CONVERGENT VALIDITY BETWEEN FIELD TESTS OF ISOMETRIC CORE STRENGTH, FUNCTIONAL CORE STRENGTH, AND SPORT PERFORMANCE VARIABLES IN FEMALE SOCCER PLAYERS

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ABSTRACT

Introduction: Previous research has failed to definitively explain the role that core fitness plays during sport performance. Movements of sport performance require the core musculature to simultaneously provide spinal stability while producing external forces that aid limb movement. The core is central to most kinetic chains; therefore, a better understanding of core function during sport should help to benefit performance. **Purpose:** The purpose of this study was to compare tests of isometric core strength that evaluate the ability of the core to provide a stable base of support, and tests of concentric functional core strength that evaluate the ability of the core to produce and transfer forces to the limbs, with the soccer kick and throw-in, to see which plays a greater role in soccer sport performance. It was hypothesized that the concentric functional core strength tests would correlate more strongly with the soccer performance tests than the isometric strength tests due to their ability to be performed in an explosive manner that better mimics sport. **Methods:** To test this hypothesis, 11 female participants (age: 19.73 ± 0.9 y, height: 1.63 ± 0.04 m, weight: 64.41 ± 11.73 kg) from the College of Idaho soccer team volunteered for this study. Isometric core strength was measured using a dynamometer during movements of trunk flexion and bi-lateral rotation. Concentric functional core strength was measured by performing the front abdominal power test (FAPT) and side abdominal power test (SAPT). Soccer performance was evaluated with a standing soccer-style kick and throw-in for maximal speed. Isometric trunk flexion and the FAPT were correlated with the soccer throw-in, while bi-lateral trunk rotation and bi-lateral SAPT were compared with the contralateral soccer kick. By correlating the tests in this manner, the muscular contributions during similar movement patterns (flexion and bi-lateral rotation) could be analyzed in different manners (isometrically, concentric/functionally) to see which correlates more strongly with tests of soccer sport performance. **Results:** A Pearson's product correlation found that the isometric core strength correlated more strongly with tests of soccer sport performance than concentric functional core strength. **Discussion:** It was found that the core plays a greater role in providing a stable base of support rather than producing/transferring force during tests of soccer sport performance. Consistent with previous studies, the external load and direction of the load placed on the core affects the muscular activation that is produced. The isometric tests had a much larger load placed on them, which elicited a greater muscular activation and could explain why there was a greater correlation with tests of soccer sport performance. The validity of the isometric and concentric functional strength tests to accurately measure force of the intended musculature remains in question. More future research is warranted to better explain the relationship between core fitness and sport performance.

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CHAPTER 1: INTRODUCTION

Athletes, coaches, and strength and conditioning specialists are always looking for the latest training trends to improve performance. Recently, much attention has been given to the role that core fitness plays in sport performance. Almost all sports involve movements that require a transfer of power through the core and out the limbs to produce a forceful action. When throwing a baseball for example, forces are first produced in the lower body followed by a pattern of muscle activation beginning with the contralateral external oblique and proceeding through the arm [1]. The core serves as the center of the functional kinetic chain and foundation for limb movement. Increasing core fitness is beneficial to athletes in order to increase force production, strengthen spinal stability, and aid in injury prevention and rehabilitation [2]. However, to date there is a dearth of literature showing that core fitness has a direct influence on sport performance. Being that the core plays a simultaneous role in providing stability and in producing/transferring force during sport movements, it has made it difficult for researchers to fully understand the relationship between core fitness and sport performance. Therefore, the purpose of this study is to examine whether the core plays a greater role in providing stability or in generating and transferring of forces to the limbs during sport movements.

When discussing the core, it is important to distinguish between core stability and core strength. These two terms are often used interchangeably, which has caused confusion in the literature. Core stability and core strength differ based on their functions, the contexts in which they are used, and the anatomy involved [3]. Core stability is achieved when the intervertebral range of motion is maintained within a safe limit in response to internal and external perturbations [4]. On the other hand, core strength is responsible for producing the muscular force around the lumbar spine to maintain functional stability [2]. Therefore, it is through core strength that core stability is provided.

