Trunk Contributions to Baseball Pitching Velocity

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Abstract

Overarm baseball throwing requires highly coordinated control of the entire body to achieve maximal performance. Muscles in the trunk of the body are theorized to play a major role in the transfer of power from the legs to the pitching arm, but few relationships between the trunk and throwing performance have been documented. The purpose of this project is to better understand the trunk contributions to baseball pitching velocity by looking at trunk transverse rotational velocity during pitching as well as trunk functional assessments. Eleven high school baseball players (71.98 ± 2.56 inches, 172 ± 17.12 lbs) were asked to throw 15 fastball pitches from a custom pitching mound built overtop force plates to allow for 3D biomechanical data collection. The final five throws for each pitcher were used for analysis. Participants wore retro-reflective markers over various bony anatomical landmarks on the body to track their movement. A partial correlation analysis, controlling for height and weight, was conducted to assess the relationship between trunk rotational velocity and the functional assessment performance with ball velocity, with an alpha level set at 0.05 a priori. The average throwing velocity was strongly correlated with the average peak trunk rotational velocity for the pitchers (r^2=0.69, p=0.011). The right and left medicine ball tosses were strongly correlated with throwing velocity as well (r^2=0.66, p=0.004; r^2=0.63, p=0.010, respectively). The trunk extension endurance, right side plank, and left side plank tests did not have significant correlations with throwing velocity (r^2=0.025, p=0.942; r^2=-0.221, p=0.539; r^2=-0.053, p=0.884, respectively). This result stresses the importance of trunk rotation velocity when trying to generate higher throwing velocities. This study will help to emphasize the impact the trunk can have on overarm baseball throwing and ultimately contribute to a better overall understanding of the baseball throwing motion to increase performance.

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Chapter 1

Introduction

Throwing is a rotational movement of the arm that is used to propel an object toward a desired target. This movement is commonly used in everyday life as well as in sports such as baseball, softball, and tennis. Baseball pitching is a specific class of the overarm throw that requires the generation and transfer of power from the legs to the trunk to the arms to generate ball velocity. Pitching is a very complex movement that places unique demands on the entire body, so it is of biomechanical significance to understand these demands. Recent research has indicated that scapular, thoracic, lumbar and lower extremity regions each have direct influences on throwing performance and injury risk. In the past, research has been directed towards the primary joints involved in throwing, that of the shoulder[1-4], elbow[5-8], and wrist[9]. While researching primarily the distal segments of the body has led to many breakthroughs for understanding the nuances of throwing[10-15], much work needs to be done to quantify the trunk contributions to throwing performance.

The trunk is a region that performs many functions, and therefore tests must be used to assess the different functions it possesses. One of the primary roles the trunk plays is the generation of power. One of the primary tests used to evaluate trunk power is a medicine ball throw. According to a study by Stodden (2008), the medicine ball throw was the test that generated the largest angular trunk velocity[16]. It is hypothesized that this test would be the best predictor of trunk rotary power because generating velocity is an important component of power. Another function of the trunk is to provide endurance. To assess trunk endurance, a trunk extension test and side planks were performed. The trunk extension endurance test followed the protocol for the Biering-Sorensen test. This test has been proven to be a suitable evaluation of lower back trunk musculature endurance[17,18]. A study by McGill et al (1999) recognized the side plank endurance test as a quality test to evaluate the trunk endurance and ratio of endurance capabilities of a person[19]. Based on the literature, this battery of trunk endurance tests should be a quality estimate of the athlete's trunk endurance, giving insight into their overall endurance level as well as any asymmetry issues for them.

The kinetic chain is defined as the sequential movement of body parts starting with the proximal segments and optimizing the timing of muscle contractions for different segments as the power generated reaches the distal segments[20,21]. The kinetic chain is one of the mechanisms that the body uses to effectively transfer the power generated in the lower extremity to the upper body. For pitching, it is understood that power must be generated using the legs and transferred to the upper extremity, but the mechanisms for optimal transfer of energy are unknown[22]. It is believed that the trunk is a launching pad for the extremities to operate off and gain power from. To illustrate this, Santana et al (2007) reported that the limiting factor for a standing bench press was the contralateral trunk musculature[23]. Therefore, someone lacking in trunk stability will be limited in performing a task involving the extremities, despite the strength of the extremity. One of the difficulties with the analysis of the trunk is its multifunctional nature. Pitching requires maximal upper extremity power generation, thus the purpose of this study was to investigate a variety of functional assessments of the trunk to determine their implications to pitching performance. With pitching, the trunk must act to stabilize the body to allow for the arm to undergo a whipping motion to generate velocity. The trunk must also act to effectively transfer the power generated in the lower extremity up through the arm. Therefore, assessments were done to determine each athlete's trunk power and trunk endurance to determine whether or not either type of task had a relationship with pitching velocity.

Statement of the Problem

The purpose of this research was to better understand the trunk contributions to pitching velocity.

Research Hypothesis

It was expected that overhead throwers demonstrating greater trunk functional assessment performance would generate greater ball velocity during pitching. It was also predicted that pitchers with a higher transverse rotational velocity in the trunk would throw with a higher ball velocity.

The dependent variables in this study were

- Peak ball velocity (mph)
- Peak transverse trunk rotational velocity
- Medicine ball toss distance
- Trunk extension endurance time
- Side plank endurance time

Operational Definitions

- Peak transverse trunk rotational velocity was the highest data value of trunk rotation in the transverse direction between stride foot contact and ball release;
- Peak transverse trunk rotational velocity used for this analysis was the average peak from all five throws;
- Medicine ball toss distance was the highest data value for each side of throws attempting to reach a maximum distance;
- Medicine ball toss for the right side was emulating a right handed batting stance;
- Trunk extension endurance time was the amount of time the athlete is able to maintain the unsupported upper body in a neutral position with legs fixed to a table[18];
- Side plank endurance time was the amount of time the athletes was able to maintain the position of laying on one side with elevated hips supported by their feet and arm forming a straight line from the top shoulder to the feet[19];
- Side plank for the right side was when the right arm is supporting the body;
- Peak ball velocity was the average ball velocity from the five analyzed trials once the ball is released from the hand.

Assumptions

- The high-speed cameras, Vicon MX-F40 (Vicon Motion Systems Ltd., Oxford, England) and the Bertec Force Plates (Bertec Corporation, Columbus, Ohio) were accurately calibrated during the experiments;
- The subjects performed the procedures as instructed by the researcher.

