Effect of Core Strength on the Measure of Power in the Extremities

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A Thesis

Presented to

The College of Graduate and Professional Studies

Department of Athletic Training

Indiana State University

Terre Haute, Indiana

In Partial Fulfillment

of the Requirements for the Degree

Athletic Training

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by

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December 2010

Keywords: Core strength, muscular power, trunk strength, athletic performance, core muscles, trunk muscles

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ABSTRACT

The purpose of this study was to determine the effects of core strength on the transfer and production of forces in the extremities. Twenty-five division 1 collegiate football players performed a series of medicine ball throws in the forward, reverse, right and left directions in a static and dynamic position. The results of the medicine ball throws were compared to several athletic performance measurements including: push press power, 1RM squat, 1RM bench press, countermovement vertical jump, broad jump, 40 yard dash, 20 yard dash, pro agility to the right and left, and the L drill. Several strong correlations were found in both the static and dynamic medicine ball throw positions when compared to the performance measures. Static reverse correlated with vertical jump (CMJ) (r=0.44), broad jump (BRD)(r=0.5) and push press power (PWR)(r=0.46). Static left (StL) and static right (StRi) correlated with PWR (r=0.59), (r=0.65) respectively, and Vel (r=0.52)(r=0.6), respectively. Fewer dynamic throws correlated significantly with the performance variables. Dynamic left (DyL) and Dynamic right (DyRi) correlated with PWR (r=0.53), (r=0.63) respectively, and Vel (r=0.55),(r=0.61) respectively. Dynamic forward (DyFw) correlated with the 1RM squat (r=0.45). A stepwise regression for push press power prediction reveals that 1RM squat is the best predictor of push press power. The results indicate that core strength does have a significant effect on the ability of an athlete to create and transfer forces in the extremities.

ACKNOWLEDGEMENTS

A special thank you goes to the members of my committee for being patient with me throughout this process. I really truly appreciate everything that they have done for me and am eternally indebted to them. Thanks for everything guys.

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CHAPTER 1

Introduction

Currently there is a lack of research that focuses on the dynamic strength and power aspect of core stability. The literature shows the importance of having a strong core in relation to static and isokinetic endurance times and the prevention of injury [1], [2], [3], [4], [5]. Some researchers even make strong claims for improved performance [6] [7] [8] [9-10], but the majority of these claims are made in the lay population where the functional demands of the core do not mirror what is demanded of the athletic population. However, most athletic events are dynamic in nature incorporating the transfer of energy from the lower body to the upper body. Currently, there has been no attempt to compare the upper and lower body power capabilities to core strength and power. It is strength and power that is an athlete's greatest asset in terms of performance. If an athlete cannot generate a powerful motion in the core it will not be transferred to the extremities.

It has been theorized that a strong core will allow a transfer of forces from the lower body to the upper body with a minimal dissipation of energy in the torso [11]. If power is created but not transferred, performance will be affected. Therefore, the purpose of this study is to develop a functional field test for core strength and power. Then compare the core strength to the measures of strength from the extremities to determine the effect core strength on extremities function.

Definitions

- *Muscular Core:* a box with the abdominals as the front, paraspinals and gluteals in back, the diaphragm as the roof, obliques as the sides, and the pelvic girdle and hip girdle musculature serving as the bottom. [8, 12]
- *Core stability*- the body's ability to control the position of the trunk and pelvis for optimum production, transfer and control of functional activities [9].
- *Core strength* -the muscles surrounding the spinal column's ability to maintain stability while acting on an external perturbation [12].
- *Static muscle action:* Action of muscle that does not produce a movement of the skeletal system. [13]
- *Dynamic muscle action:* Action that produces movement of the skeletal system.

Delimitations

Subjects have to meet requirements set by the researchers. The subjects have to be able to lift at an experienced level and not have injuries that may decrease their performance. All eligible subjects must be between 18-25 years of age, and perform a minimum of three hours of resistance training weekly. Within their weekly training regimen the subject must perform Olympic style lifts in combination with medicine ball training.

Limitations

The study will take place on the campus of Indiana State University.

Hypothesis

It is believed that the dynamic strength and power of an individual's core will have an overall effect on the performance capabilities of the upper and lower extremities. An individual who has a dynamically strong and powerful core will be able to transfer forces to the extremities more efficiently. The efficiency of the core will facilitate a better performance in the upper and lower extremity strength measures.

Assumptions

The researchers will assume that the subjects will perform to the best of their abilities in all aspects of our study.

CHAPTER 2

Review of Literature

Anatomy of the Core

The human core has several different anatomical definitions as to what actually constitutes the "core" of the body. The simplest definition is that the core is a box with the abdominals as the front, paraspinals and gluteals in back, the diaphragm as the roof, and the pelvic girdle and hip girdle musculature serving as the bottom [8, 12]. There is one vital aspect of the core that is not addressed by this definition which is the obliques and latissimus dorsi acting on the sides of the box, but this definition is still very true to the actual structure of the core in the way it acts and is structured. Bergmark's definition of the core is focused more on muscular actions rather than true anatomical structure. This definition breaks the core musculature into global and local muscles as they act on the lumbosacral spine[45].

The local muscles are the "stabilizing" system. They are deeply placed, aponeurotic, slow twitch in nature, most active in endurance natured activities, have poor recruitment patterns, activate at low resistance levels (postural adjustments), and lengthen when activated [14]. This muscular system can be divided into primary and secondary muscles. The primary muscles are the main stabilizers of the spine which include the transverse abdominus (TA) and multifidi [8, 14]. The secondary muscles are the secondary stabilizers of the spine, but also have a secondary movement action. The secondary muscles include the internal oblique (IO), medial fibers of external oblique (EO), quadratus lumborum (QL), diaphragm, pelvic floor muscles, iliocostalis and longissimus [8 12]. There is some debate in the literature over whether or not the QL is a major stabilizer of the spine, rather than a secondary stabilizer.

Global muscles or the "movement" system are superficial, fusiform, mainly fast twitch in nature, active in powerful activities, have the preferred recruitment pattern, shorten and tighten when activated at higher resistance levels [14]. This system is primarily responsible for producing movement and torque of the spine [14]. Global muscles are capable of producing high amounts of torque due to the size of the lever arms they possess [14]. These lever arms also help to cope with external loads as they transfer the perturbations to the local muscles. The global muscles are: rectus abdominus (RA), lateral fibers of external oblique (EO), psoas major, erector spinae (ES), thoracic portion of the iliocostalis.

Table 1 Anatomy of the Core

Passive Musculoskeletal	**Active Musculoskeletal**	**Neural and Feedback**
Vertebrae Facet articulations Intervertebral discs Spinal ligaments Joint capsules.	All muscles and connecting tendons surrounding spinal column.	All proprioceptors located in the passive and active systems along with their neural control units. Panjabi (1992)[15]

Panjabi divides the core into three subdivisions; the passive musculoskeletal subsystem, active musculoskeletal subsystem, and neural and feedback subsystem[15]. The passive musculoskeletal subsystem consists of the vertebrae, facet articulations, intervertebral discs, spinal ligaments and joint capsules. The active musculoskeletal subsystem is the muscles and tendons surrounding the spinal column. The neural and feedback subsystem includes all the proprioceptors in the ligaments, tendons, and muscles along with the neural control centers.

