this study was to determine which lower extremity field tests correlate with throwing velocity in order to provide coaches and athletes with more direction in creating training programs that ultimately lead to increases in throwing velocity. In order to achieve this objective, lower body field tests, which include bilateral and unilateral actions along with movements in various planes and muscle contractions (eccentric and concentric) will be correlated to throwing velocity results.

2.1 Hypothesis

It is hypothesized that due to the independent and differing actions of the lower limbs during the throwing motion that field tests, which emphasize unilateral actions, will correlate to throwing velocity more than bilateral tests. In particular the concentric strength of the trail leg and the eccentric strength of the lead leg will correlate to throwing velocity.

Chapter 3 - Methods

3.1 Experimental Approach to the Problem

To address the hypothesis that concentric power of the trail leg and the eccentric power of the lead leg will correlate to throwing velocity a wide variety of lower body tests were performed including both bilateral and unilateral movements. This study was designed to determine if the chosen lower body field tests were correlated to throwing velocity. The experimental protocol was conducted during the fall season of the college baseball season, which primarily consists of practices and intersquad games. A stepwise multiple regression analysis was computed between both shuffle and stretch throwing velocities (dependent variables) and the results of the lower body field tests (independent variables). The lower body field tests consisted of medicine ball scoop toss, medicine ball squat throw, bilateral vertical jump, left leg vertical jump, right leg vertical jump, broad jump, triple broad jump, hop and stop from left to right, hop and stop from right to left, lateral to medial jump right, lateral medial jump left, 10 yard dash, 60 yard dash and both left and right single leg 10 yard hop for speed.

3.2 Subjects

Forty two college level baseball players from two teams (Northwest Athletic Association of Community Colleges (n=19) National Association of Intercollegiate Athletics (n=23)) were used for this study, all of whom have at least 10 years of experience playing baseball. The mean age was 19.8 years (+/- 1.2). The subjects had a mean height and weight of 183.3 cm. (+/- 9) and 83.1kg (+/- 14) respectively. Each subject had not reported any arm problems within the last 3 months. Participants were verbally informed of the procedures and read and signed a consent form and a Physical Activity Readiness Questionnaire (PAR-Q) before participation (Thomas et al.1992). The Memorial University of Newfoundland Human Investigation Committee approved the study.

3.3 Testing Schedule

The subjects were carefully familiarized with the testing protocols 3 weeks in advance of the actual testing date in order to minimize the learning effect.

After a standardized 10-minute warm-up period that included low-intensity running, dynamic mobility drills and several acceleration runs, subjects were randomly assigned to one of four testing stations. Physical field tests were divided into four groups:

(1) medicine ball throws (2) vertical jumps (3) horizontal jumps and (4) sprints & timed hops.

3.4 Medicine Ball Throws

Two types of medicine ball throws (squat and scoop) were performed on the field and consisted of three throws with the farthest throw being recorded. A 2.7kb (6lbs) medicine ball was used for all of the tests. One investigator marked the spot where the ball landed while another would measure the distance from the starting line to the landing spot.

3.4.1 *Medicine Ball Squat Throws*

Subjects were instructed to perform a countermovement (flexion and extension) with the lower body and explosively extend through the hips and knees into a forward jump while performing a chest pass motion with both arms extending to allow for maximal power. Thirty seconds of recovery were allocated between throwing attempts to prevent muscular fatigue.

3.4.2 *Medicine Ball Scoop Throws*

Subjects stood facing away with their backs towards the intended target. Subjects were instructed to grasp the medicine ball with both hands and swing the ball between their legs before explosively extending their hips and throwing the ball as far as possible behind themselves.

3.5 Vertical Jumps

Vertical jumps tests were recorded using a contact mat (Jump Mat, Axon, USA)

3.5.1 *Bilateral Jump*

Subjects were asked to perform a maximal jump on the contact mat from a stationary position while standing on both feet. Subject's performed a preparatory countermovement with the lower body coupled with arm swings to achieve maximal height. Arm swings were allowed since subjects were accustomed to jumping with an arm swing action. The jumping height was calculated from the flight time. Each subject performed three jumps with approximately 10 seconds between jumping attempts. Subjects were instructed not to tuck their legs upon landing in an attempt to increase flight time. The best reading was used for further analysis.

