1-1-2013

# Correlation of throwing velocity to the results of lower body field tests in male college baseball players

G Lehman

Eric J. Drinkwater
*Edith Cowan University*

David Behm



10.1519/JSC.0b013e3182606c79
This is an Author's Accepted Manuscript of: Lehman, G., Drinkwater, E. J., & Behm, D. (2013). Correlation of throwing velocity to the results of lower body field tests in male college baseball players. Journal of Strength and Conditioning Research, 27(4), 902-908. Available here

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

**Authors:** Graeme Lehman[1], Eric J. Drinkwater[1,2] and David G. Behm[1]

1. School of Human Kinetics and Recreation
Memorial University of Newfoundland
St. John's, Newfoundland, Canada, A1C 5S7

2. School of Human Movement Studies
Charles Sturt University
Panorama Avenue, Bathurst, 2795, NSW AUSTRALIA

**Corresponding Author:** Dr. David G. Behm

School of Human Kinetics and Recreation

Memorial University of Newfoundland

St. John's, Newfoundland, Canada, A1C 5S7

709-864-3408 (tel)

709-864-3979 (fax)

dbehm@mun.ca

**Running Title:** Throwing Velocity Correlations

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

**ABSTRACT**

Baseball specific athleticism, potential and performance have been difficult to predict. Increased muscle strength and power can increase throwing velocity but 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. Baseball 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 sprints, and both left and right single leg 10 yard hop for speed in 42 college baseball players. A multiple regression analysis (forward method), 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 were most strongly 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) predicted left stretch throw. Right-handed shuffle throw was most strongly predicted by LMJR and medicine ball scoop ($R^2$=0.338); whereas, LMJL, BW and LMJR all significantly contributed to left-handed shuffle throw ($R^2$=0.982). 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 the first study to correlate throwing velocity with a unilateral jump in the frontal plane, mimicking the action of the throwing stride.

**KEY WORDS**: jumps, pitching, shuffle, throwing speed, hops,

## INTRODUCTION

Throwing velocity is an important factor in deciding success in the game of baseball (13). 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 (10). 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 (17). 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 (22). The difference seen in throwing velocities between these two groups is a result of increased strength and muscle mass (9). This statement is in agreement with DeRenne (3) who stated that throwing velocity could be increased through the improvement in throwing technique or through the use of resistance training (3) 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 (3). Resistance training in the form of free weight (18), band training (8), medicine balls (16) and isokinetic machines (27) have all shown positive effects on throwing velocity as well as special resistance training of throwing over-weight and under-weight balls (4). However, there are very few sport specific studies examining the relationship between field tests / exercises and throwing velocity. Furthermore, 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 (25). 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 (5). This creates a gap between the research and the application of strength and conditioning practices.

Katasumata (11) 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. Spaniol (21) demonstrated higher mean scores in 60 yard dash, horizontal jump, broad jump and throwing velocity with higher levels of competition but no correlation was 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. These few correlational studies used similar bilateral movements whereas the baseball throw emphasizes distinct or separate functions for each leg. In accordance with the concept of training specificity (28), research is necessary to help athletes and coaches incorporate field tests that would correlate highly with throwing velocity.

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. (14) 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 (15) who reported that the ability to demonstrate knee extension upon landing was a common characteristic among high velocity throwers. Members of the slow throwing 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. (17) 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 (14) in the frontal plane while the lead leg eccentrically absorbs the energy created by the trail leg then concentrically redirects kinetic energy up the kinetic chain via a concentric contraction (15). The difference between the lower extremities was noted by Tippett et al. (24) 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 (20) 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 correlate poorly 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 are highly associated with 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) were correlated to throwing velocity results. According to the concept of training specificity (28), field tests, which most closely simulate the throwing action should more efficiently train those muscles associated with a high throwing velocity.

## METHODS

### Experimental Approach to the Problem

This study was designed to determine if the chosen bilateral and unilateral 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. Individual multiple regression analyses (forward method) were calculated between both shuffle and stretch throwing velocities of left and right handed players (dependent variable) 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 sprint, 60 yard sprint and both left and right single leg 10 yard hop for speed. To determine which exercises performed on a frontal or sagittal plane with unilateral or bilateral actions provided the greatest correlation with throwing velocity, a variety of field tests were conducted.