Another variation refers to the core as a cylinder; the top and bottom thirds of the cylinder are rigid. Going from the top down, the rib cage and pelvis influence the action of their attaching extremities, with the pelvis also influencing the position of the rib cage [6]. The middle third is described as mainly soft tissue that functions as the neuromuscular center to guide the upper and lower thirds. The musculoskeletal core is the spine, hips, pelvis, proximal lower limb, and the abdominal structures. The muscles included are those of the trunk and pelvis that maintain stability of spine and aide in the transfer and generation of forces from large to small body parts during many activities. The muscles are broken into small, single joint, "length dependent" activation patterns, and multi joint, "force dependent" activation patterns as they function as the prime movers [9].

Core Strength vs Core Stability

In all literature accessed there is no common definition of core stability and core strength. Some authors use the terms interchangeably, whereas others draw a clear line of distinction between strength and stability of the core. The definitions of strength and stability are very close when defined anatomically.

Stability is the ability of the body to effectively control the entire range of motion of a joint [9]. "Core stability is the ability of the lumbopelvic-hip structures and musculature to withstand compressive forces on the spine and return the body to equilibrium after perturbation" [9]. Core stability in relation to athletics is the ability to control the position of the trunk in relation to the pelvis for optimum production, transfer, and control of forces demanded by athletic activities [9]. Panjabi makes an anatomical reference to core stability as the integration of the passive spinal column, active spinal muscles, and neural control unit all working together to stabilize the spine during activities of daily living [15]. Core stability requires coordination, strength, and endurance for effective control of the spinal column [16].

McGill uses an interesting analogy for the description of core stability [1]. He refers to core stability in regards of potential energy within each segment of spinal control. For example; a ball is in a bowl or "energy well", when the bowl is tilted and not returned to an upright position the ball will fall out, or the spine will buckle. If the sides of the bowl are made deeper by increasing the muscular stiffness it takes more energy to tilt the ball out of the hole. The ball always wants to return to the area of the least amount of potential energy. If the sides of the bowl are stiffened it in turn deepens the energy well and makes it less likely for the ball to roll out of the bowl. One unique aspect of the spine is that it has a component of motion active in all three planes, therefore for each vertebra there are 6 degrees of freedom for a total of 36 in the lumbar spine. This means that the ball has to be effectively controlled within all 36 degrees of freedom and if one muscle has an inappropriate force there can be a total loss of stability in the lumbar spine [1]. By this model muscular stiffness is achieved through a very low level contraction and maximal strength never becomes an issue as long as the muscles are able to "deepen the bowl." The problem is that the "energy well" is not infinite and therefore "maintaining a stability margin of safety when performing tasks is not compromised by insufficient muscle strength but rather by insufficient endurance" [1].

"Strength is the maximal force that a muscle or muscle group can generate at a specified velocity"[46]. Core strength in reference to this definition would be the ability of the core musculature to move the spine with a maximal load at a safe and efficient (requiring minimal energy) velocity, but this is not the general consensus within the literature. Some definitions of core strength are as follows, the ability of the muscles around the spine to maintain functional stability [8]. The ability of the core musculature to produce force through contractile forces and intra-abdominal pressure [14].

Although the two terms have different definitions according to the literature, a person cannot have core stability without core strength and vice versa. It is the combination of the two that allows the spine to stabilize and act as the base of movement for the body. "Core stability requires coordination in addition to core strength and endurance" [16].

Performance Implications

Almost all kinetic chains within sport related activities pivot to and from the core. It is the control of stability and motion in the core that will allow a smooth link in the kinetic chain of the upper and lower extremities [9]. Research shows that the activation of the core stabilizers precedes gross motor movements to provide a stable base for the extremities [17]. This activation leads to the core being labeled as the "powerhouse" or engine of all limb movement [8]. The transfer of energy that is created within the core to the extremities has been termed the serape effect [18].

The stabilization system of the spine has to function effectively to fully utilize the strength, power, and endurance capabilities of the surrounding muscles [19]. The body will be put at a higher risk of injury if the core does not properly function to provide a stable base for extremity motion [20, 9, 12, 21].

Two authors within the literature attempted to determine if core stability has any effect on performance within an athletic population. Nesser et al used the McGill methods of testing the endurance of core stabilizers on football players[11]. The results of the core stability tests were correlated against measurements of performance (20 yd dash, vertical jump, bench press, squat, etc) and found some significant findings but could not definitively say that core stability had an effect on performance. Tse et al used college age rowers, and put them through a core strength training protocol with a pre and post McGill method of endurance testing[19]. The training protocol significantly improved the core endurance testing times throughout the entire group but no significant differences were found among any of the performance variables that were measured.

Methods of Testing the Core

There are several different methods that are used to test the core. The most common forms of testing in the literature accessed include: Biering-Sorenson's test for the back extensors[3], Ito and other's version of the prone isometric back extensor test[33], McGill et al's version of the side bridge for the lateral muscles and the flexor test with the torso held at 60 degrees of flexion[7]. All methods of testing used in the literature accessed is listed in Table 2. One study performed by Cowley & Swenson introduced a power test for the core musculature done in all three planes of core muscle activation[17]. Other studies used expensive isokinetic or other fabricated machines to perform their studies. Overall there is an infinite amount of tests for the core muscles and all of them have their own purpose within a given field, but some are impractical for the purposes of this study. Isokinetic machines are too expensive and do not test the core functionally through all three planes of motion, isometric tests focus only on endurance and not strength but are very effective at predicting low back pain in athletes and non-athletes alike. The tests used in this study are based off the original methods of Cowley & Swenson but are modified to fit the requirements of our testing needs.[17]

Medicine Ball Testing

Recent core training protocols have begun to incorporate the use of medicine balls into the daily routine with the intention of improving core strength and power. Throws are often used due to their power specificity. Several of the exercises are performed with very powerful throws of the medicine ball. Several authors have indicated that these exercises can be adapted into a very reliable and valid method of testing power and strength in both the lower and upper body [17, 22-25]. These exercises work well to test core strength due to the exercises requiring the core to act as an intermediary to transfer forces to the extremities. [25]

Extremity Strength Measures

<u>Myotest</u>

The Myotest is a highly portable accelerometer that can measure many aspects of performance. The device was developed in Switzerland in 2004 and mimics abilities very similar to a force plate. It is capable of measuring power, force, reaction time, jump height, muscle stiffness, ground reaction force and several other aspects of athletic performance. The size of the device allows it to be connected to either the athlete via an elastic holster or clip onto the weight bar.

The device is preprogrammed to several different test protocols that are commonly used in performance testing. The tests include squat, jump squat, bench press, countermovement jump, plyometric jump test. There is also a trainer mode that allows the clinician to design a test for specific activities. The squat, jump squat, and bench press come with three preprogrammed resistance weight-classes that are divided by strength level. The program involves a 5 repetition set that begins and ends with a beep to lower the weight and then a beep to maximally move the resistance with each repetition. The jump tests use a similar protocol without the division of resistance classes.

Published literature involving the use of the myotest is very limited however there are several preliminary studies and abstracts showing the reliability and validity of the unit as a measurement device in the athletic performance realm. The device has been used to measure peak force during jump squats in comparison to a force plate and dynamometer with a reliability coefficient of 0.91, criterion validity was also very good with a coefficient of 0.91[26] . The device has also been used to predict the 1RM of the bench press through the Holm's Bonferroni equation. No significant difference was identified between the predicted 1RM and the subjects actual 1 RM bench press. Reliability between trials was very good (r=0.97)[27]. Similar results have been found utilizing the various capabilities of the Myotest in studies performed by Baboult and Cometti when they looked at vertical jump, along with the measurement of power in Boris's study on bench press assessing the validity of the Myotest at different percentages of the 1RM. The current literature indicates that the Myotest is a very reliable and valid tool for the measurement of athletic performance tests.