The functions of core stability and core strength given above stem from a rehabilitation viewpoint of the core. Being that the current study is in the sport performance realm, it is important to define them in such a manner. Therefore, core stability will be defined as the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities [5]. Core strength will be defined as the ability of the musculature to produce force via contractile forces and intra-abdominal pressure [6]. In the current study, the term core fitness will be used to describe the combination of core stability and core strength working together to perform a sport specific task. When the two systems of core fitness optimally function together, the result is proper force distribution and maximum force generation with minimal perturbations acting on the joints of the kinetic chain [7].

The kinetic chain is the coordinated, sequenced activation of body segments that places the distal segment in the optimum position at the optimum velocity with the optimum timing to produce the desired athletic task [8]. Success in a majority of sports is dependent upon producing external forces while maintaining dynamic stability. Instability of the core during athletic tasks leads to an increase in co-contractions of antagonistic muscles, which takes away from production of external forces [9]. Instability is the failure of the core musculature to apply enough force to maintain correct vertebral alignment [6]. The interaction between core fitness in the kinetic chain and sport performance lead Kibler to coin the phrase, "proximal stability for distal mobility," which describes the patterning of the generation of force in athletic movements [5]. Kibler's concept suggests that for the distal segments to function maximally in skilled movements, a stable base (core) must first be provided.

In the current study, the kinetic chain was examined with tests of isometric core strength and functional core strength. Tests of isometric core strength evaluated the ability of the core to provide a stable base of support with the assumption that greater isometric strength results in a greater ability to resist external perturbations. Tests of functional core strength evaluated the ability of the core to generate and transfer forces to the distal segments with the assumption that greater functional strength results in greater production of external force. These two components of core fitness were correlated with tests specific to soccer to see which plays a greater role in soccer sport performance. The specific tests of soccer sport performance that require an external force to be produced while maintaining sufficient stability were the standing soccer kick and throw-in.

The core musculature was originally separated by Bergmark into two functional regions, local or global, based on their role in stabilizing the core [10]. Local muscles attach to the lumbar vertebrae and are responsible for inter-segmental control [3]. These small and deep muscles provide the stability needed when tensile and compressive forces are acting on the lumbar vertebrae. Examples of local muscles are the transverse abdominis, multifidus, diaphragm, and the pelvic floor muscles [10] (Figures 1 & 2). Global muscles attach to the hips and pelvis in order to influence spinal orientation and control external forces on the spine [3]. These superficial muscles possess long lever arms, which make them capable of producing powerful movements. Examples of global muscles include the rectus abdominis, external oblique, internal oblique, erector spinae, and the lateral parts of the quadratus lumborum [10] (Figures 1 & 2).

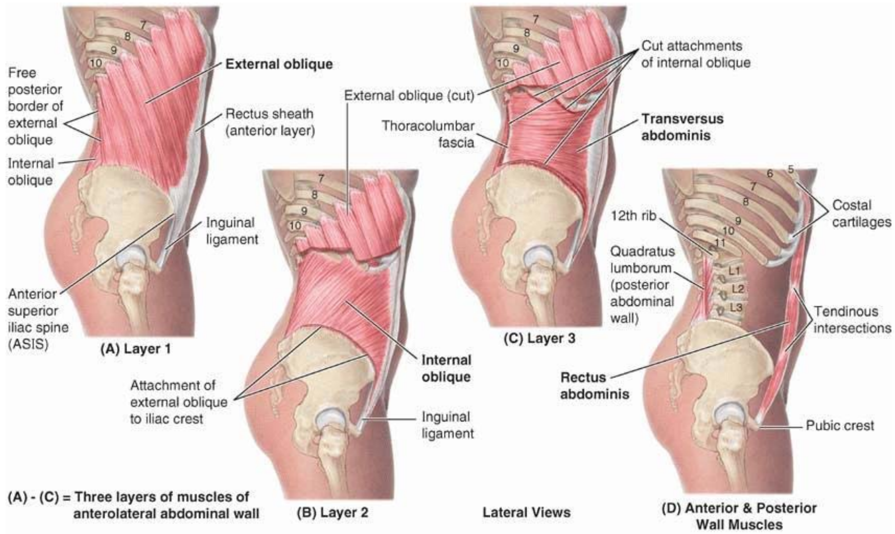

Figure 1: Lateral View of Core Musculature [11]