Limitations

- The measurements were taken in a laboratory setting, which may not exactly mimic a "real life" situation;
- The participants in this study were limited to high school baseball players;
- Each subject had varying degrees of sport experience and years of competitive experience that may influence their throwing ability;
- This study was limited to baseball pitching.

Delimitations

- This study used high school baseball players who have pitched competitively;
- The subjects ranged in age from 14-18 years of age;
- There were no females used in this study;
- Any player demonstrating injury or an inability to produce maximum effort was not be included in this study;
- All players included in the study were active high school baseball players
- Players who did not utilize an overhead throw were excluded from the study

Chapter 2

Review of the Literature

The following review of literature will focus on baseball pitching and the associated concerns: participation, anatomy breakdown, and biomechanical considerations. These have been theorized to be important factors in understanding the mechanisms involved in baseball throwing performance. While many studies have focused on various aspects of the body during baseball pitching, there is a need to better understand the specific contributions of the trunk to baseball throwing velocity.

United States Baseball Participation and Epidemiology

In 2012, there were 13.6 million participants in baseball in the United States[24]. Of this number, 66% of these players were under the age of 25[24]. Of these players under the age of 25, 476,000 participated in high school baseball during the 2012-2013 school year[25]. According to Janda et al (2003), baseball ranks third behind basketball and football in annual injuries to children[26]. Collins et al (2008) compiled high school baseball injury data during the 2005-2006 and 2006-2007 school years resulting in a reported rate of 1.26 injuries per 1000 athletic exposures[27]. A recent survey of players during the 2012-2013 school year showed 161 injuries in 182,376 exposures, resulting in a rate of 0.88 injuries per 1000 exposures[28]. This same study estimated a total of nearly 50,000 injuries for high school baseball players that year[28]. A study of shoulder injuries among high school baseball players showed 179 injuries per 1,203,807 exposures between the 2005-2006 and 2011-2012 school years. This resulted in an injury rate of 0.149 shoulder injuries per 1000 exposures[29]. A study by Krajnik et al used data from 2005-2008 to show a similar exposure rate of 0.172 shoulder injuries per 1000 exposures[30]. The 2008 study by Collins et al showed that 17.6% of injuries were to the shoulder and 13.6% of injuries were to the elbow, with 41.1% of the total injuries being to ligaments and muscles[27]. They reported that 60.3% of injuries to pitchers were non-contact injuries with 53.1% of injuries sustained to either the shoulder or elbow[27]. Cain et al (2010) showed that of the 1210 ulnar collateral reconstructions performed over 19 years for baseball players by Dr. James Andrews, 89% of the players were pitchers[31]. While much of the current research assesses shoulder and elbow injuries and injury mechanisms, it is important to understand how other aspects of the body contribute to throwing. Improving the overall understanding of throwing mechanics and performance can eventually lead to new ways to prevent injuries in baseball throwers and better address their rehabilitation strategies.

Anatomy

Shoulder

The primary bony features comprising the shoulder complex are the clavicle, scapula, and humerus. The bones act to create three primary joints, the glenohumeral, acriomoclavicular, and sternoclavicular joints. In order to effectively perform overhead sports, a fully active and coordinated motion of these joints is required[32]. The scapula has several primary functions when acting in the shoulder all working to maintain appropriate positioning of the shoulder complex. The scapula must preserve a stable glenohumeral articulation. In order to promote proper throwing mechanics, the scapula must properly retract, allowing for cocking of the baseball, and protract, which allows for proper acceleration forward. The scapula must also properly elevate the acriomion to allow for the rotator cuff to have a proper amount of space during arm rotation[33]. Kibler (1994) reported 54% of the total force generated in the arm is developed proximally and must be maintained through proper rotation of the scapula, thus indicating that the scapula plays a vital role in maintaining the progression of energy throughout the kinetic chain during overarm motion[34]. The labrum also plays an important role as it is the fibrocartilage structure which allows for smooth rotation of the glenohumeral joint[35].

In terms of shoulder musculature, the three primary movers of the arm are the pectoralis major, latissimus dorsi, and deltoid muscles. There are also four muscles that originate on the scapula and act to provide rotation and are commonly called the "rotator cuff": supraspinatus, infraspinatus, teres minor, and subscapularis. The serratus anterior of the anterior thorax muscle group works to protract the scapula while the trapezius, levator scapulae, and rhomboid muscles of the posterior thorax group act to retract the scapula[36]. According to a study by Zaremski and Krabak, a primary mechanism for shoulder injuries is excessive stress on the shoulder stabilizing muscles[15]. It is also believed that weakened posterior shoulder musculature combined with overdeveloped anterior musculature can over propel the arm and lead to injury due to the lack of arm eccentric deceleration control[37].

Elbow

The primary bony features of the elbow complex are the humerus, ulna, and radius. The humerus meets with the ulna and radius to form the elbow joint. In terms of musculature, there are four main functions of the muscles of the elbow complex: flexion, extension, pronation, and supination[36]. The primary flexors of the elbow are the biceps brachii, the brachioradialis, and the brachialis. The primary extensors of the elbow are the triceps brachii and the anconeus. The muscles acting in the supination of the elbow are the biceps brachii and supinator, along with the brachioradialis having an accessory role. The pronator teres and pronator quadratus act to pronate the elbow[38]. The role of ligaments in the elbow is to provide joint stability and stabilize the articulation of the joint. The primary restraining ligaments of valgus loads are the ulnar collateral ligament (UCL) and the anterior capsule[31,39]. The UCL acts to contribute stabilization for 55% of the valgus stress created in the elbow. The primary restraints to varus loads are the lateral collateral ligament (LCL), anterior capsule, and the osseus structures forming the joint[39].

Lower Extremity

Beginning at the hip, the anterior muscles of the thigh and hip act to flex the hip and extend the knee. The primary flexors of the hip are the iliopsoas, tensor fasciae latae, and rectus femoris. These muscles are very important in the pitching motion because the leg raise motion utilizes these muscles to begin every pitch. In terms of hip extension, the gluteus maximus and the hamstring muscles play a major role. These are very important in the leg drive of the pitching motion. In order to extend the knee, the quadriceps femoris muscle must activate. The adductor and abductor muscle groups are also active during the pitching motion due to the leg rotation taking place. These muscles help to rotate the pelvis to optimize the kinetic chain and generate the necessary rotational velocity[36].