Vertical Jump

The vertical jump is a test designed to evaluate the jump height of an individual which in turn when compared to body mass can give clinicians a very effective manner of measuring lower body power [28]. An effective means of measuring the vertical jump is the use of the Vertec jump height system (Sports Imports, Hilliard OH). The Vertec is composed of a series of plastic vanes that are moved by the subject in an overhead swinging motion when the jump is performed. The plastic vanes are set up on a swivel attached to an adjustable pole, and are in .0127m increments [29]. The pole is adjusted to the subjects standing reach and then the jump is performed with the highest point being recorded as the vertical jump height. The accuracy of the Vertec depends on the experience of the subject in using the device and the ability of the clinician to properly count and measure the correct number of vanes moved [29].

Table 2 Methods of Testing the Core

Author	**Description of Test/Tests used**	**Purpose of testing**	**Subjects Used**
Akebi et al 1998[30]	Isokinetic testing of flexion/extension with 3 repetitions at 60 °/second 5 reps at 120 °/second	Test relationship of torque curves with occurrence of low back pain (LBP)	143 subjects that had been treated for LBP 200 subjects with no history of LBP

Table 2 (cont)

Arab & Salavati 2007[2]	Sorensen Test: subject lies prone on table with iliac crests aligned with the edge. Lower body is fixed to table with straps and subject is asked to maintain the upper body in a horizontal position Prone Isometric Chest Raise Test: subject lying prone on table with a pad under the abdomen. The upper body is lifted 30 degrees of the table and held in this position as long as possible Prone Double Straight Leg Raise Test: Prone with extended hips, subject was asked to raise both legs until knee clearance from table was achieved. Test was stopped when knee clearance diminished Supine Isometric Chest Raise Test: subject lying supine on table with hands crossed on chest. The hips and knees were in 90 degrees of flexion. Subject was asked to raise neck and upper trunk from table and hold it as long as possible Supine Double Straight Leg Raise Test: subject lies supine with the hips extended. Test was performed by lifting both legs off the table to 20 degrees and hold it as long as possible	Determine the sensitivity, specificity and predictive value of isometric endurance tests in low back pain	200 subjects with and without LBP ranging from 20 to 65 years of age
Biering - Sorensen 1984[3]	Trunk Raising Test: dynamic measure of trunk strength as the subject was asked to complete a slow trunk curl up from a supine position with the legs extended Leg Lowering Test: The supine lying patient raised legs to 90 degrees of hip flexion and then lowered them slowly. The angle was measured when the pelvis began to tilt anteriorly. Isometric Endurance of Back Muscles: Patient supported upper body in the horizontal position with the legs fixed to the table. This is the most widely used test in the isometric evaluation of the trunk extensors.(Arab & Salavati 2007)	Testing for weakness of the core as an indicator of future LBP	449 men and 479 women ranging from 30-60 years of age

Table 2 (cont)

Cowley & Swensen 2007[17]	Front Abdominal Power Test: Subject lies on back with arms extended over head. A 2kg medicine ball with thrown forward with straight arms while curling up at the abdomen. Side Abdominal Power Test: Subject sat with the knees in 90 degrees of flexion, and 45 degrees of hip flexion with the arms straight out in front of the body. A 2kg medicine ball was placed in the subjects hands, then the subject rotated 90 degrees to the right. An explosive contraction was used to propel the ball to the left of the body.	Develop a field test for the strength and power components of core stability. This study is the only method of testing that uses an explosive muscular contraction.	24 women with an average age of 20.9 years of age. All subjects were free of cardiovascular and neurological disease.
Delitto et al 1991[31]	Standing Isokinetic Tests: Maximal tests at 60, 120, and 180°/second.	Assessed repeatability of isokinetic testing measures.	61 asymptomatic subjects ranging from 21-60 years of age
Durall et al 2009[4]	Biering Sorenson trunk extensor test: subject lies prone on table with iliac crests aligned with the edge. Lower body is fixed to table with straps and subject is asked to maintain the upper body in a horizontal position McGill trunk flexor test: Subjects sat on the floor with knees and hips flexed to 90 degrees. Feet were stabilized as the torso was reclined to 60 degrees. Subject held this position for as long as possible. McGill side bridge endurance test: Subject was side lying on foam mat with the top foot in front of the other. The body was supported on one elbow as the hips were raised until body made a straight line. The subject held this position for as long as possible.	Studied the effects of a preseason core strengthening program on LBP occurrence during the season.	15 members of an NCAA division III gymnastics team. 15 non-athletes with no specialized core training served as control group

Table 2 (cont)

Evans et al 2007[32]	McGill right and left side bridge tests: Subject was side lying on foam mat with the top foot in front of the other. The body was supported on one elbow as the hips were raised until body made a straight line. The subject held this position for as long as possible. McGill trunk flexor test: Subjects sat on the floor with knees and hips flexed to 90 degrees. Feet were stabilized as the torso was reclined to 60 degrees. Subject held this position for as long as possible.	Assessed reliability of the tests and determined gender differences in athletes.	24 non-athlete subjects between the ages of 20 and 49 completed the study 79 elite athletes aged 19 to 23 from 6 different sports
Evans et al 2005[5]	Biering Sorenson trunk extensor test: subject lies prone on table with iliac crests aligned with the edge. Lower body is fixed to table with straps and subject is asked to maintain the upper body in a horizontal position McGill trunk flexor test: Subjects sat on the floor with knees and hips flexed to 90 degrees. Feet were stabilized as the torso was reclined to 60 degrees. Subject held this position for as long as possible. McGill side bridge endurance test: Subject was side lying on foam mat with the top foot in front of the other. The body was supported on one elbow as the hips were raised until body made a straight line. The subject held this position for as long as possible.	Tested muscles of the core as a predictor of LBP in young elite golfers	18 trainee professional golfers. All subjects were male between the age of 18 and 35 years old
Ito et al 1996[33]	Flexor endurance test: subjects lie supine with lower extremity raised to 90 degrees of knee and hip flexion. Subjects held this position as long as possible. Extensor endurance test: Subjects lie prone with a pillow under the abdomen. The upper body was raised and held for as long as possible.	To introduce their methods of testing core musculature, compare measures of healthy subjects to those who have LBP	90 healthy subjects ages 35-49 years of age 100 subjects with CLBP

Table 2 (cont)