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 who had at least 10 years of experience playing baseball and at least 2 years experience with resistance training. 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 with throwing velocities ranging from 74-87 miles per hour (118 – 141 km/hr). Each subject had not reported any arm problems within the last 3 months. Participants were verbally informed of the procedures and read and voluntarily signed a consent form and a Physical Activity Readiness Questionnaire (PAR-Q) before participation (23). The Memorial University of Newfoundland Human Investigation Committee approved the study.

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 and timed hops.

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. Each subject performed three throws with the farthest throw being recorded. Thirty seconds of recovery were allocated between throwing attempts to prevent muscular fatigue.

For the 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. When performing, 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.

Vertical Jumps

The bilateral and unilateral vertical jumps tests were recorded using a contact mat (Jump Mat, Axon, USA). For the 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.

When performing unilateral jumps, subjects were asked to perform a maximal jump on the contact mat from a stationary position while standing only on one foot. Subjects 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.

Horizontal Jumps

A series of horizontal jumps were performed in the same order. Approximately 10 seconds rest was given between attempts on each test and 3 minutes were given between different horizontal jump tests. The horizontal broad jump was performed on turf (both takeoff and landing) from a stationary position, with arm swings, a 2 foot take-off and was 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. For the 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 a 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.

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.

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.

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). For the 10 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. The 60-yard (54.86m) sprint (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 faster of the two attempts recorded for further use. With the 10-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 faster 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.

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.

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.

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.

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). Four separate multiple regression analyses were performed (forward method) 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 performed for both right handed (n=33) and left handed (n=9) throwers. Statistical Analysis was performed with PASW Statistics 17 (Release Version 17.0.2, SPSS Inc., Chicago, Illinois, USA). Results are expressed with the adjusted $R^2$, and regression equations with the standard error of the estimate (SEE) for each regression.

**RESULTS**

Stretch - Right Hand Throw

Equation 1 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) played substantial contributing roles throwing velocity (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.

Equation 1

$$y^{\wedge}{}'=101.9+(LMJR\times-0.050)+(BW\times0.374)$$

Adjusted R2=0.322, SEE=5.77

Shuffle - Right Hand Throw

Equation 2 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) played substantial contributing roles throwing velocity (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.

Equation 2

y^'=101.2+(LMJR×-0.068)+(MB Scoop×0.021)

Adjusted R2=0.338, SEE=6.80

Stretch - Left Hand Throw

Equation 3 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) played substantial contributing role throwing velocity (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 left-handed throwers can be accounted for by the LMJL scores and BW.

Equation 3

$y\hat{}' = 135.4 + (LMJL \times -0.092)$

Adjusted R2=0.688, SEE=3.79

Shuffle - Left Hand Throw

Equation 4 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, LMJL, BW and LMJR played substantial contributing roles throwing velocity (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 left-handed throwers can be accounted for by the LMJL, BW and LMJR.

Equation 4

$y\hat{}' = 208.0 + (LMJL \times -0.072) + (BW \times -0.770) + (LMJR \times -0.206)$

Adjusted R2=0.982, SEE=0.65

## Discussion

There was a consistent appearance of the lateral to medial jumps as a factor correlated to high throwing velocity in each of the throwing techniques for both left and right handed throwers. This was the first published study 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. (22) who reported 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 (1) while Salter et al. (19) 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. (14) 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 (14) 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 (6). MacWilliams et al. (14) 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 (7).

The specificity of the lateral to medial horizontal jump may be the primary reason that it correlated to high throwing velocity. 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 (28). Traditional bilateral tests such as vertical, horizontal jumping and running speed in the sagittal plane did not substantially correlate to high throwing velocity in the current study. These results agree with the findings of Spaniol (20) 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 (12) 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. (28) also found low transferability between linear speed and agility.

The results of this study also demonstrated that body weight had a substantial relationship with throwing velocity for right handed throwers from the stretch position and left handed throwers with a shuffle approach. These findings are congruent with those from Werner et al.

(26). 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 substantial 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 not 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 have a high relationship with 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.

## 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 (2). 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. (2). 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.

## REFERENCES


1. 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.

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

3. 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.

4. 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.

5. 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.

6. 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.

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

8. 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.

9. 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.

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

11. Katsumata, Y, Kawakami, Y, and Fukunaga T. Relationships Between Throwing Velocity and Muscle Strength Measures in Japanese Baseball Players *NSCA 2006* e40, 2006.

12. 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.

13. 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.

14. 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.

15. 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.

16. 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.

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

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

19. 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.

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

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

22. 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.

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

24. 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.

25. 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, 1974. pp. 169–174.

26. 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.

27. 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.

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