3.5.2 *Unilateral Jumps*

Subjects were asked to perform a maximal jump on the contact mat from a stationary position while standing only on one foot. Subject's performed a preparatory countermovement with the lower body coupled with dual arm swing to achieve maximal height. Subjects performed a one legged take off and were instructed to land on both feet simultaneously. The jumping height was calculated from the flight time. Each subject performed three jumps with approximately 10 seconds between jumping attempts. The best reading was used for further analysis. Following a 90 second recovery, subjects repeated this process on the opposite leg. The order was randomized.

3.6 Horizontal Jumps

A series of horizontal jumps were performed in the same order. Approximately 10 seconds were given between attempts on each test and 3 minutes were given between different horizontal jump tests.

3.6.1 *Broad Jump*

From a stationary position, horizontal jumps with arm swings were performed on turf (both takeoff and landing) and were measured with a tape measure. Each subject performed two maximal jumps; the distance was measured from the heel of the foot closest to the starting line. The best of the three jumps were recorded for further analysis.

3.6.2 *Hop and Stop*

Subjects stood at the starting line on one foot and were instructed to perform a countermovement forward jump along with dual arm swing to allow for maximal distance. Subjects were required to land on their opposite leg and come to complete stop with no trunk or limb movement in less than one second.

Subjects were allotted five attempts to land three jumps that met the above criteria the farthest of which was recorded for further analysis. If three scoring jumps were not accomplished subjects were allotted 120 seconds of rest before attempting again. Distance was measured from the back of the heel to the starting line. One investigator determined if the jump counted by starting a stop watch upon landing and stopping it upon the cessation of movement. Subjects then repeated the process jumping with the opposite leg. The order of the jumps was randomized.

3.6.3 *Lateral to medial jump (LMJ)*

Subjects were instructed to stand parallel to the starting line on their left foot with the inside of their foot closest to the starting line. Subjects were instructed to perform a countermovement with their lower body and jump as far as possible to their right in the frontal plane while landing on both feet simultaneously parallel to the starting line. The distance was recorded from the outside of the left foot to the starting line. Three attempts were given with approximately 10 seconds of rest; the greatest distance was recorded for further use. This process was repeated on the opposite leg.

3.6.4 *Bilateral Triple Jump*

Three consecutive two-legged hops were recorded with the use of a measuring tape fixed to the ground perpendicular to the starting line. Participants stood with the great toe of both feet at the starting line. They performed 3 consecutive maximal hops forward with minimal time spent on the ground to allow for maximal use of stored elastic energy. Arm swings were allowed. The investigator measured the distance from the starting line to the point where the heel of the foot closest to the starting line landed upon completing the third hop. Three trials were given with the greatest being recorded for further use.

3.7 Speed Tests

All speed tests were conducted on an Astroturf field and were recorded with an infrared testing device (Speed Trap II; Brower Timing Systems, Draper, UT, USA)

3.7.1 *Ten Yard (9.14m) Sprint*

Subjects stood in a two-point stance with one foot just behind the starting line. Subjects performed two attempts with approximately 120 seconds of rest between attempts with the fastest of the three attempts recorded for further use.

3.7.2 *Sixty yard (54.86m) Sprint*

This traditional baseball test was completed by having subjects stand in a two-point stance with one foot just behind the starting line. Subjects performed two attempts with approximately 120 seconds of rest between attempts with the fastest of the two attempts recorded for further use.

3.7.3 *Ten-yard (9.14m) single leg hop test*

Subjects stood on one leg just being the starting line and covered the 10 yard distance as fast as possible while hopping exclusively on the same leg. Two attempts were given with approximately 120 seconds of rest between attempts with the fastest of the two being recorded for further use. Following a three minute recovery, this process was repeated for the opposite leg. Choice of legs was randomized.

3.8 Throwing velocity

After an adequate throwing warm up each subject was given 3 attempts to reach their maximal throwing velocity. Each subject threw overhand from flat ground at maximal effort to a target positioned at approximately chest level from 18.44m away, which is the distance between the pitching rubber and home plate. Throwing velocity was recorded from a calibrated Jugs Sport Radar gun (Jugs Pitching Machine Company, Tualatin, OR, USA) as the ball left the player's hand and is accurate within 0.22m/s.

3.8.1 *Stretch Throwing Velocity*

Athletes started with both feet together and were allowed to take one stride towards the target. This mimics the "stretch" position that pitchers are forced to throw from when runners are on base. Thirty seconds were given between throwing attempts to prevent muscular fatigue. The throw with the highest velocity was recorded.