Kumar et al 1999[34]	Isometric tests of flexion and extension at 20,40, and 60 degrees of flexion in a special device called the flexion-extension and lateral-flexion tester. Isokinetic testing at 60 degrees/sec.	Conducted to build a low back function profile of control and LBP patients	41 normal males, 32 normal females, 9 male patients and 1 female patient. Patients had symptoms of LBP
Latimer et al 1999[35]	Biering Sorenson trunk extensor test: subject lies prone on table with iliac crests aligned with the edge. Lower body is fixed to table with straps and subject is asked to maintain the upper body in a horizontal position.	Determined the reliability of the Biering Sorenson test in asymptomatic subjects	23 subjects with LBP 20 subjects with a history of LPB 20 subjects with no history of LBP
Larivier e et al 2008[36]	Functional Endurance Test: repeated(cyclic) intermittent back extension efforts at a predefined absolute force level.	Determine construct validity of the functional endurance test.	32 healthy subjects between 20 and 60 years of age from the general population, with no history of LBP in the previous year
Latikka et al 1995[37]	Isokinetic back lift test: isokinetic tests at 2 different speeds Biering Sorenson trunk extensor test: subject lies prone on table with iliac crests aligned with the edge. Lower body is fixed to table with straps and subject is asked to maintain the upper body in a horizontal position. Isometric psychophysical back lift test:	To examine relationship of isokinetic and isometric tests	100 men, 50 pairs of identical twins aged between 35-67 years with no current issues of LBP
Liemoh n et al 2005[16]	4 balance tests were performed on a stability platform. A quadruped arm raise was performed twice, once parallel to the axis and the other perpendicular to the axis. Bridging and kneeling arm raise were also performed	Develop a test that would allow quantification of core stability.	16 university students free of any orthopedic disability

Table 2 (cont)

McGill et al 1999[7]	McGill side bridge tests: Subject was side lying on foam mat with the top foot in front of the other. The body was supported on one elbow as the hips were raised until body made a straight line. The subject held this position for as long as possible. McGill trunk flexor test: Subjects sat on the floor with knees and hips flexed to 90 degrees. Feet were stabilized as the torso was reclined to 60 degrees. Subject held this position for as long as possible. Modified Biering Sorenson test: The main difference in this test from the other Sorenson tests is that the testing surface was closer to the floor to allow a better resting position before the test began.	To establish a normal baseline for these isometric tests that clinicians can compare to.	75 subjects from a university community with a mean age of 23 years and no history of LBP
Nesser et al 2008[11]	McGill side bridge tests: Subject was side lying on foam mat with the top foot in front of the other. The body was supported on one elbow as the hips were raised until body made a straight line. The subject held this position for as long as possible. McGill trunk flexor test: Subjects sat on the floor with knees and hips flexed to 90 degrees. Feet were stabilized as the torso was reclined to 60 degrees. Subject held this position for as long as possible. Biering Sorenson trunk extensor test: subject lies prone on table with iliac crests aligned with the edge. Lower body is fixed to table with straps and subject is asked to maintain the upper body in a horizontal position.	Identify relationships between core stability and measures of athletic performance in power trained collegiate athletes.	29 NCAA Division I male strength and power athletes
Roetert et al 1996[10]	Isokinetic Testing: Concentric flexion and extension of the spine was tested at speeds of 60 degrees per second and 120 degrees per second.	Examined the relationship between back strength and results of field tests of physical fitness.	Sixty nationally ranked junior tennis players ages 13-17

Table 2 (cont)

Tse et al 2005[19]	McGill side bridge tests: Subject was side lying on foam mat with the top foot in front of the other. The body was supported on one elbow as the hips were raised until body made a straight line. The subject held this position for as long as possible. McGill trunk flexor test: Subjects sat on the floor with knees and hips flexed to 90 degrees. Feet were stabilized as the torso was reclined to 60 degrees. Subject held this position for as long as possible. Biering Sorenson trunk extensor test: subject lies prone on table with iliac crests aligned with the edge. Lower body is fixed to table with straps and subject is asked to maintain the upper body in a horizontal position.	Determine the effectiveness of core training on improving core endurance and if increases of core endurance effect performance.	45 subjects with an average of one year rowing experience. 25 underwent a core strengthening program and 20 did not

CHAPTER 3

Methodology

Subjects

The subjects of this study will be football players at Indiana State University between ages of 18-25 participating in an offseason weight training program. All individuals selected will be familiar with the use of free weight training techniques and medicine balls in their daily training regimen as they will have performed them for the previous semester. They must be free of injury that would alter performance for the previous six weeks at the time of data collection. All participants must submit a consent form prior to data collection.

Experimental Design

This study is descriptive in nature with a dependent variable of core strength and an independent variable of extremity force production.

Procedures

Subjects will report to the Strength and Conditioning facility on the first day of the study dressed in proper athletic attire for performing a normal training protocol of the strength and conditioning staff. Before data collection begins, all subjects will be instructed on the proper techniques of all tests being performed in the study. The subjects will be divided into groups by their football specific positions, and will perform the tests in a set order over a week. Before the testing session all subjects as a team will go through a dynamic warm-up

Dynamic Warm-up

The dynamic warm-up is the warm-up that the subjects perform on a daily basis prior to their normal workout routines. The Indiana State University Strength & Conditioning Staff developed the warm-up and they will also lead all subjects in the activities prior to data collection on every day of the study. The warm-up consists of: Jump Rope, BW Squats, Windmills, Way backs, Cruicifix, Spidermans, Double leg roll squats, Scorpions. The warm-up will take approximately 15-20 minutes to complete.

Medicine Ball Throws

All subjects will report on their specific day to the north gym. The instructions for each throw will be explained to the group. Each subject will perform 6 medicine ball tests with two minutes rest between each throw. Throws will be marked and measured in meters upon landing and then returned and prepped for the next throw. Each test will be performed twice with the longest distanced of the two throws being used for analysis. Each medicine ball throw is described in the following.

Frontal Throws

Stationary Frontal Throw

The subject will sit on a standard weightlifting bench chair with their feet flat on the floor, and a strap across the chest securing the back to the chair to prevent movement. They will sustain 90 degrees of hip flexion and a fully erect spine from the beginning of the test until the medicine ball has been thrown forward. The subject will grab a 3kg medicine ball in both hands and hold it just above the head with the shoulder abducted and elbows flexed. The subject will maintain an upright position of the spine and abdominal area during the throw. The throw begins with the subject taking the ball from above their head and powerfully contracting in the arms to throw the ball forward. If the subject does not maintain the starting core position, and attempts to gain momentum from movement at the core or hips the throw will not be counted and will be attempted again.

Core Flexion Throw

The subject will sit on a standard weightlifting bench with their feet flat on the floor. The 3kg medicine ball will be raised overhead and the subject will then lean back as far as they feel comfortable as long as feet stay on the floor. To throw the medicine ball the subject will initiate a contraction at the hips/abdomen that starts them into flexion. The throw will be initiated with a powerful contraction of the core, hips, and arms propelling the body forward until the ball is released.

Reverse Throws

Stationary Reverse Throw

The subject will sit on a standard weightlifting bench chair with their feet flat on the floor, and a strap across the chest securing the back to the chair to prevent movement. They will sustain 90 degrees of hip flexion and a fully erect spine from the beginning of the test until the medicine ball has been thrown. The 3kg medicine ball will be placed in the subjects hand and positioned just below the umbilicus. The throw will be initiated with only the arms as they are raised upward and over the head directing the ball behind them. The ball should be released in an upward direction just above the head. If the subject attempts to gain momentum with movement of the core the throw will not be counted and must be repeated.

Core Extension Reverse Throw

The subject will sit on a standard weightlifting bench with their feet flat on the floor .The subject will then flex the spine and hips in an effort to crunch down towards the knees. The 3kg medicine ball will be placed in the subject's hands and positioned in front of the legs just distal to the knees. To initiate the throw the subject will extend at the hips and abdomen while raising the arms above the head. The medicine ball will be released just above the head as it is directed behind the subject. The subject is to remain seated throughout the test.