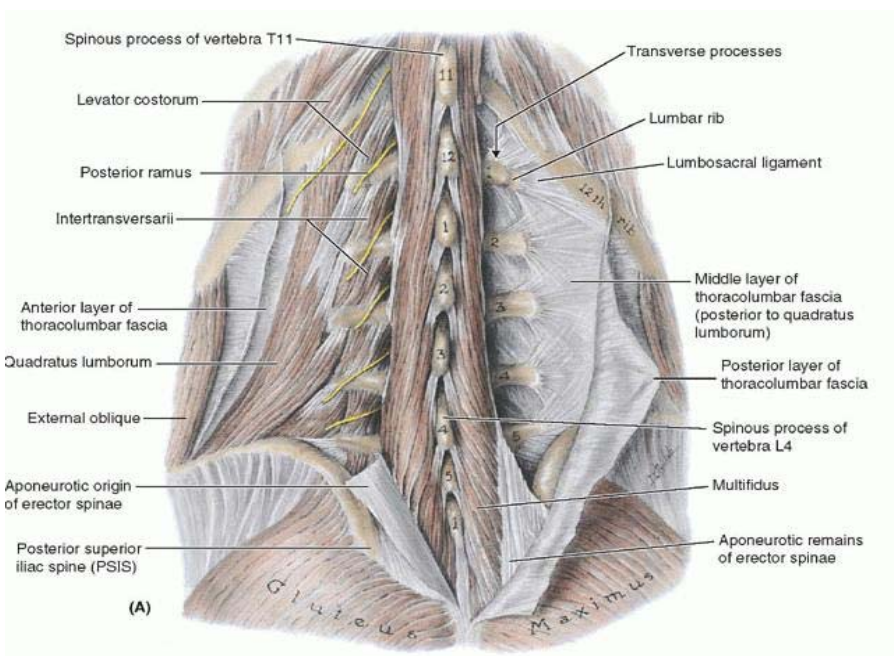

Figure 2: Posterior View of Core Musculature [11]

Examining the core from a sport performance perspective has broadened the scope of musculature that plays a role during core fitness. Some have recently included the muscles of the pelvis and shoulder as they are crucial in transferring energy from the larger torso to the smaller extremities [12]. For example, the hip musculature plays a crucial role within the kinetic chain in both the stabilization of the trunk and pelvis and in the transferring of force from the lower extremities [13]. Muscles of the mid-upper back have similarly been included when discussing the core musculature due to their attachment to the core of the spine and the role they play in scapular stabilization and upper limb movement [5].

The theoretical framework of the current study considered that since the kinetic chain encompasses local, global, pelvic/hip, and shoulder muscles, more accurate tests and correlations between core fitness and sport performance should be possible. Thus, the purpose of this study was to test the core musculature for isometric and functional core strength to determine which plays a greater role in sport performance during similar movement patterns. The movement patterns consisted of trunk flexion and bilateral rotation. Tests of isometric core strength measure the ability of the core to provide a stable base of support for limb function. Tests of functional core strength measure the ability of the core to generate and transfer forces through the core to the limbs. By correlating the isometric core strength and functional core strength tests with soccer sport performance tests, it will be determined which plays a greater role during soccer sport performance.

Previous research regarding core fitness and sport performance has failed to show a positive correlation between the two [12, 14-16]. Problems with these studies were that they failed to test the strength and power component of the core. Instead, they tested the endurance component and tried to correlate it with tests of muscular strength and power. Core stability in the Nesser studies [14, 15] was measured using McGill's protocol [17] for determining core endurance of the torso stabilizer muscles. McGill's protocol includes isometric trunk flexion, trunk extension, and left and right lateral musculature tests in which the subjects hold a static contraction for as long as possible [17]. Sport performance determinants were a 40-m sprint, pro agility, vertical jump, and single repetition maximum bench press, squat, and power clean tests. Nesser stated, "An accurate comparison of these two tests cannot be made because the strength and power tests involve primarily fast-twitch muscles fibers, maximum force production, and the adenosine-triphosphate-phosphocreatine energy system, whereas the core strength/stability tests focus more on slow-twitch muscle fibers, submaximal muscle contractions, and anaerobic glycolysis [14 (p. 1753)]."