3.8.2 *Shuffle Throwing Velocity*

Following the 3 throws from the stretch position each athlete performed an additional 3 throws where they were allowed to build momentum by shuffling in the frontal plane towards the target within a 3-meter (~10ft) limit. Again subjects threw overhand from flat ground at maximal effort to a target positioned at approximately chest level from 18.44m away. Thirty seconds were given between throwing attempts to prevent muscular fatigue. The throw with the highest velocity was recorded.

3.9 Statistical Analysis

The mean and SD of the selected anthropometric and physical performance tests were calculated for both left and right handed throwing subjects (Tables 1 & 2). Regression analysis was performed to determine the contribution of anthropometric as well as all physical capability tests (independent variables) to throwing velocity scores (dependent variable) with a shuffle approach and from the stretch position. This was done for both right handed ($n=33$) and left handed ($n=9$) throwers.

Statistical Analysis was performed with the SPSS statistical package (17.0) for Windows; SPSS Inc., Chicago, Illinois, USA). Statistical significance was assumed at the conventional level of $p<0.05$.

Table 1. Test results for Right Handed subjects (n=33)

Test	Mean	±SD
Height (cm)	183.80	5.26
Weight (kg)	83.97	7.81
Stretch (m/sec)	35.26	1.92
Shuffle (m/sec)	36.47	2.28
10 yd. dash (sec)	1.62	0.08
60 yd. dash (sec)	7.30	0.26
10 yd. hop right (sec)	2.30	0.19
10 yd. hop left (sec)	2.30	0.16
VJ Bilateral (cm)	49.45	6.92
VJ Right (cm)	27.12	4.13
VJ Left (cm)	28.44	4.09
Broad Jump (cm)	245.56	17.37
HS Right (cm)	193.27	13.36
HS Left (cm)	188.46	13.97
LMJ Right (cm)	189.29	13.55
LMJ Left (cm)	186.52	14.05
Triple Jump (cm)	298.61	22.58

MB Squat Throw (cm)	1168.33	80.33
MB Scoop Throw (cm)	1381.33	151.40

Table 2. Test results for Left Handed subjects (n=9)

Test	Mean	±SD
Height (cm)	181.47	4.81
Weight (kg)	79.90	5.91
Stretch (m/sec)	35.72	1.77
Shuffle (m/sec)	35.94	1.26
10 yd. dash (sec)	1.66	0.09
60 yd. dash (sec)	7.57	0.39
10 yd. hop right (sec)	2.38	0.17
10 yd. hop left (sec)	2.45	0.14
VJ Bilateral (cm)	47.54	9.42
VJ Right (cm)	26.83	4.54
VJ Left (cm)	26.93	4.12
Broad Jump (cm)	223.13	20.77
HS Right (cm)	179.27	11.09
HS Left (cm)	182.91	13.49
LMJ Right (cm)	177.59	18.28

LMJ Left (cm)	182.25	18.04
Triple Jump (cm)	285.78	34.22
MB Squat Throw (cm)	1101.78	133.32
MB Scoop Throw (cm)	1314.22	129.36

Chapter 4 - Results

4.1 Stretch - Right Hand Throw

Table 3 represents the results of the regression analyses between right handed throwing velocity from the stretch position. The scores from both the anthropometric and physical performance tests showed that 2 factors, lateral to medial jump right (LMJR) and body weight (BW) had significant contribution to throwing velocity with adjusted R^2=0.322, F=8.609, SEE = 6.437, p=0.001. These results indicated that approximately 32.2% of the variance of ball throwing velocity from the stretch position in right-handed throwers can be accounted for by the LMJR scores and BW.

Table 3. Multiple Regression for Right Handed Stretch Throwing Velocity

Variable (n=33)	R^2	Standard Error

LMJR	0.160	6.437
LMJR + BW	0.322	5.773

*LMJR = lateral to medial jump right; BW=Body Weight

4.2 - Shuffle - Right Hand Throw

Table 4 represents the results of the regression analyses between right handed throwing velocities with a shuffle approach. Regression scores from both the anthropometric and physical performance tests showed that 2 factors, lateral to medial jump right (LMJR) and medicine ball scoop (MB Scoop) had significant contribution to throwing velocity with adjusted R^2=0.338, F=9.181, SEE = 6.795, p=0.001. These results indicated that approximately 33.8% of the variance of ball throwing velocity from the stretch position in right-handed throwers can be accounted for by the LMJR and MB Scoop scores.