Trunk

The trunk is defined as the anatomical region bordered superiorly by the diaphragm, inferiorly the pelvic floor, anteriorly the abdominal musculature, and posteriorly the paraspinal musculature[40]. This trunk region acts to maintain stability in the body to help resist perturbations and to provide a steady base against which the extremities can generate force[41,42]. The anterior abdominal musculature consists of the rectus abdominus, transverse abdominus, and the internal and external obliques. The rectus abdominus acts to flex and rotate the trunk. The internal and external obliques primarily act to laterally rotate the trunk. The transverse abdominus acts to compress the abdominal region and stiffen the torso and lumbar region. The muscles of the pelvic floor consist of the levator ani and the coccygeus. These muscles act to provide stability for the pelvic region. This is important because it allows for a stable base for the extremities to move from. The final piece of the trunk musculature that has relevance to the pitching motion is the lumbar muscle group. The erector spinae is one of the most prominent muscles that help to extend the back, prevent forward bending, and promote an erect spinal position[36]. Muscles such as the iliocostalis and the longissimus also assist in maintaining proper posture, which can be important during the pitching motion because excessive trunk tilt has been shown to increase injury risk in the upper extremity [43].

The musculature in the trunk also functions in a method that allows for rotation and anti-rotation. A study by Kavcic et al (2004) performed a variety of trunk endurance tests on subjects to determine the activation of different musculature [44]. During side bridge tasks, they observed that the trunk muscles on one side of the body remained dominant, but for multiple reasons. They determined that the muscles were not only acting to hold up the body and create their own force, but they also needed to oppose the forces generated by the opposing side [44]. This was important because if either of these tasks were not achieved, there would be an imbalance and instability would result. A study by Cholewicki and McGill also showed similar results, testing a power lifter who had an injury during a workout. They were able to show that certain muscles were not accurately promoting stability by resisting opposing forces, and this resulted in improper posture which caused the injury [45]. A balance between both sides of the musculature must be maintained, so it is important for athletes to not only have adequate strength, but to also show proper symmetry between musculature.

Biomechanical Contributions to Throwing

Shoulder

The shoulder plays a significant role in the pitching motion, as the glenohumeral joint is the primary rotation joint for overhead throwing[4]. This makes it a very important aspect of the biomechanics of the throwing motion, with much of the current research dedicated to shoulder kinetic and kinematic functions. According to a study by Keeley et al, increased peak proximal force experience by the shoulder was a significant predictor of shoulder pain ($p = 0.001$)[1]. This is the sum of the forces that the torso is applying on the upper extremity, so the shoulder must properly transfer the entire proximal load to the distal arm. They hypothesized that the repetitive pitching motion causes microtrauma to the labrum, and this repetitive microtrauma is causing the increased risk for shoulder injury in baseball throwing athletes[1]. Another common area of interest is the range of motion properties of the shoulder. An increased external range of motion has been shown to decrease the load experienced by the elbow during pitching. This suggests that increasing the external rotation flexibility of the shoulder can assist in limiting the injury risk for pitchers[2]. Shanley et al also showed that decreases in passive horizontal adduction and internal rotation moments have also been shown to be correlated to shoulder injury risk. They reported that players with a 25° deficit in their dominant shoulder when compared with their bilateral shoulder were at a 4 to 5 times greater risk for shoulder injury[3].

Elbow

Moving distally from the shoulder, the elbow has the second highest injury rate per body part among baseball pitchers[27]. When pitching, the wrist flexor-pronators are the muscle group acting to create varus torque in the elbow [7]. The UCL is the structure that is believed to handle the greatest percentage, 50% of the varus torque in the elbow [8]. Fleisig et al (2009) demonstrated that the peak elbow varus torque is generated during the cocking phase when the shoulder is at maximal external rotation [8]. There has also been an established statistically significant association ($P = 0.0354$) between throwing velocity and injury in the elbow, with a small sample of players ($n=3$) who suffered a torn UCL who also happened to be the three players with the fastest recorded pitch velocities [6]. Theoretically this seems an intuitive expected result because generating a larger fastball velocity requires a greater amount of force, and the force must be transferred distally through the elbow to be exerted on the ball. Valgus torque on the elbow has a significant positive correlation with maximum shoulder external rotation ($r=0.60$) and elbow valgus loading rate ($r=0.74$). Elbow valgus torque had a significant negative correlation with a delayed onset of trunk rotation ($r=-0.24$), delayed maximum elbow flexion time ($r=-0.32$), and elbow flexion angle at peak valgus torque ($r=-0.36$) and ball release ($r=-0.35$) [46].

Lower Extremity

Although it is believed to be an important aspect of the throwing motion, a minimal amount of research has been published regarding the lower extremity contribution to pitching performance and injury. Elliott et al (1988) reported some of the earliest data examining the lower extremities contribution to baseball throwing performance. They examined the timing of the lower extremity during pitching and showed that pitchers throwing with greater velocity generated larger resultant ground reaction forces during stride foot landing, while pitchers with lower velocities had larger resultant ground reaction forces earlier in the motion, although there were no statistical significance between the timing of ground reaction forces and throwing velocity [47]. Another study by MacWilliams et al showed a strong correlation between ground reaction forces in the push-off leg and linear wrist velocity (r^2=0.76), suggesting the push-off leg plays an important role in ball velocity. This same study also showed a strong correlation between a higher landing resultant force and linear wrist velocity (r^2=0.88) [48]. A study by Guido and Werner investigated collegiate baseball pitchers and showed a correlation between the braking ground reaction force and ball velocity[49]. Another important aspect of the lower extremity contributions to pitching is stride foot angle and distance data. A study by Fleisig found the average stride foot distance to be 87% of the player's height within 10 cm in either direction of a centerline between the pitchers mound and home plate [50]. Pitchers with an open stride, that greater than 10 cm from the midline, were found to have as much as 3.0 Newtons of increased shoulder anterior force for every additional centimeter past 10, which is important because the elbow is already experiencing loads near the maximum level it can handle. Pitchers with a more closed stride were not found to generate greater kinetics [50,51]. A small amount of research has also been done examining the relationship between throwing velocity and lower extremity functional assessments. This study showed substantial correlations between lateral hops and throwing velocity[52]. While there has been enough research to show importance between the lower extremity and throwing velocity, it is an area that still has plenty of room for further study.