Lateral Throws

Stationary Lateral Throw

The subject will sit on a standard weightlifting bench chair with their feet flat on the floor, and a strap across the chest securing the back to the chair to prevent movement. They will sustain 90 degrees of hip flexion and a fully erect spine from the beginning of the test until the medicine ball has been thrown. The 3kg medicine ball will be held by the subject at the side of his/her legs in a comfortable position. To throw the medicine ball the subject will move his/her arms in a direction that is contra-lateral to the starting point. This throw should take place with minimal spinal rotation and if too much occurs the throw will not be counted and it will be repeated. After the first throw the same procedure will be repeated for the opposite side.

Rotational Lateral Throw

The subject will sit on a standard weightlifting bench with the feet flat on the floor and knees flexed to 90 degrees. The subject will forward flex at the hips and abdomen while rotating to one side. The increased flexion and rotation will allow the subject to get a more powerful movement as they unload to the contra-lateral side of the starting point using both the muscles of the core and arms to maximally throw the medicine ball. Upon completion of the first throw the subject will then repeat the procedure for the opposite side.

Push Press

The push press is a free weight lifting technique that effectively tests the strength of the body from the toes to the head. The weight used for this test will be 50 percent of their bodyweight that is on file with the strength and conditioning staff from previous testing sessions. The standing push press starts with the bar positioned on the front portion of the chest resting on the clavicles. The arms will be in full flexion with the hands around the bar and wrists extended. The subject will then flex at the knees and hips pausing midway. After the pause an explosive movement extends the hips and knees while simultaneously driving the arms and weight bar overhead to a fully extended position. This lift will be performed to the cadence of the Myotest and the subject will lift the bar explosively when the Myotest beeps and lower it back down on the second beep. This will occur for five repetitions and the bar will then be placed back on the rack to complete the test. Total power output from the test will be used for data analysis.

Vertical Jump

The vertical jump will be measured using the Vertec vertical jump measuring system (Sports Imports, Hilliard Ohio). The subject will have three attempts to obtain maximum height. A vertical jump is performed with a one-step approach with a slight countermovement and the hips and knees. During the countermovement the knees and hips are bent as the subject gathers momentum to jump. The arms are thrust upward in an explosive manner as the knees and hips are extended propelling the subject upward. At the highest point the subject moves the vanes on the Vertec giving the height of the jump. The vanes will not be reset between jumps and the measurement will be taken after the third attempt. Between jumps the subject will have a minimum of one minute rest and will jump when they feel that they are ready for the next maximal attempt.

Data Analysis

All data collected will be placed into a spreadsheet and prepared for statistical analysis using SPSS.

Previously existing data that has been collected by the strength and conditioning staff will also be used in the study. This data consists of a 1 repetition maximum back squat, 20 yd dash, and 1 repetition bench press maximum.

Statistical Design

The statistics for this study will consist of Pearson product correlations, and related and unrelated two sample t-tests on the core tests and weight, and a stepwise regression for power prediction. All procedures will be run at the .05 level of significance. Correlations allow us to determine if the results of the tests are in any way related

CHAPTER 4

Results

The means and standard deviation of the medicine ball throws and performance measurements are shown in table 1. Independent sample T-tests (Table 2) identified significance differences between the respective static and dynamic throws, with the exception of the forward throw.

All correlation coefficients between the medicine ball throws and performance tests are listed in table 3. Several significant correlations were identified between the static medicine ball throws and the performance variables. Static reverse correlated with vertical jump (CMJ) (r=0.44), broad jump (BRD)(r=0.5) and push press power (PWR)(r=0.46). Static left (StL) and static right (StRi) correlated with PWR (r=0.59), (r=0.65) respectively, and Vel (r=0.52)(r=0.6), respectively. Fewer dynamic throws correlated significantly with the performance variables. Dynamic left (DyL) and Dynamic right (DyRi) correlated with PWR (r=0.53), (r=0.63) respectively, and Vel (r=0.55),(r=0.61) respectively. Dynamic forward (DyFw) correlated with the 1RM squat (r=0.45).

A stepwise regression was run in attempt to determine which independent variables best predict push press power (watts). Analysis identified 1RM squat as the only predictor (r=.53).

CHAPTER 5

Discussion

The demands that athletic performance places on the body cannot be created and/or dissipated locally; it takes the entire body reacting on a stable surface to create aspects of performance (speed, power, strength, motion). The muscles of the core are responsible for providing the stable base for extremity function and force transfer. There are very few athletic activities that do not require a transfer of forces. The primary intent of this research was to gain insight into any effect that the muscles of the core have on the transfer of forces through the body. By developing and implementing a dynamic core test, several indices of the effect that the core has on forces in the body have been shown.

The medicine ball throws used in this study were designed to test upper extremity strength and power generation through static positions, and then to put upper extremity function together with a powerful movement of the trunk musculature in the dynamic positions to measure the effect of core strength on throw distance. The theory behind this is that in a static position with the chest secured to the bench the subject was not able to use the core musculature to aid in propulsion. The dynamic position allowed the subject to obtain a position that would enable them to more effectively utilize the muscles of the core to improve the distance of the throw in comparison to the static position.

Speaking in terms of global (major movers of trunk) and local (stability muscles of trunk, little movement responsibility) muscles there are global muscles that mimic the local musculature. The rectus abdominus and erector spinae have global movement characteristics in certain activities but in most athletic activities they function mainly as stabilizers of the spine and not as major movers. Very few athletic activities require flexion or extension during activity. To initially get into a functional position to perform a task it may require spinal flexion/extension, but once an activity ensues that spinal position is held throughout in a stable manner. After completion of the desired movement pattern the spinal position may need to flex or extend but it will again stabilize and will serve as the stable base for extremity function.

The results indicate that the core does have some relationship with performance. The medicine ball throws show very strong relationships in both the static and dynamic positions. All medicine ball throws except the static forward and dynamic reverse throws correlated with a performance measurement.

The reverse static throw correlated moderately with the vertical jump, broad jump and push press power. These correlations may come from the similarity in the motions of the throw and the three performance measurements. The throw mimics the action of the upper extremities in the performance measurements as they are rapidly and forcefully moved upward to enhance the momentum created by the lower extremity action. The relationships shown for this throw are most likely a result of extremity strength and function.

A complete lack of relationships in the dynamic reverse throw reinforces that the relationships of the static reverse throw are extremity function and strength. The incorporation of the core in the dynamic reverse throw altered the effect of the arm and shoulder musculature as they were no longer the primary movers for the action. The subjects relied more on the momentum from the rapid extension of the spine to throw the ball rather than extremity strength alone and this alters the relationship to the goal of functional performance. Dynamically it became a nonfunctional test in relation to the selected measurements of performance. There are very few functional activities within athletics that would require an individual to extend the spine backwards to complete a task. If very few functional activities require the individual to provide a dynamic extension of the spine that indicates that the posterior core musculature serves as a stabilizer during dynamic activities.

The dynamic forward throw correlated with two strength measurements, the 1RM squat and 1RM bench. The throwing position of this throw required the subject to lean back as far as possible while maintaining foot contact with the floor, while holding the medicine ball directly overhead. Just obtaining the starting position put a great deal of stress on the anterior trunk musculature because the feet had to remain in contact with the floor, and from that starting position they were asked to throw the ball forward as far as possible. This position required the subject to forward flex the spine while moving the extremities forward. For the subject to move the extremities forward a stable base is needed, but if the core is also forward flexing (moving) while trying to provide a stable base the actions seem to be contradictory. The duality of this motion really tests the true function of the anterior core. According to the results of the t-tests the forward throws were the only throws that did not have a significant difference in the distance thrown. In relation to all other tests the addition of the core musculature increased throw distance, but not with the forward throws. Due to the starting position of the throw the subject had to choose to either forward flex and then throw, or throw and then forward flex. The core is not designed to explosively flex while the extremities are in motion, so one action has to take place at a time. In a sense both forward throws were a test of extremity strength, with the dynamic throw adding a stability requirement.