Table 4. Multiple Regression for Right Handed Shuffle Throwing Velocity

Variable (n=33)	R^2	Standard Error
LMJR	0.199	7.475
LMJR + MB Scoop Throw	0.338	6.795

*LMJR = lateral to medial jump right; MB = medicine ball

4.3 Stretch - Left Hand Throw

Table 5 represents the results of the regression analyses between left handed (n=9) throwing velocity from the stretch position and the scores from both the anthropometric and physical performance tests showed that only one factor, lateral to medial jump left (LMJL) had significant contribution to throwing velocity with adjusted R^2=0.688, F=18.659, SEE =3.786, p=0.003. These results indicated that approximately 68.8% of the variance of ball throwing velocity from the stretch position in right-handed throwers can be accounted for by the LMJL scores and BW.

Table 5. Multiple Regression for Left Handed Stretch Throwing Velocity

Variable (n=9)	R^2	Standard Error
LMJL	0.688	3.786

*LMJL = lateral to medial jump left; BW=Body Weight

4.4 Shuffle - Left Hand Throw

Table 6 represents the results of the regression analyses between left handed (n=9) throwing velocity with a shuffle approach. These scores from both the anthropometric and physical performance tests showed that 3 factors, LMLL, BW and LMJR had significant contribution to throwing velocity with adjusted R^2=0.982, F=144.115, SEE = .648, p=0.001. These results indicated that approximately 98% of the variance of ball throwing velocity from the stretch position in right handed throwers can be accounted for by the LMJL, BW and LMJR.

Table 6. Multiple Regression for Left Handed Shuffle Throwing Velocity

Variable (n=9)	R^2	Standard Error
LMJL	0.773	2.285
LMJL + BW	0.892	1.572
LMJL + BW+ LMJR	0.982	0.648

*LMJL = lateral to medial jump left; BW=Body Weight: LMJR = lateral to medial jump right

Chapter 5 - Discussion

There was a consistent appearance of the lateral to medial jumps as a significant factor correlated to high throwing velocity in each of the throwing techniques for both left and right handed throwers (Tables 3-6). This was the first study to our knowledge to correlate throwing velocity to a unilateral jump in the frontal plane, which mimics the action of the stride.

The importance of the stride was noted in a biomechanical study of the throwing motion by Stodden et al. (2006) who noted that the stride functions as the initial factor to generate and transfer force of momentum up through the kinetic chain by initiating linear momentum of the body towards the intended target. This need for linear velocity has been reported with other throwing activities. Top level javelin throwers exhibited both longer strides and higher approach velocities (Bartlett et al. 1996) while Salter et al. (2006) demonstrated that 87.5% of ball release speed for a cricket bowler can be attributed to run-up velocity, angular velocity of the bowling arm, vertical velocity of the non-bowling arm, and stride length.

This correlation between lateral to medial jump scores and throwing velocity is congruent with the information provided by MacWilliams et al. (1998) which stated increased ground reaction forces created by the trail leg in the direction towards the target were highly correlated with ball velocity. Theoretically, the increase in momentum would allow baseball players to transfer more energy through the kinetic chain from the trunk, to the throwing arm, and finally to the ball to produce increased ball velocities.

While the ability to generate momentum is important, one must be careful to not artificially produce linear momentum towards the intended target. MacWilliams (1998) noted that while the correlation of ground reaction force to throwing velocity was high (r^2=0.82) some subjects demonstrated the reverse trend with what the authors called "overthrowing". The authors noted that the athletes must integrate the powerful leg drive as a natural part of their throwing motion due to its complexity. If peak ground reaction forces occur too early during the throwing motion, throwing velocity is reduced (Elliot et al. 1988). MacWilliams et al. (1998) found that the forces were gradually built up and peaked just prior to the lead foot making contact with the ground. The need to create momentum towards the target is taught by some pitching coaches who stress the involvement of the lower body by emphasising the need to ``push`` or ``drive`` towards the target as part of a well-integrated pitching motion (Empey 2002).

The specificity of the lateral to medial horizontal jump may be the primary reason that it correlated to high throwing velocity. The intuition of a pitchers stride towards the target is also Strength and conditioning coaches apply the principal of specificity to athletes who desire the ability to improve a specific task. The specificity principal implies that to become better at a particular skill the training must involve the skill by replicating the biomechanical movements (Young et al. 2001). Traditional bilateral tests such as vertical, horizontal jumping and running speed in the sagittal plane did not significantly correlate to high throwing velocity in the current study. These results agree with the findings of Spaniol (1997) who did not find any correlation between either running speed (60 yard dash) or lower body power (vertical jump) and throwing velocity.