Trunk

The trunk acts as a proximal base for the movement of more distal segments in the body[21]. Myer et al (2008) hypothesized that implementing a training program to improve trunk control could help improve lower extremity function in female athletes after they were able to show the impact an ACL prevention program had on improving lower extremity function[53]. There has also been research done to show that when athletes specifically activate their core musculature their hip and knee kinematics improved during a single leg squat task [54]. This bolsters the argument that the kinetic chain plays a major role in promoting distal mobility. Athletes who are unable to have normal and adequate trunk function, both statically and dynamically, are at a greater risk for injury because the primary base for their extremity movement is unstable [55]. This has been shown to be true in a variety of sports. In terms of tennis, athletes showed prominent patterns of developing force and power in the lower extremity and allowing that power to propagate through the trunk to the upper extremity [56]. Soccer kicking also utilizes a similar mechanism, with the trunk initiating movement to allow for the legs to lag behind and generate greater power in the kick [20]. A study by Shan and Westerhoff (2005) confirmed this by reporting that upper body movement played a major role in allowing the leg muscles to contract with more power, thus generating a stronger soccer kick[57]. This similar type of mechanism is used in pitching with the upper extremity. When pitching, generating greater rotation in the trunk will lead to increased torques at the shoulder. This increased torque at the shoulder will ultimately lead to greater elbow torques to protect against the rotation generated at the shoulder [20]. Because shoulder and elbow proximal forces are strongly correlated with ball velocity, it is essential to generate the proper trunk rotation proximally to allow for the necessary distal rotation and forces [58]. The rate of axial torso rotation was also shown to account of 60% of the variance in the plane of shoulder elevation. Shoulder elevation is often related to overuse injuries in the shoulder, so the rate of axial torso rotation could be an indication of potential injury risk[4]. The timing of rotation also plays an important piece in the kinetic chain transfer of forces. Players who were able to properly time their peak pelvis angular velocity after stride foot contact had much better kinetic parameters [14]. This supports the theory that lumbopelvic control is essential for pitching, which was found in a study by Chaudhari et al[59]. This combined power and stability allows for the trunk to be the necessary base for the upper extremities to perform as needed. Without a proper base with which movement begins, the desired results of the athlete will not be achieved.

Chapter 3

Introduction

The baseball pitching motion is a very complex movement that places unique demands on the entire body, so it is of biomechanical significance to understand these demands. Recent research has indicated that scapular, thoracic, lumbar and lower extremity regions each have direct implications on throwing performance and injury risk. In the past, research has been directed towards the primary joints involved in throwing, that of the shoulder[1-4], elbow[5-8], and wrist[9]. While researching primarily the distal segments of the body has led to many breakthroughs for understanding the nuances of throwing[10-15], much work needs to be done to quantify the trunk contributions to throwing performance via the kinetic chain.

The kinetic chain is defined as the sequential movement of body parts starting with the proximal segments and optimizing the timing of muscle contractions for different segments as the power generated reaches the distal segments[20,21]. The kinetic chain is one of the mechanisms that the body uses to effectively transfer the power generated in the lower extremity to the upper body. For pitching, it is understood that power must be generated using the legs and transferred to the upper extremity, but the mechanisms for optimal transfer of energy are unknown[22]. It is believed that the trunk is a launching pad for the extremities to operate off and gain power from. To illustrate this, Santana et al (2007) reported that the limiting factor for a standing bench press was the contralateral trunk musculature[23]. Therefore, someone lacking in trunk stability will be limited in performing a task involving the extremities, despite the strength of the extremity.

One of the difficulties with the analysis of the trunk is its multifunctional nature. One of the primary roles the trunk plays is the generation of power. One of the primary tests used to evaluate trunk power is a medicine ball throw. According to a study by Stodden (2008), the medicine ball throw was the test that generated the largest angular trunk velocity[16]. It is hypothesized that this test would be the best predictor of trunk rotary power because generating velocity is an important component of power. The trunk must also have strong enough endurance to maintain correct posture and adequate bodily function throughout an entire athletic contest. To assess trunk endurance, a trunk extension test and side planks were performed. The trunk extension endurance test followed the protocol for the Biering-Sorensen test, a validated assessment of lower back trunk musculature endurance[17,18]. A study by McGill et al (1999) recognized the side plank endurance test as a quality test to evaluate the trunk endurance and ratio of endurance capabilities of a person[19]. Based on the literature, this battery of trunk endurance tests should be a quality estimate of the athlete's trunk endurance, giving insight into their overall endurance level as well as any asymmetry issues for them. Pitching requires maximal upper extremity power generation, thus it is important to further investigate different factors that can lead to adequate power generation. With pitching, the trunk must act to stabilize the body to allow for the arm to undergo a whipping motion to generate velocity. The trunk must also act to effectively transfer the power generated in the lower extremity up through the arm. Therefore, the purpose of this study is to better understand the trunk contributions to the pitching motion. This will consist of quantifying the trunk rotation during the pitch as well as assessments to determine each athlete's trunk power and trunk endurance to determine whether or not there is a relationship between these factors and pitching velocity.

Methods

Before participation, Institutional Review Board consent was obtained by all subjects. The study consisted of 11 male high school pitchers (16.63 years, 71.98 ± 2.58 inches, 172 ± 17.12 lbs). These athletes were free of lower or upper extremity injury within the last six months. Athletes were allowed to perform any normal warm-up procedure to ensure they were ready to pitch and comfortable with the laboratory setting. The players were asked to throw 15 fastball pitches from a custom built pitching mound to allow for 3D biomechanical data collection. The mound was custom built to allow for the use of force plates to collect ground reaction data. The mound consists of six sections, four of which screw directly into separate force plates, and two runners on the side to give the pitcher an easier landing zone should they deviate from center. The pitchers were asked to throw only fastballs, so as to keep everything consistent among pitchers and to better assess natural throwing velocity. The final five pitches were analyzed to ensure that each pitcher was fully comfortable with the mound and lab setup. The pitching mound is situated over four force plates (Bertec Corporation, Columbus, Ohio) and the athletes pitched into a net approximately 9 meters from the pitching mound. The velocity of each pitch was tracked and recorded using a radar gun (Bushnell, Overland Park, Missouri). While pitching, the athletes had 54 reflective markers placed on anatomical landmarks to track their movement. The markers were tracked by ten Vicon MX-F40 motion capture cameras at a frame rate of 300 Hz. Ground reaction force data were collected at a sampling rate of 1500 Hz.