Perhaps Nesser [14, 15] and Tse [12] used McGill's core endurance testing protocol [17] because there exists no gold standard to measure core strength and power [3]. Specificity of testing and training is vital to sport performance [18]; however, previous research has failed to use tests that are specific to performance capabilities. The current study will use tests that measure the isometric and concentric strength components of core fitness. Isometric core strength will be evaluated using tests adapted from Daniels and Worthingham's *Muscle Testing: Techniques of Manual Examination* 7th Ed [19]. Concentric, functional core strength will be evaluated using tests that were adapted from trunk medicine ball exercises [20]. To date, these isometric core strength and functional core strength tests have not been correlated to sport performance. They differ from previous studies in that they will measure the isometric and concentric strength components of core fitness rather than the endurance component.

Hypotheses

It was hypothesized that there would be a stronger correlation between the functional core strength tests and soccer performance variables than between the isometric core strength tests and soccer performance variables. This is due to the functional core strength tests being performed dynamically in a manner more similar to the tests of sport performance as opposed to the static tests of isometric core strength. Three hypotheses were investigated in this study:

1. Concentric trunk flexion would correlate more strongly with the soccer throw-in than isometric trunk flexion.
2. Concentric trunk rotation to the right side would correlate more strongly with the left footed soccer kick than isometric trunk rotation to the right side.
3. Concentric trunk rotation to the left side would correlate more strongly with the right footed soccer kick than isometric trunk rotation to the left side.

Limitations

The participants in this study have several years of soccer and weight lifting experience, which makes them familiar with the testing methods. Inexperienced participants could skew results due to poor test execution. Due to the sport specific nature of the tests involved, these results cannot be generalized to athletes in other sports. Therefore, results of this study are limited only to collegiate, female soccer players.

Delimitations

In order to have a more homogenous testing population, this study was limited to trained athletes from the same team. This way it can be ensured that all participants are at or near the same training level. Using a trained participant pool that is familiar and comfortable with the testing procedures should also provide for more accurate results by reducing the effect of learning.

Work done by Arokoski et al. [21] showed that differences exist between males and females in the activation of trunk muscles during various core exercises. Specifically, they found rectus abdominis, external oblique, and multifidus electromyographic activity to be significantly greater in women than men, which reflects higher abdominal and paraspinal muscle loading relative to maximal voluntary contractions (MVC). Therefore, women may be better able to activate their stabilizing muscles than men [21]. Due to trunk muscle activation differences in males and females, this study will consist of only female participants.

Definitions

<u>Core Fitness</u> – The combination of isometric core stability and concentric core strength to perform a task of sport performance.

<u>Core Stability</u> – The ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities [5].

<u>Core Strength</u> – The ability of the musculature to generate force through contractile forces and intra-abdominal pressure [6].

Kinetic Chain – The coordinated, sequenced activation of body segments that places the distal segment in optimum position at the optimum velocity with the optimum timing to produce the desired athletic task [5].

Specificity of Training – The distinct adaptations to the physiological systems that arise from a training program. Training is most effective when resistance exercises are most similar to the sport activity in which improvements are sought [18].

CHAPTER 2: REVIEW OF LITERATURE

Recent trends in strength and conditioning have placed an emphasis on core fitness for the purpose of improving sport performance. The core is viewed as the "powerhouse" of the body where power is not only created, but also transferred to and from the lower and upper body as an integral part of the kinetic chain [2]. Therefore, improving core fitness has been viewed as a principle way of improving performance across a variety of sports. This idea seems relatively simple but testing and training the core for the purposes of improving sport performance has created many questions among strength and conditioning professionals: What exactly are core strength and core stability? What structures and musculature define the core? How is core fitness related to sport performance? Much of the previous research has done little to answer these questions as good measures of core performance are lacking and the correlation between core fitness and sport performance has not been well established [12, 14-16].

Core Stability vs. Core Strength

Much confusion exists as to the differences between core stability and core strength. Often, these terms are used interchangeably, which exacerbates this confusion. Core stability occurs as a result of input from the passive spinal column, active spinal muscles, and neural control unit, which maintain intervertebral range of motion within a safe limit in response to internal and external perturbations [4]. Perturbations can be expected or unexpected and occur as a result of internal and external forces due to distal body segment motion [13]. In order to provide sufficient stability to protect the spine from perturbations, input from the passive, active, and neural subsystems are needed. These conceptually separate but functionally interdependent systems work together to provide core stability [4].