The correlation between throwing velocity and lateral to medial jumps suggest that there is a high degree of specificity in regards to power in a specific direction and plane of movement. The poor carryover from training in one plane of motion and testing in another has been shown by King and Cipriani (2010) who reported reduced improvements in vertical jump scores of subjects that trained exclusively with frontal plane plyometric exercises compared to those that trained in the sagittal plane. Young et al. (2001) also found low transferability between linear speed and agility.

The results of this study also demonstrated that body weight played a significant role in throwing velocity for right handed throwers from the stretch position (table 3) and left handed throwers with a shuffle approach (table 6). These findings are congruent with those from Werner et al. (2008). Increased body weight increases the total amount of energy that can be ultimately transferred to the ball allowing for higher throwing velocity. In each case that body weight was a significant factor it was also coupled with the lateral to medial jump which indicates increased amounts of body mass must be accompanied by the appropriate amounts of power. Added body mass in the form of fat would be beneficial as it can be assumed that it would decrease the lateral to medial jump scores. Increased distance from a lateral to medial jump coupled with increased body weight would again account for increased amounts of kinetic energy in the direction of the target allowing for high throwing velocity scores.

Throwing a baseball with high velocity requires a complex combination of kinematics and kinetics that must be in place in order to optimize the athlete's ability to transfer energy to the baseball. However if these motor patterns are in place due to years of practice the results of this study lead us to believe that increased levels of power in the frontal plane result in higher throwing velocity scores. Future studies will have to determine if increases in the athlete's ability to jump further in the frontal plane will translate into higher levels of throwing velocity.

Chapter 6 - Practical Applications

This study found that lateral to medial jumps, which measured the athlete's ability to create power in the frontal plane, which is specific to the act of throwing a baseball, best predicted throwing velocity. Coaches should integrate unilateral jumping drills and resistance training in the frontal plane in order to apply the principal of specificity. Traditional exercises performed in the sagittal plane (lunges, single leg squats, deadlifts) should not be excluded but rather serve as a means of increasing overall lower body power in the initial phases, such as anatomical adaptation, hypertrophy and maximum strength of an off-season strength program (Bompa 1999). The de-emphasis of frontal plane movements following the baseball season which consists primarily of frontal and transverse plane movement like throwing and hitting will serve both as change of stimulus while potentially reducing the chance of an overuse injury.

It is our opinion that frontal plane unilateral exercises would be best suited during the final phases of a periodized program when strength is converted to power following a well-planned periodized program. (Bompa 1999). Traditionally this final phase would consist of sagittal plane movements like vertical jump, depth jumps or medicine ball squat throws however the results of this study indicate that plane specific movements would best suit the baseball athlete who wishes to increase throwing velocity.

Bibliography

Bartlelt, R, Muller, E, Lindinger, S, Brunner, F, and Morris, C. Three-dimensional evaluation of the kinematic release parameters for javelin throwers of different skill levels. *J of App Biomech* 12: 58-71. 1996.

Bompa, TO. *Periodization Training for Sports*. Human Kinetics. Champaign, Il. 1999.

Derenne, C, Ho, KW, and Murphy, JC. Effects of general, special and specific resistance training on throwing velocity in baseball: a brief review. *J Strength Cond Res* 15(1):148-156. 2001.

Derenne, C, Buxton, BP, Hetzler, RK, and Ho, KW. Effects of under-and over-weighted implement training on pitching velocity. *J. Strength Cond. Res* 8:247–250. 1994.

Ebben, WP, Hintz, MJ, and Simenz CJ. Strength and conditioning practices of Major League Baseball strength and conditioning coaches. *J Strength Cond Res* 19(3):538-546. 2005.

Elliot, B, Grove, R, and Gibson, B. Timing of the lower limb drive and throwing limb movement in baseball pitching. *Int J Sports Biomech* 4: 59-67. 1988.

Empey, D. *Developing Pitchers*. Vancouver, BC: Club House Publishing, 2002.

Escamilla, RF, Fleisig, GS, Yamashiro, K, Mikla, T, Dunning, R, Paulos, L, and Andrews, JR. Effects of a 4-week youth baseball conditioning program on throwing velocity. *J Strength Cond Res* 24(12): 3247–3254, 2010.