In addition to the pitching, the athletes were asked to perform a battery of functional assessments. These tests consisted of a combination of trunk power and trunk endurance tests. To test trunk power, athletes were asked to do a medicine ball throw. The athletes assumed their typical batting stance with a 6 lb. medicine ball. They then threw the ball as far as they could

(Figure 1). This test assessed how effectively they could transfer power from their legs up their trunk to their arms. There were also three different trunk endurance tests. The first test was the Biering-Sorensen test, one that assessed posterior trunk endurance. Subjects lay prone with their legs and hips on a table. With their legs supported, they were then told to lift their upper body so that they maintain a straight line as long as possible (Figure 2). The second and third tests were side planks for each side, which was a test for lateral trunk endurance. The subjects were required to maintain a straight line from their shoulders to their ankles without any rotation or lowering of the hips (Figure 3).

Statistical Analysis

Statistical analysis was completed using SPSS (version 17; SPSS Inc, Chicago, IL). Graphs were generated using Microsoft Excel (2010). A partial correlation was used to control for both height and weight. An alpha level was set *a priori* 0.05.

Results

The average throwing velocity was strongly correlated with the average peak trunk rotational velocity for the pitchers (r^2=0.69, p=0.011). This correlation can be seen in Figure 4. Figures 5 and 6 show that the distances thrown in the right and left medicine ball tosses were strongly correlated with throwing velocity as well (r^2=0.66, p=0.004; r^2=0.63, p=0.010, respectively). Figures 7-9 show that the trunk extension endurance, right side plank, and left side plank tests did not have significant correlations with throwing velocity (r^2=0.025, p=0.942; r^2=-0.221, p=0.539; r^2=-0.053, p=0.884, respectively).

Discussion

The results of this study stress the importance of the trunk during pitching. Based on the results, the transverse trunk rotation accounted for 69% of the variability in ball velocity for the pitchers. This strongly supports the theory that the trunk plays a major role in transferring power from the lower extremity to the upper extremity for ball release. If a player is unable to utilize the power created in their lower extremity to create trunk rotation, they likely will not be able to throw the ball with a high velocity relative to a player that is able to create the rotation. In addition to the performance aspect, this supports the idea that the trunk can play a major role in rehabilitation strategies. If an athlete is returning from injury, the trunk will be a primary source for rehabilitation, regardless of where the injury is at. Based on the results of this study, if pitchers are trying to return to play and are unable to generate powerful trunk rotations then any work they have done on recovering the injury will be somewhat wasted because they are still lacking in a primary aspect of throwing.

The second piece of the study examined the relationship between functional trunk assessments and throwing velocity. The primary finding here was that the medicine ball throw from the right side was strongly correlated with throwing velocity. This was the expected result because both pitching and the medicine ball toss require the generation of power in the lower extremity and the transfer of that power through the trunk to either throw the baseball or medicine ball. The three endurance tests were not highly correlated with pitching velocity. This emphasizes that the pitching motion is much more about the generation of kinetic chain trunk power and less about trunk endurance. The pitching motion is an event that typically takes less than four seconds total from beginning of wind up to end of follow through motion, with even less of that time in an active motion trying to create ball velocity. It is likely that these tests were not highly correlated with pitching velocity because they examined only trunk endurance, which is not required when looking at only one inning.

The results regarding the trunk power assessment agree with the results by Stodden et al showing that the medicine ball toss was a similar task to pitching in terms of trunk velocities generated[16]. Based on the idea that power is the product of force multiplied by velocity, an athlete generating more velocity will generate more power. When a pitcher is able to effectively generate power in the trunk, they are likely to be able to generate greater power in the distal arm, which allows them to assert more force on the baseball. The study by Stodden et al in 2005 also would suggest that trunk rotation is essential because the way distal rotation and force generation helps to create larger proximal forces [58]. The results regarding the medicine ball toss and trunk power generation support what they have found. This generation of velocity on the baseball is an important aspect in the success of a baseball pitcher, so trunk power training should be an integral piece in all strength training programs.

The results from the trunk endurance tests were relatively surprising. As the study by Kavcic et al (2004) determined, the trunk muscles need to create their own force and oppose forces generated by the opposite side [44]. Intuitively, this should be important during pitching because the whip motion generates large forces that must be withstood to keep the pitcher upright. Trunk muscular endurance tests were used to determine if the proper balance of musculature were present, but the results here did not provide any correlation between having muscular endurance and being able to produce higher ball velocities. It is likely that when looking at just one inning of pitching, trunk endurance is not necessary for high performance. The study by Chaudhari et al regarding lumbopelvic control suggests that a pitcher with improved lumbopelvic control will be more successful[59]. This study, combined with our results, suggest that trunk control is more important than trunk endurance when looking at the pitching motion. Also, one difference between that study and this study is that they looked at actual pitching performance in games as opposed to pitching velocity, which is simply an aspect of pitching performance. It is possible that increased trunk endurance and control can lead to better control during pitching, but not necessarily improved velocity. Both are important aspects of pitching, and a player must have the proper balance of both in order to be successful.

There are a few ways that this study can be expanded upon in the future. First, this study only examined the first five pitches in the first inning. This requires very little endurance for the pitchers to complete the inning. It is possible that the endurance tests could play a more important role when looking later in a game. A potential future study could look at how well pitchers are able to maintain velocity throughout a simulated game and see how that relates to performance on trunk endurance tests. Another potential study could be to look deeper into validated trunk assessments to find tests that will better analyze trunk stability, and not necessarily endurance. It is possible that there is a trunk stability test that can better correlate with throwing velocity, as some level of stability is required to keep the pitcher upright while generating such high angular velocities. We have established the importance of being able to generate rotational power, but not much has been done to further examine stability. Finally, studies can continue to look at the timing aspect of the trunk in the pitching motion. When players begin their trunk rotation and when they reach their peak trunk rotation could both play critical roles in generating power and throwing velocity. Some work has already been done in examining timing of the throwing motion, but more can be done to incorporate the relationship between timing and different factors such as ground reaction forces and how forces are effectively transferred through the kinetic chain.