The anatomy of the rectus abdominus provides minimal forward movement when contracted. The muscle fibers are so short that the ability to contract is minimal and a great deal of forward flexion cannot be produced by this muscle. This leads to the assumption that if it can only move a short distance its main function has to be to provide stability and on occasion provide small amounts of trunk flexion. The relationship to 1RM squat and bench press maximums comes from the individual's ability to provide anterior stability while resisting forces of an external load and extremity action.

The lateral medicine ball throws show relationships with performance measurements in both the static and dynamic positions. Both statically and dynamically to the left and right the medicine ball throws correlated with push press power and the broad jump. The vertical jump related to the left static throw, and to both the left and right dynamic throws. For push press power the relationship with the static throw is most likely a result of the subject's ability to generate force in the upper extremity, which would be an expected relationship. A person with strong extremities should be able to throw the medicine ball further and have a better push press power output. However, when the core became involved in the throw the relationship to power, and the broad jump did not significantly change. The lack of significance in the dynamic forward and reverse throws indicates that the core may not provide dynamic flexion and extension of the spine for athletic performance, but does provide a drastic effect on stability of the spine. The lateral throws indicate differently, their relationship to performance may be more dynamic stability with more movement responsibilities in comparison to anterior and posterior musculature. The external oblique is the main global rotator of the core and has minimal stability requirements in comparison to other muscles of the core acting directly on the spine[38]. This means the effect of the external oblique should be strong with athletic activities, if it is the main rotator it should be the main resistor of rotation as well. Therefore a strong external oblique would lead to less disruptive forces altering the core allowing better force transfer. This is a big difference in anatomical function of the four sides of the core. The anterior and posterior both have muscles that are global by definition but not by athletic function. The rectus abdominus and erector spinae are both global muscles in nature and in a lot of daily activities, but when it comes to athletic function they in a sense become the primary stabilizers of the spine, and help to control the motion of the external oblique. The main difference between the lateral aspects of the core when compared to the anterior and posterior is that in a dynamic function the main movers of the anterior and posterior have to provide stability, but laterally the external oblique doesn't have to provide stability do to other muscles providing that stability.

The effect not only comes from external oblique strength but it also appears to be the ability of the athlete to activate the external oblique and utilize that strength for improved performance. In a study on throwing athletes, Ikeda et al found that subjects who performed better in a side medicine ball throw had a higher external oblique activation[39]. Ikeda et al also suggests that isometric trunk rotation to one side has a significant effect on the dynamic trunk rotation of the opposite side[39]. This would indicate that while one side of the core creates a rotational force the opposite side must control the motion and provide stability for extremity function. The possible relationship of the dynamic throw to push press power, broad jump, and vertical comes from the ability of the subject to effectively activate the external oblique for both rotation and stability in conjunction with the other muscles of the core.

In athletics nearly every activity is based on some sort of rotational axis. “Running is a series of unilateral hip flexion and extension movements that can place considerable amounts of destabilizing torques on the trunk ”[38]. More simply stated as, the hips and pelvis rotate on the stable base created by the core allowing movement of the subject. If the core is weak the forces created will not be utilized properly. The function of the core as a unit is to resist the rotational forces of the activity and keep all motion moving in the desired direction, but not all activities mimic the demands of running. For instance take the pitch or bat swing in baseball, both of the activities require the stable base and transfer of force through the body into the arms but they also require rotation of that same stable base. The core has to be complex in design and function to accomplish these demands. All of the local muscles function as the main stabilizers of the spine and several of the global muscles do as well. The lower abdominals (rectus abdominus, internal oblique, and transverse abdominus) function to provide anterior stability to aid in spinal stabilization and the erector spinae act on the posterior to keep the upper body erect. Those muscular actions function as the stable base. The external oblique along with the muscles of the hip and upper back function to create the rotation needed to complete these tasks, and to control the rotation. In regards to running, no matter where the rotation occurs in the task it is does not fit into the desire of a fully functional kinetic chain. The most efficient method of moving from point A to point B is a straight line, and any rotation occurring between those two points adds distance. Rotation equals lost energy and lost energy equates to decreased performance. Therefore, it is the responsibility of the lateral core musculature to not only facilitate a rotational action is several activities, but to also resist rotational forces in other activities.

The push press was chosen as a measurement of performance because of the way that it utilizes the forces created by the body. A push press requires a transfer of forces that are created in the lower extremities to the upper extremity as the weight is driven upward. The stepwise regression revealed that 1RM squat is the only predictor of the total power output (watts) in the push press. This relationship shows that the lower body has an effect of the transfer of forces to the upper body. A strong lower extremity creates forces that are transferred to the upper body via the core musculature. While the medicine ball throws did not test the function of the core on forces created within the lower body the throws still help to understand how the forces created at the feet are transferred to the hands. If a lower body exercise is the best predictor of an upper body strength measurement there has to be a significant transfer of forces occurring through the core. This transfer can be seen in the relationship between the dynamic front throw and 1RM bench and squat maximums, and also between the lateral throws and push press power and velocity. The stability created by the anterior and posterior core musculature in conjunction with the stability provided by the lateral musculature resisting rotation allows the forces created by the bigger movers of the lower extremity to transfer into the arms. If the core is too weak to handle the forces properly an improper rotation will occur and an energy leak is created, but if the core is strong it will transfer the forces with minimal rotation and minimal energy loss.

The core has a very demanding job in providing a control system on forces within the body. This demand has to be met with not only an adequate amount of strength as discussed previously, but also precise control and timing. When forces are created in the lower extremity and are transferred into the extremities the core has to react and perform with proper timing and control. For example in the baseball pitch, if the core reacts to early the forces are dissipated and the arm has to create more forces placing it at higher risk of injury[40]. Borghuis states that motion at one segment will influence that of all other segments in the chain[41]. The core is the central component to most athletic activities, if it fails so does the effectiveness of the forces being created and transferred. An increase or decrease of forces created from the improper distribution from the core can be very detrimental to performance and possibly lead to injury.

In previous studies attempting to determine an effect of core strength/stability on athletic performance little support had been identified for a relation to performance[11,19, 42-44]. The difference between these studies and the current study is that the measurements of core function were static and endurance based. This study required the subjects to perform a more functional activity to assess strength. The functionality of the tests used in this study more accurately assessed the core musculatures effect on performance. Our results indicate that core strength does have an effect on performance in an athletic population.

To completely understand how the core transfers forces to and from the extremities it will be necessary to include the lower body in the core assessment. Several authors state that the core includes several of the muscles in the hip and thighs[8,9,12]. The core assessment used in this study did not assess those muscles. However, the relationship to the transfer of forces has been seen in the results of this study and should not alter with the addition of the hips. It is still necessary to include these muscles to completely understand the force transfer within the body.