Similarly, core strength provides the muscular control required around the lumbar spine to maintain functional stability [2]. Strength in its most basic terms is the ability of a muscle to exert or withstand force [6]. One of the three subsystems of core stability is the active control of the muscles surrounding the spine and the ability of these muscles to produce the forces needed to provide spinal stabilization that make up core strength. Therefore, it is through the contractile forces created by the active muscles surrounding the spine that core stability is provided. The close relationship between core stability and core strength could be the reason as to why they may be confused for one another in the literature and by practitioners.

Another source of confusion between core stability and core strength stems from the sectors in which they are used: rehabilitation versus sport performance. The demands placed on core stability and core strength are vastly different within these sectors. In rehabilitation, core fitness focuses on the ability to perform pain-free activities of daily living with an emphasis placed on the control of spinal loading. In sport performance, core fitness focuses on the ability to maintain stability during highly dynamic and sometimes loaded movements [3]. Based on the sector in which core stability and core strength are used, they should be approached differently.

Being that the current study is being performed from a sport performance perspective, the terms core stability and core strength are combined into a single term, core fitness. For the purposes of this study, core stability will be defined as the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment in integrated athletic activities [5]. Whereas, core strength will be defined as the ability of the musculature to generate force through contractile forces and intra-abdominal pressure [6]. Since the core is central to almost all kinetic chains of sport performance tasks, control of core stability, core strength, and motion will maximize upper and lower body extremity function [5]. For the kinetic chain to function at its maximal capability, athletes must maximize the relationship between providing sufficient stability while producing forceful motions of sport performance.

Anatomy and Physiology of the Core Musculature

In order to understand the role that core fitness plays in sport performance, understanding the anatomy and physiology of the core musculature is imperative. However, there is not a fully agreed upon designation of which muscles comprise the core musculature. Again, defining the core musculature may differ depending on whether it is a rehabilitation study or a sport performance study [3]. As previously stated, the rehabilitation viewpoint proposed by Bergmark placed the muscles of the core into local or global groups based on their role in acting directly on the lumbar spine or in transferring a load between the pelvis and thoracic cage. Sport performance based views of the core musculature have also included the shoulder and pelvic muscles for the role they play in the transfer of power through the core and out the extremities [3]. Richardson et al. described the core musculature as a box with the abdominals in the front, paraspinals and gluteals at the back, diaphragm as the roof, and pelvic floor and hip girdle as the floor [22]. Within this box are 29 pairs of muscles that function to support the lumbo-pelvic-hip complex in order to stabilize the spine, pelvis, and kinetic chain during functional movements [7]. The latissimus dorsi, trapezius, and rhomboid muscles have also been included when describing the core musculature from a sport performance perspective due to their attachment to the core of the spine and the role they play in scapular stabilization and upper limb movement [5].

Sometimes overlooked in being included within the core musculature, the hip musculature plays a significant role in sport performance and should be included in this discussion of the core musculature because they provide pelvic and spinal stability and, due to their large cross-sectional area, are capable of producing significant amounts of force for trunk flexion, extension, and rotation. The iliopsoas is the primary muscle of hip flexion and its attachment to the lumbar spine also gives it potential to provide stability during movements of increased lumbar flexion [2]. The glutei produce hip extension, produce power for forward leg movements, and provide trunk stability over the planted leg [8]. The hip musculature plays a significant role in the kinetic chain by transferring forces from the lower extremities to the pelvis and spine; i.e., the hip and trunk musculature has been shown to contribute about 50% of the kinetic energy and force to throwing motion [5], which makes it a pertinent piece of the core musculature from a sport performance perspective.

In order for powerful movements of sport performance to take place, the core musculature must provide a stable base of support. Theoretically, contraction of the transverse abdominis acts as a girdle by increasing intra-abdominal pressure and putting tension on the thoracolumbar fascia, which creates a rigid cylinder to enhance lumbar spine stiffness [2, 5, 13]. The importance of this is demonstrated in studies that show contractions that increase intra-abdominal pressure precede the initiation of large segment movements of the upper and lower limbs [23], creating a stable base of support prior to limb movements. Hodges and Richardson found that the transverse abdominis and multifidus contract 30 ms prior to shoulder movement and 110 ms prior to leg movement [24]. Postural support has also been shown to be provided by the rectus abdominis and oblique abdominal muscles, which contract in a direction-specific pattern prior to limb movement [5].