Figure 1

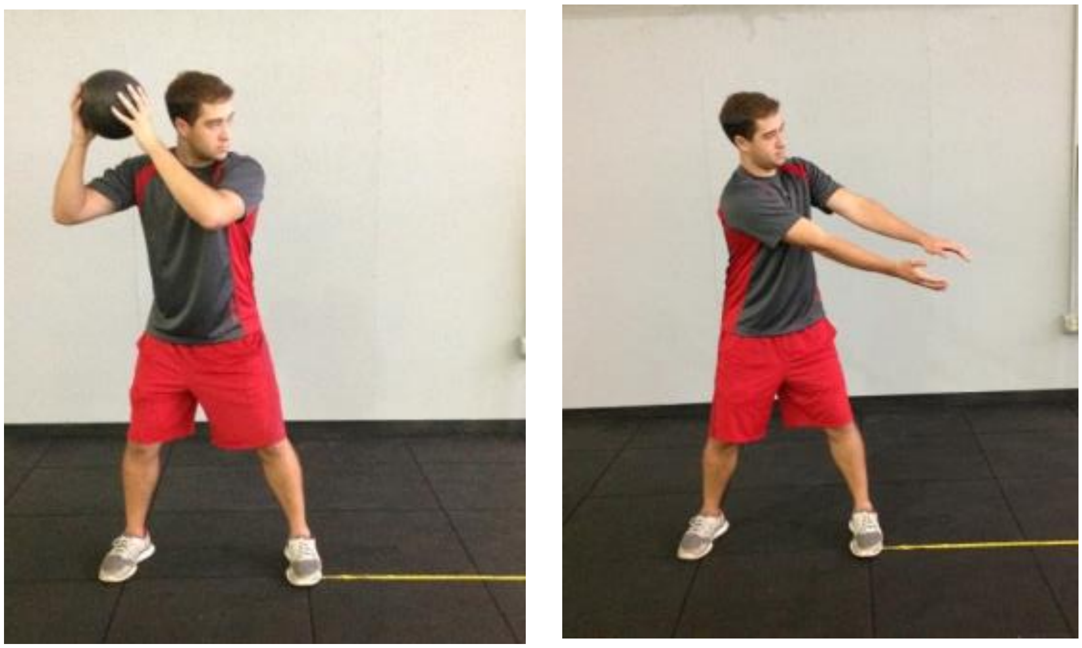

Figure 1: Medicine ball toss from the right side.

Figure 2

Figure 2: Trunk extension endurance test.

Figure 3

Figure 3: Side plank endurance test for the right side.

Figure 4

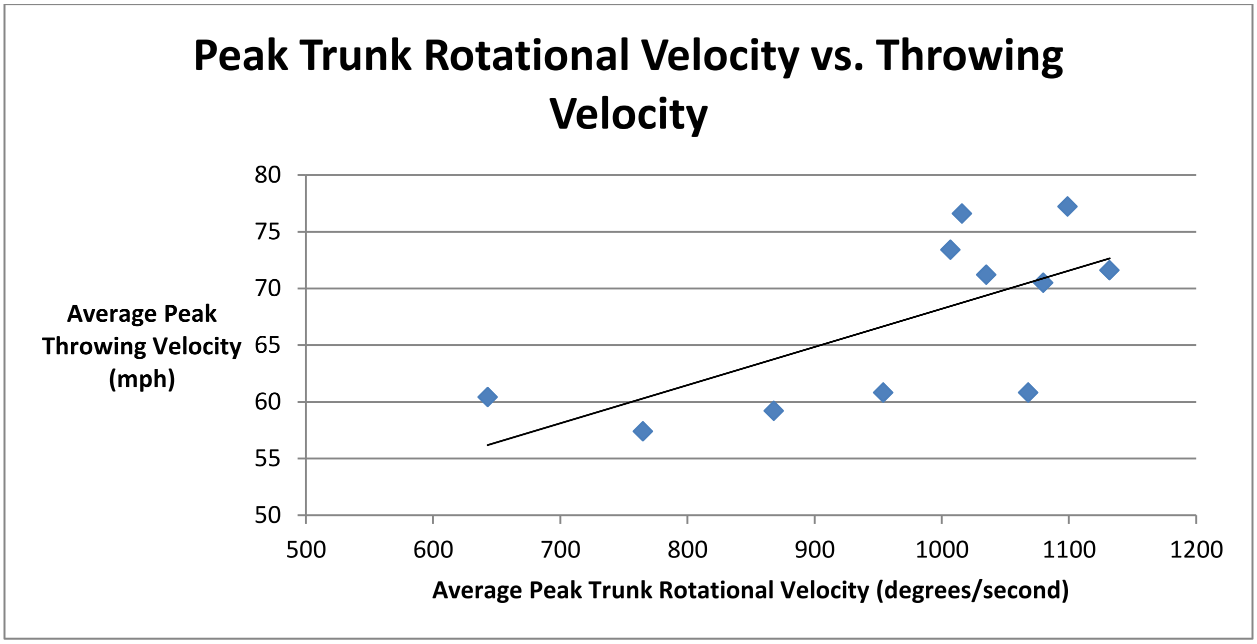

Figure 4: Average peak trunk rotational velocity during the pitch (degrees/second) versus the average peak throwing velocity (mph).