Practical Implications

In sports, muscular demands vary greatly from athlete to athlete. This makes it very difficult to have one statement that will address all inadequacies of the core, but it is possible to say that the core has to be trained for sport specificity. To train for the majority of sports it requires a dynamic motion. Currently plank exercises are considered an adequate method of training the core for athletes to improve core strength and stability. The problem with these exercises it puts the athletes in a non-functional static position that is very rarely replicated in the demands of sport related activities. The core is the center of most kinetic chains in the body and should be trained accordingly. Athletes play dynamically and should train the same way.

REFERENCES

1. McGill SM. Low back stability: from formal description to issues for performance and rehabilitation. *Exercise and Sport Sciences Reviews.* 2001;29(1):26-31.

2. Arab AMS, M., Ebrahimi, I., Mousavi M. E., . Sensitivity, specificity and predictive value of the clinical trunk muscle endurance tests in low back pain. *Clinical Rehabilitation.* 2007; 21:640-647.

3. Biering-Sorensen F. Physical measures as risk factors for low back trouble over a one year period. . *Spine.* 1984; 9(2):106-119.

4. Durall CJ, Uderman B. E., Johansen, D. R., Gibson, B., Reineke D. M., Reuteman P. The effects of preseason trunk muscle training of low back pain occurrence in women collegiate gymnastics. *The journal of Strength and Conditioning Research.* 2009;23(1):86-92.

5. Evans K, Refshauge, K. M., Adams, R., Aliprandi, L. Predictors of low back pain in young elite golfers: a preliminary study. *Physical Therapy in Sport.* 2005;6:122-130.

6. King MA. Core stability: creating a foundation for functional rehabilitation. *Athletic Therapy Today*. 2000;5(2):6-13.

7. McGill SM, Childs, A., Liebenson, C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil.* 1999;80:941-944.

8. Akuthota S.F N. Core strengthening. *Arch Phys Med Rehabil.* . 2004;85(3 suppl):S86-92.

9. Kibler BW, Press, J., Sciascia. The role of core stability in athletic function. *Sports Medicine.* 2006;36(3):189-198.

10. Roetert PE, McCormick, T. J., Brown, S.W., Ellenbecker, T.S. . Relationship between isokinetic and functional trunk strength in elite junior tennis players. *Isokinetics and Exercise Science.* . 1996;6:15-20.

11. Nesser T, Huxel, K., Tincher, J., & Okada, T. The relationship between core stability and performance in division I football players. *Journal of Strength and Conditioning Research.* 2008;22(6):1750-1754.

12. Hibbs AE, Thompson, K. G., French, D., Wrigley, A., Spears, I. Optimizing performance by improving core stability and core strength. *Sports Medicine.* 2008;38(12):995-1008.

13. McArdle WD, Katch, F. I., & Katch, V. L. *Exercise physiology energy, nutrition, and human performance.* Baltimore MD: Lippincott Williams & Wilkins; 2001.

14. Faries MD, & Greenwood, M. Core training: stabilizing the confusion. . *Strength and Conditioning Journal.* 2007;29(2):10-25.

15. Panjabi MM. The stabilizing system of the spine. Part I. function, dysfunction, adaptation, and enhancement. *Journal of Spinal Disorders.* 1992;5(4):390-397.

16. Liemohn WP, Baumgartner, T. A., Gagnon, L. A. . Measuring core stability. *Journal of Strength and Conditioning Research.* 2005;19(3):583-586.

17. Cowley PMS, T. C. . Efficacy of instability resistance training. . *International Journal of Sports Medicine.* 2007;28:829-835.

18. Konin JG, Beil, N., Werner, G. Facilitating the serape effect to enhance extremity force production. *Athletic Therapy Today.* 2003;8(2):54-56.

19. Tse MA, McManus, A. M., & Masters, R. S.W. Development and validation of a core endurance intervention program: implications for performance in college age rowers. *Journal of Strength and Conditioning Research.* 2005;19(3):547-552.

20. Nadler SF, Malanga, G.A., Bartoli, L.A., Feinberg, J.H, Prybicien, M., Deprince, M. Hip muscle imbalance and low back pain in athletes: influence of core strengthening. *Medicine and Science in Sports and Exercise.* 2002;4:9-16.

21. Bliss LS, Teeple, P. Core stability: the centerpiece of any training program. *Current Sports Medicine Reports* 2005;4:179-183.

22. Duncan MJ, Al-Nakeeb, Y., Nevill, A. M. . Influence of familiarization on a backward overhead medicine ball explosive power test. *Research in Sports Medicine.* 2005;13:345-352.

23. Davis KL, Kang, M., Boswell, B. B., DuBose, K. D., Altman, S. R., Binkley, H.M. Validity and reliability of the medicine ball throw for kindergarten children. *Journal of Strength and Conditioning Research.* 2008;22(6):1958-1963.

24. Mayhew JL, Bird, M., Cole, M. L., Koch, A. J., Jacques, J. A., Ware, J. S., et. al Comparison of the backward overhead medicine ball throw to power production in college football players. *Journal of Strength and Conditioning Research.* 2005;19(3):514-518.

25. Stockbrugger BAH, R. G. Validity and reliability of a medicine ball explosive power test. *Journal of Strength and Conditioning Research.* 2001;15(4):431-438.

26. Weiss LF, L., Schilling, B., Hammond, K., Trepanowski, J., Landrum, D., Grindle, M. Validity of accelerometer-derived peak force output during loaded jump squats. In: Musculoskeletal Dynamics Laboratory UoM, ed. Memphis TN.

27. Haff GG, Stone, M.H., Ramsey, M.W., Hornsby W.G. The comparison of accelerometer based estimates of maximal bench press strength and actual 1 repetition maximum tests in untrained college students. Morgantown WV: West Virginia University School of Medicine.

28. McClenton LS, Brown, L.E., Coburn, J.W., Kersey, R.D. The effect of short-term vertimax vs. depth jump training on vertical jump performance. *Strength and Conditioning Research.* 2008;22(2):321-325.

29. Leard JS, Cirillo, M.A., Katsnelson, E., Kimiatek, D.A., Miller, T.W., Trebincevic, K., Garbalosa, J.C. Validity of two alternative systems for measuring vertical jump height. *Strength and Conditioning Research.* 2007;21(4):1296-1299.

30. Akebi T. SS, Hieda H., Goto H. Factors affecting the variability of the torque curves at isokinetic trunk strength testing. *Arch Phys Med Rehabil.* 1998; 79:33-35.

31. Delitto A, Rose, S. J., Crandell, C. E., Strube, M. J. . Reliability of isokinetic measurements of trunk muscle performance. *Spine.* 1991;1991(16):800-803.

32. Evans K, Refshauge, K. M., Adams, R. Trunk muscle endurance test: reliability and gender differences in athletes. *Journal of Science and Medicine in Sport.* 2007;10:447-455.

33. Ito T, Shirado, O., Suzuki, H., Takahashi, M., Kaneda, K., Strax, T. E. Lumbar trunk muscle endurance testing: an inexpensive alternative to a machine for evaluation. *Arch Phys Med Rehabil.* 1996;77:75-79.

34. Kumar S, Dufresne, R. M., Schoor, T. V. Human trunk strength profile in flexion and extension. *Spine.* 1995;20(2):160-168.

35. Latimer J, Maher, C. G., Refshauge, K., Colaco, I. The reliability and validity of the biering sorensen test in asymptomatic subjects and subjects reporting previous nonspecific low back pain. *Spine.* 1999;24(20):2085-2090.