It has also been found that the multifidi and abdominal muscles require only 5% of a maximal voluntary contraction (MVC) for activities of daily living and 10% of a MVC for rigorous activities to stiffen the spinal segments [25]. Therefore, a forced maximal contraction is not needed in order to increase core stability. Work done by Cholewicki et al. found that the amount of stability provided during a given task is dependent upon the load and direction of the load placed on the core [26, 27]. Stability is greatest during the most difficult tasks and decreases during periods of low muscular activity [26]. Thus, only the amount of stability required to provide proper vertebral alignment during a task is given.

Core stability is dependent on three subsystems: the passive spinal column, active spinal muscles, and a neural control unit [4]. Passive core stability is provided by the osseous and ligamentous structures of the lumbar spine. These structures alone provide little support but may have a more important role of providing proprioception of the lumbar spine segments [2]. Without assistance from active muscles, the spine itself is not capable of supporting heavy loads. Therefore, the active spinal muscles of the trunk and pelvis are responsible for maintaining core stability as well as providing and transferring energy from proximal to distal body parts [5]. Finally, dynamic stability is dependent on two-way neuromuscular input to control the trunk during movements in response to forces generated from distal body segments and from expected or unexpected perturbations [28]. The core base of support provided by these three subsystems is crucial in allowing movement between body parts, supporting loads, and protecting the spinal cord and nerve roots [4].

The current study approached the core musculature from a sport performance perspective. Due to the complex interaction in providing both components of core fitness, the local, global, and hip musculature were analyzed to find whether they play a larger role in providing a stable base of support or in generating/transferring of forces during movements of soccer sport performance.

Previous Research on Core Fitness and Sport Performance

Prior to sport performance and training, testing should be done in order to evaluate an athlete. Proper testing can be used to assess athletic talent, identify any physical limitations, provide reference values to evaluate the effectiveness of a training program, and set training goals [18]. However, previous work on the relationship between core fitness and sport performance has shown little to no correlation. A possible reason for this was the failure to select appropriate testing methods. Test selection should consider the physiologic energy systems and movement specificity patterns required by the sport [18]. Previous studies (Table 1) [12, 14-16] did not employ testing protocols specific to the physiologic characteristics and movement patterns of the core musculature relative to the sport performance tests they were correlated with, and have failed to show a correlation between core fitness and sport performance.

Table 1: Previous Research Examining the Relationship between Sport Performance and Core Testing Measures.

Study	Measures	Data Collected	Subjects	Results	Key Conclusions
Cowley and Swensen [20]	Tested the reliability of the front and side abdominal power tests (FAPT and SAPT)	A test-retest method was used to find relative and absolute reliability of the FAPT and SAPT	24 untrained women	The FAPT and SAPT had high levels of relative reliability and moderately high levels of absolute reliability	There was no learning effect between testing sessions and these are reliable tests to assess power component of core stability in young women
Nesser et al. [14]	Subjects were tested using strength, performance, and core stability variables	Strength variables (1RM bench, 1RM squat, and 1RM power clean), performance variables (vertical jump, 20- and 40-yard sprint, and 10-yard shuttle), and core stability variables (back extension, trunk flexion, and side bridges)	29 male collegiate football players	Core stability is moderately related to strength and performance	Increases in core strength are not going to contribute to strength and power and should not be focus of strength and conditioning.
Nesser and Lee [15]	Subjects were tested using strength, performance, and core stability variables	Strength variables (1RM bench and 1RM squat), performance variables (vertical jump, 40-yard sprint, and 10-yard shuttle), and core stability variables (back extension, trunk flexion, and side bridges)	16 female collegiate soccer players	Core strength is not related to strength and power	Core strength does not contribute significantly to strength and power and should not be focus of strength and conditioning
Roetert et al. [29]	Subjects were tested using isokinetic and functional trunk strength measures	Isokinetic trunk flexion and extension strength (60° s^{-1} and 120° s^{-1}) and functional trunk strength (forehand, backhand, overhead, and reverse overhead medicine ball throws)	60 male and female elite junior tennis players	Significant relationship between isokinetic trunk testing and functional movement patterns in tennis	The isokinetic and functional trunk strength tests would be useful additions to a tennis training program
Sato and Mokha [30]	Effects of 6-week core strength training (CST) on running performance	Ground reaction forces (GRF), star excursion balance test for lower leg stability, and 5000-m run.	28 runners Experimental group n=12, control group n=8.	The CST experimental group showed faster times in 5000-m run but no influence on GRF or lower leg stability.	A high CST volume can have a significant effect on running performance
Stanton et al. [16]	Effect of short term Swiss ball training on core stability and running economy	Core stability using Sahrmann test, electromyographic activity of abdominal and back muscles, VO_{2max}, and running economy	18 young male athletes (experimental group n=8, control n group n=10)	Swiss ball training positively affected core stability without concomitant improvements on physical performance	The Swiss ball training failed to follow principle of specificity. Training following this principle may have improved performance
Tse et al. [12]	Examine effect of core endurance training on rowing performance	Trunk endurance measured using flexion, extension, and side flexion tests. Performance measured by vertical jump, broad jump, shuttle run, 40-m sprint, overheard medicine ball throw, and 2,000-m maximal rowing ergometer test.	45 college-age rowers (core training group n=25, control group n=20)	No significant differences were found for any of the functional performance tests after the 8-week core endurance training program	Although core stability muscles have positive effects on reducing low back pain, it may actually be strength and power of the trunk muscles that influence physical performance tasks