Figure 5

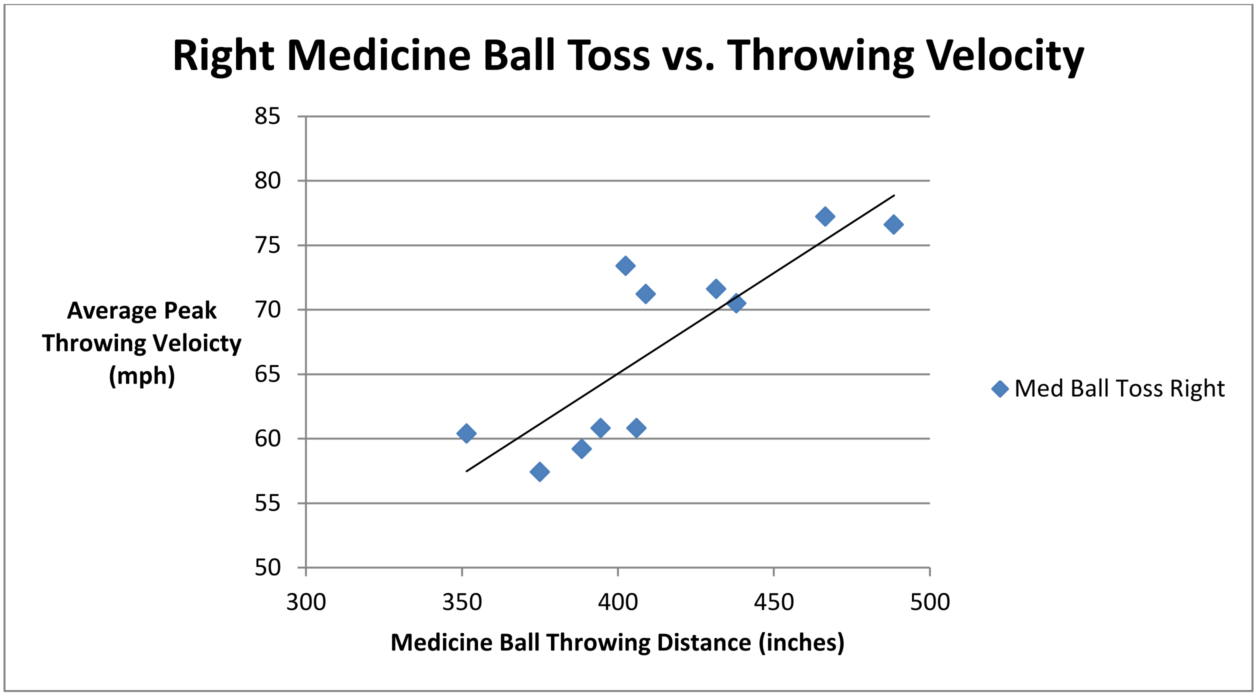

Figure 5: Right side medicine ball throwing distance (inches) versus the average peak throwing velocity (mph).

Figure 6

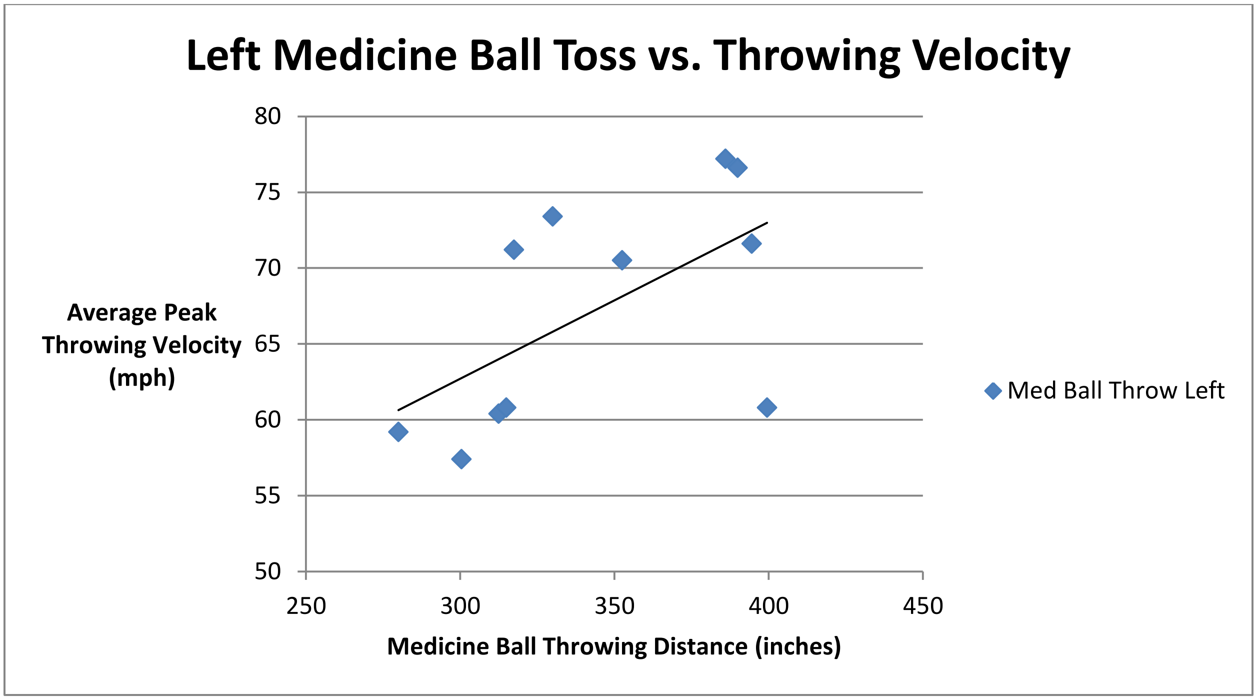

Figure 6: Left side medicine ball throwing distance (inches) versus the average peak throwing velocity (mph).

Figure 7

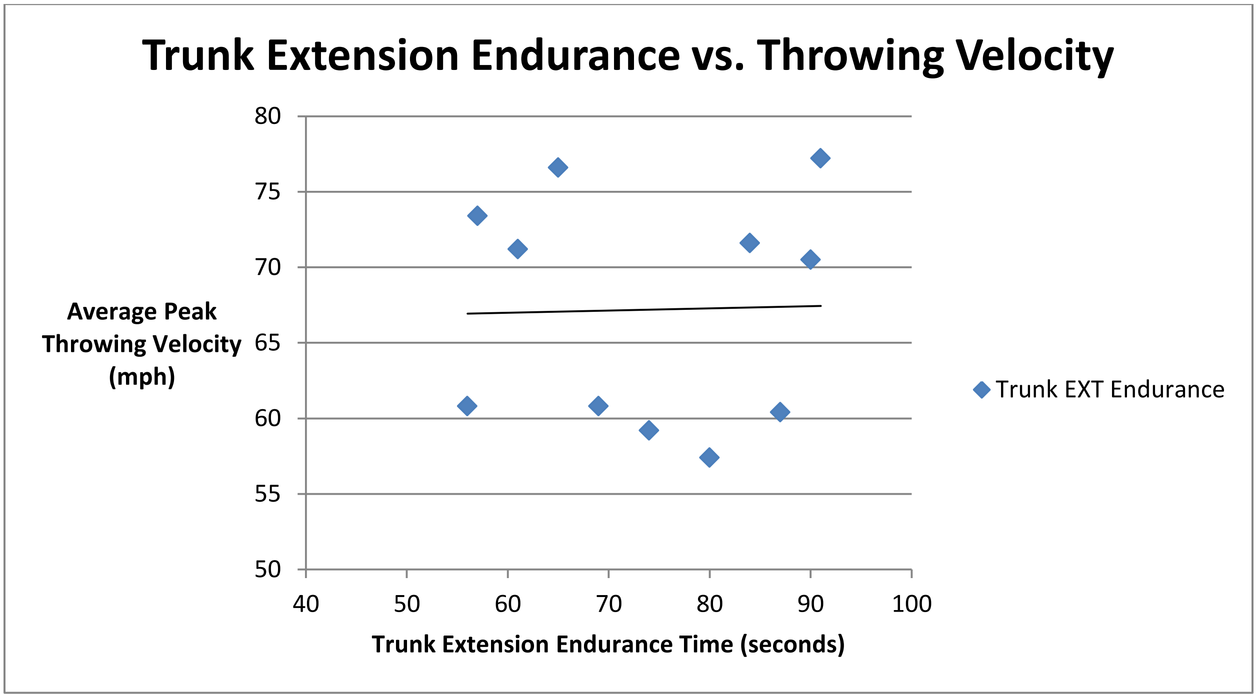

Figure 7: Trunk extension endurance time (seconds) versus the average peak throwing velocity (mph).