36. Lariviere C, Gravel, D., Gardiner, P., Arsenault, B. A., Gagnon, D., Loisel, P. . A submaximal test to assess back muscle capacity: evaluation of construct validity. *Journal of Electromyography and Kinesiology.* 2008:1-7.

37. Latikka P, Battie, M. C., Videman, T. Gibbons, L. E. Correlations of isokinetic and psychophysical back lift and static back extensor endurance tests in men. *Clinical Biomechanics.* 1995;10(6):325-330.

38. Behm DG, Cappa, D., Power, G.A. Trunk muscle activation during moderate and high-intensity running. *Appl. Physiol. Nutr. Metab.* 2009;34:1008-1016.

39. Ikeda Y, Miyatsuji, K., Kawabata, K., Fuchimoto, T., Ito, A. Analysis of trunk muscle activity in the side medicine ball throw. *Journal of Strength & Conditioning Research.* 2009;23(8):2231-2240.

40. Aguinaldo AL, Buttermore, J., Chambers, H. Effects of upper trunk rotation on shoulder joint torque among baseball pitchers of various levels. *Journal of Applied Biomechanics.* 2007;23:42-51.

41. Borghuis J, Hof, A.L., Lemmink, K. The importance of sensory motor control in providing core stability. *Sports Medicine.* 2008;38(11):893-916.

42. Scibek JS, Guskiewicz, K.M., Prentice, W.E., Mays, S., Davis, J.M. *The effect of core stabilization training on functional performance in swimming*. Chapel Hill, University of North Carolina; 2001.

43. Nesser TW, Lee, W.L. The relationship between core strength and performance in division I female soccer players. *Journal of Exercise Physiology (online).* 2009;12(2):21-28.

44. Stanton R, Reaburn, P.R., Humphries, B. The effect of short term swill ball training on core stability and running economy. *Journal of Strength & Conditioning Research.* 2004;18(3):522-528.

45. Bergmark., The local and global systems. *Acta Orthop Scand*. 1989; 60(suppl), 20-23

46. Baechle TR, Earle RW. Essentials of strength training and conditioning. 2000. Human Kinetics, Champaign, IL.

APPENDIX A: DATA

Medicine Ball Throws							
St/FW	**ST/R**	**ST/L**	**ST/Ri**	**DY/ F**	**DY/R**	**DY/ Ri**	**DY/L**
6.9	8	8	9	6.0	18.6	12.6	13.6
8.0	10.5	8.9	9.7	8.4	17.5	10.5	11.2
7.0	8.8	8.0	7.9	8.1	14.8	11.2	11.0
8.1	8.8	8.0	8.2	7.9	18.5	10.1	9.3
7.7	9.9	10.1	8.8	7.4	15.8	12.1	12.5
7.1	7.4	7.0	7.7	6.8	13.1	9.4	10.1
7.9	9.4	9.0	7.9	8.0	16.8	11.6	11.4
8.8	9.5	8.7	8.2	8.6	17.4	11.3	11.6
6.3	9.1	8.2	8.7	8.4	12.9	10.0	10.9
7.7	8.5	7.3	7.3	6.3	14.9	9.4	9.8
6.5	8.1	7.1	7.3	7.3	14.9	9.4	10.1
9.1	8.8	8.0	7.6	8.7	11.7	10.9	9.5
6.3	6.4	8.0	7.8	8.5	11.7	9.4	9.8
7.4	9.4	8.8	8.7	8.8	14.5	11.7	12.0
7.5	9.8	8.7	8.2	8.1	14.7	11.5	11.1
8.8	10.0	8.7	8.9	10.0	19.9	13.3	12.4
7.3	7.8	9.4	9.8	8.8	16.8	12.5	11.7
7.0	7.1	6.6	7.6	7.4	14.4	8.9	9.2
9.3	8.9	8.1	8.4	9.0	13.1	10.9	11.5
7.3	9.0	7.9	7.6	8.4	12.5	10.9	9.5
8.0	8.8	8.6	7.8	8.4	12.0	10.1	11.3
6.5	8.9	7.3	6.2	6.8	12.1	6.9	8.4
6.8	6.9	5.8	5.4	8.0	13.3	7.3	8.3
6.4	8.6	9.4	8.6	7.3	17.2	10.7	10.6
8.0	9.2	8.4	7.3	8.6	15.9	10.9	10.8

Performance Measurements									
Squat	**Bench Press**	**Reach**	**Jump**	**Vertical**	**Broad**	**50% BW**	**Power**	**Force**	**Velocity**
365	255	96	122	26	8'4"	105	45.7	18.8	292
435	300	94.5	119	24.5	7'10.5"	105	50.8	26.6	269
515	325	98	122.5	24.5	8'4"	140	44	21.5	274
435	375	96	117.5	21.5	6'9"	155	31	22	216
365	315	93.5	123.5	30	9'3"	95	40.3	24	242
410	300	91	117.5	26.5	7'6"	100	32.4	19	219
385	295	97	125.5	28.5	8'6.5"	105	38.1	22.7	235
435	265	96.5	123	26.5	8'2"	115	35.9	24.5	226
435	265	95.5	121	25.5	8'1"	115	36	20.6	233
385	295	102	122	20	6'8.5"	155	29.8	21.7	229
405	250	93.5	117.5	24	7'7"	105	36.8	18.2	259
495	305	96	121.5	25.5	7'1"	145	38.8	18.1	261
370	305	95	120	25	7'6.5"	90	37.5	23	234
455	360	97	126.5	29.5	8'8.5"	110	46.2	20.9	286
305	265	85	121.5	36.5	9'7.5"	80	47.2	24.2	271
435	315	95	126.5	31.5	9'	115	38.2	22.8	230
385	300	97.5	123.5	26	8'10"	115	35.6	19.9	244
365	235	90.5	114.5	24	7'3.5"	95	32.8	21.1	213
425	315	97	122	25	7'7"	120	39.3	20.7	251
385	265	92.5	120	27.5	8'2.5"	105	31.1	18.1	221
475	335	99	120.5	21.5	7'7"	150	79.6	22.7	459
325	185	91.5	118.5	27	8'6"	85	32.6	26.2	218
425	345	97.5	120	22.5	7'1"	155	27.8	21.2	190
415	295	95	120.5	25.5	7'10"	115	43.8	20.8	274
525	315	98	121	23	7'7.5"	145	31.4	16.6	227

Push Press Power Measurements			
50% BW	**Power**	**Force**	**Velocity**
105	45.7	18.8	292
105	50.8	26.6	269
140	44	21.5	274
155	31	22	216
95	40.3	24	242
100	32.4	19	219
105	38.1	22.7	235
115	35.9	24.5	226
115	36	20.6	233
155	29.8	21.7	229
105	36.8	18.2	259
145	38.8	18.1	261
90	37.5	23	234

110	46.2	20.9	286
80	47.2	24.2	271
115	38.2	22.8	230
115	35.6	19.9	244
95	32.8	21.1	213
120	39.3	20.7	251
105	31.1	18.1	221
150	79.6	22.7	459
85	32.6	26.2	218
155	27.8	21.2	190
115	43.8	20.8	274
145	31.4	16.6	227

APPENDIX B: RECOMMENDATIONS

For future research in this topic area the study should be formulated in a manner that it involves a movement within core and hips. The throws in this study were performed in a purely stationary setting for the lower extremity, and the lack of lower body involvement may alter the manner in which the core functions.

Also a more diverse subject population could potentially alter the relationships of the core that were found in this study. Incorporate females into the study as well as both males and females of several different sport populations.