Nesser et al. [14] reported a weak relationship between what they defined as core strength and performance variables. Using McGill's muscular endurance protocol [17], core strength of the torso stabilizer muscles was measured. McGill's protocol consisted of an isometric trunk flexor test, trunk extensor test, and left and right lateral muscular test with a minimum of five minutes between tests. Participants were required to hold isometric positions for as long as possible until the starting positions were no longer able to be maintained [17], a test of endurance rather than strength. Nesser then measured strength variables of 29 NCAA division 1, male, football players (height 184.0 ± 7.1 cm; weight 100.5 ± 22.4 kg) using a single rep max test for the bench press, squat, and power clean. Power variables were measured using the vertical jump, 20- and 40-yard sprint, and 20-yard shuttle run. Each core test, as well as a total core endurance score, was correlated with each strength and performance test. Although a number of significant correlations were found, they ranged from weak to moderate and were not consistent. This is to be expected when attempting to correlate strength and power to muscular endurance.

In a separate study that utilized the same test methods, Nesser and Lee [15] evaluated 16 NCAA division I female soccer players (height 163.6 ± 5.2 cm; weight 60.7 ± 7.5 kg). No significant correlations were found between core endurance and the performance variables. Reasons given for the lack of a strong relationship between core endurance and sport performance were that the core muscular endurance tests were not specific to the strength and power variables or that core strength plays only a small role in strength and power performance [14, 15]. Although Nesser and Lee claimed to be measuring core strength, the core tests they used were endurance in nature. Comparisons cannot be made between tests of strength and core endurance because measures of core endurance are not a good representation of how muscles operate under functional loads and movements [14].

Tse et al. [12] performed a study that examined the effectiveness of a core endurance training program on college-aged rowers (core group N = 20: age 21 ± 1.0; height 1.74 ± 0.04 m; weight 68.4 ± 8.6 kg and control group N =14: age 20.1 ± 1.0; height 1.75 ± 0.06 m; weight 67.3 ± 5.8 kg). McGill's protocol [17] was again used to measure torso muscular endurance. Performance tests included: vertical jump, standing broad jump, 10-meter shuttle run, 40-meter sprint, 2 kg medicine ball overhead throw, and a 2,000-meter rowing ergometer test. Maximal heart rate and final lactate were measured after the rowing ergometer test in order to ensure maximal effort. During the 8-week study, all participants continued to participate in their regular exercise regimen, which consisted of one exercise for each major muscle group with two sets of 12-15 repetitions at 50% of their single repetition maximum. In addition, the core group participated in two core endurance training sessions per week lasting 30-40 minutes in which participants were taught how to properly activate the transverse abdominis and multifidus muscles as well as perform static and dynamic core endurance exercises. After the 8-week intervention, performance variables were measured and Tse et al. found that there was no improvement in any of the tests. They cited possible reasons for the lack of improved performance as the short duration of the intervention or the elite beginning training level of these athletes. Tse et al. neglected to consider that muscular endurance does not play a role in strength or power production. They went on to say that although endurance is effective in the treatment of low back pain, it may be the strength and power of the core muscles that influence performance tasks [12].