Fleisig, G, Barrentine, S, Zheng , N, Escamilla, R, and Andrews, JR. Kinematic and kinetic comparison of baseball pitching among various levels of development. *J Biomech* 32: 1371-1375, 1999.

Hay, JG. Baseball. In: *Biomechanics of Sports Technique* (3rd ed.). Englewood Cliffs, NJ: Prentice-Hall, Inc. pp. 188–213. 1985.

Hoffman, JR, Vazquez, J, Pichardo, N, and Tenenbaum, G. Anthropometric and performance comparisons in professional baseball players. *J Strength Cond Res* 23(8): 2173-2178. 2009.

Katsumata, Y, Kawakami, Y, and Fukunaga T. Relationships Between Throwing Velocity and Muscle Strength Measures in Japanese Baseball Players *(Abstract)-NSCA 2006* Abstracts e40. 2006.

King, JA and Cipriani, DJ. Comparing preseason frontal and sagittal plane plyometric programs on vertical jump height in high-school basketball players. *J Strength Cond Res* 24(8): 2109–2114, 2010.

Kohmura, Y, Aoki, K, Yoshigi, H, Sakuraba, K, and Yanagiya, T. Development of a baseball-specific battery of tests and a testing protocol for college baseball players. *J Strength Cond Res* 22(4):1051-1058. 2008.

MacWilliams, B, Choi, T, Perezous, M, Chao, E, and McFarland, E. Characteristic ground-reaction forces in baseball pitches. *Am J Sports Med* 26: 66-71. 1998.

Matsuo, T, Escamilla, R, Fleisig, G, Barrentine, S, and Andrews, J. Comparison of kinematic and temporal parameters between different pitch velocity groups. *J Appl Biomech* 17:1-13, 2001.

Newton, RU, and McEvoy, KP. Baseball throwing velocity: A comparison of medicine ball training and weight training. *J.Strength Cond. Res* 8:198–203. 1994.

Pappas, AM, Zawacki, RM, and Sullivan, TJ. Biomechanics of baseball pitching. A preliminary report. *Am J Sports Med* 13: 216–222, 1985.

Popescue, MG. Weight training and the velocity of a baseball. *Athlet J* 55:74–106. 1975.

Salter, CW, Sinclair, PJ, and Portus, MR. The associations between fast bowling technique and ball release speed: A pilot study of the within-bowler and between-bowler approaches. *J Sports Sci*, 25(11): 1279 – 1285. 2007.

Spaniol, FJ. Predicting throwing velocity in college baseball players. (Abstract) *J Strength Cond Res* 11: 286. 1997.

Spaniol, FJ. Baseball athletic test: a baseball-specific test battery. *J Strength Cond Res* 31: 26–29. 2009.

Stodden, DF, Langeddorfer, SJ, and Fleisig, GS. Kinematic constraints associated with the acquisition of overarm throwing part I: Step and trunk actions. *Res Quar for Exer and Sport* 77: 417-427, 2006.

Thomas, S, Reading, J and Shephard, RJ. Revision of the Physical Readiness Questionnaire (PAR-Q). *Can J Sport Sci*; 17 (4): 338-345. 1992.

Tippett, SR. Lower extremity strength and active range of motion in college baseball pitchers: A comparison between stance leg and kick leg. *J Orthop Sports Phys Ther* 8: 10-14, 1986.

Toyoshima, S, Hoshikawa, T, and Miyashita, M. Contributions of the body parts to throwing performance. In: *Biomechanics IV*. R.C. Nelson and C.A. Morehouse, eds. Baltimore: University Park Press. pp. 169–174. 1974.

Werner, SL, Suri, M, Guido Jr, JA, Meister, K, and Jones, DG. Relationships between ball velocity and throwing mechanics in collegiate baseball pitchers. *J Shoulder Elbow Surg* 17 (6): 905-908. 2008.

Wooden, MJ, Greenfield, B, Johanson, M, Litzelman, L, Mundrane, M, and Donatelli, RA. Effects of strength training on throwing velocity and shoulder muscle performance in teenage baseball players. *J. Orthop. Sports Phys. Ther* 15:223–228. 1992.

Young, WB, McDowell, MH, and Scarlett, BJ. Specificity of sprint and agility training methods. *J Strength Cond Res* 15: 315–319, 2001