Figure 8

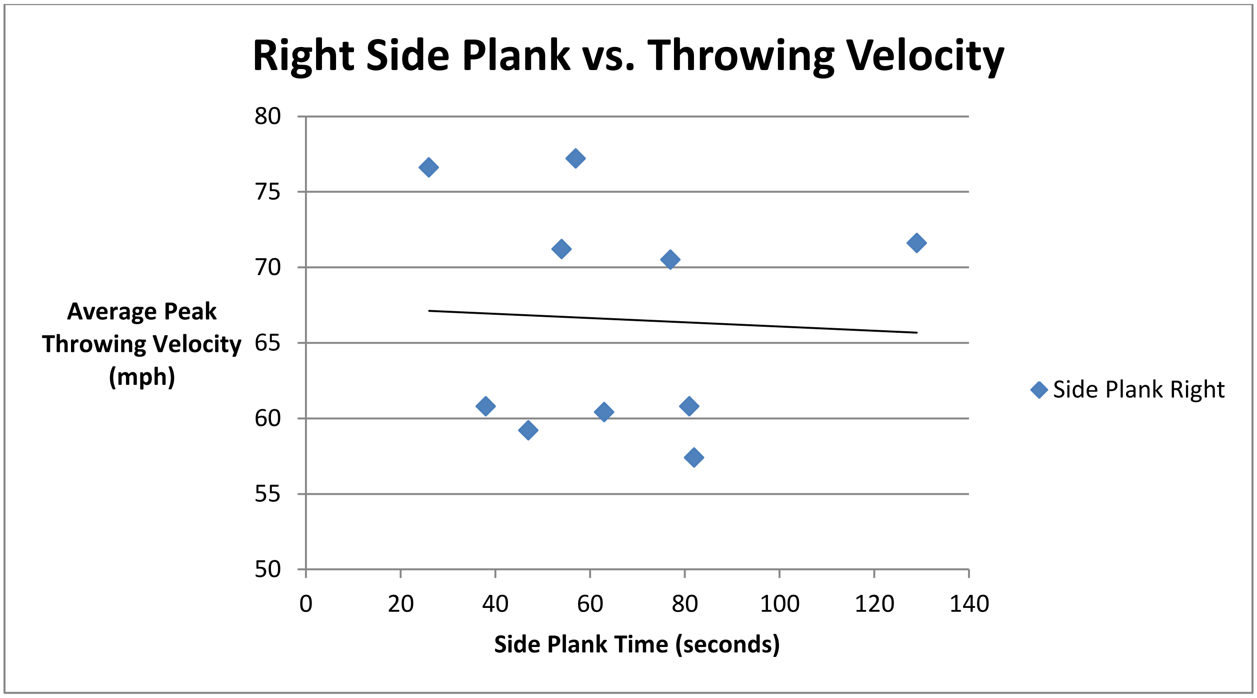

Figure 8: Right side plank endurance time (seconds) versus the average peak throwing velocity (mph).

Figure 9

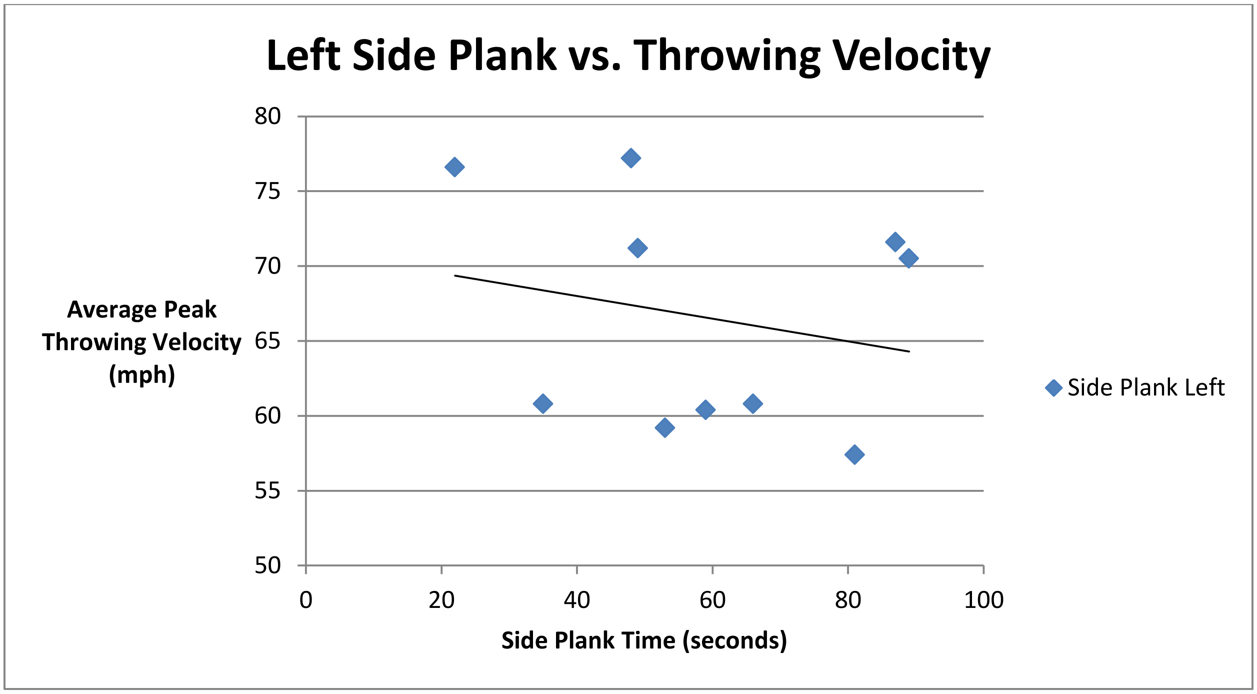

Figure 9: Left side plank endurance time (seconds) versus the average peak throwing velocity (mph).

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