Studies by Stanton et al. [16] and Sato and Mokha [30] regarding core fitness and running performance showed conflicting results. The study by Stanton et al. investigated the role that short term core stability training had on running economy. Twenty-two male athletes (15.5 ± 1.4 years; $\dot{V}O_2max$ 55.3 ± 5.7 ml/kg/min) were recruited for this study. Core stability was measured using the Sahrmann and a Swiss ball prone stabilization tests [16]. The Sahrmann core stability test is performed by placing a pad inflated to 40 mmHg under the lordotic curve of the participant. There are five test levels with increasing difficulty. Level 1 is performed by first producing an isometric contraction of the abdominal musculature that braces the trunk without a movement being produced. The legs are then raised to 100˚ of hip flexion with comfortable knee flexion; this position becomes the starting position for each subsequent level. During level 2, the participant lowers one leg until the heel contacts the ground, the knee is fully extended, and the leg is then returned to the starting position. Level 3 is performed in same manner as level 2 except the heel does not contact the ground, but is instead lowered until it is 12 cm above the ground. During level 4, the subject lowers both legs until the heels contact the ground, knees are fully extended, and legs are then returned to the starting position. Level 5 is performed in the same manner as level 4 except the heels do not contact the ground, but are instead held 12 cm above the ground, knees are fully extended, and legs are then returned to the starting position. Failure at any level occurs when a 10 mmHg change above or below the baseline value of the pad is measured at any point during the test.

The Swiss ball prone stabilization test was performed by placing the toes on the vertical apex of a Swiss ball, with the hands on the ground and elbows locked so that the participant's body was parallel to the ground. The participant was required to hold this position until failure. Running economy and $\dot{V}O_2max$ were measured during an incremental treadmill test to volitional fatigue. The treadmill speed was set at 7 $km \cdot h^{-1}$ during a five minute warm-up and then the speed was increased 1 $km \cdot h^{-1}$ every minute until volitional fatigue was reached. Both the control and experimental groups performed their normal training activities with the experimental group also participating in a 6-week Swiss ball core strengthening program. The program was performed twice a week for 25 minutes with six core stability exercises being performed on the Swiss ball, including: lunge, supine lateral roll, alternating superman, forward roll on knees, supine two leg bridge, and supine Russian twist. The study found that although core stability improved as a result of the training, running economy and performance did not. The failure of improved performance variables may have been due to a lack in specificity of training or an insufficient training volume [16].

On the other hand, Sato and Mokha [30] were able to show an improvement in running performance in their study, which tested the influence of core strength training on running kinetics, lower extremity stability, and 5000 meter performance in runners. Using 28 adult subjects (36.9 ± 9.4 years), ground reaction forces, lower extremity stability, and 5000 meter run performance were measured before and after a 6-week study. Lower extremity stability was measured using the Star Excursion Balance Test. This test was performed by having the participant stand barefoot on one leg at the center of a 0-180˚ line. The participant then reached out their other leg as far as possible in the direction of the 0, 90, and 180° lines while maintaining balance. Participants lightly touched their toe to the ground at the maximum reaching point and held this position for three seconds. The test was then performed on the opposite leg.

The experimental group performed core strengthening exercises four times a week, with the training volume increasing every two weeks in order to elicit strength gains. Five exercises were performed that targeted the abdominal, hip flexor/extensor, and back extensor muscles: an opposite arm/opposite leg raise as well as an abdominal crunch, back extension, hip raise, and Russian twist on a stability ball. After 6-weeks of training, the experimental group showed a significant improvement in 5000 meter run performance but not in ground reaction forces or lower extremity stability. The experimental group dropped 47 seconds off their time as compared to only 17 seconds in the control group. While studies such as Stanton et al. [16] have also implemented a core strength training protocol, they have failed to show an improvement in performance. Sato and Mokha increased the training volume bi-weekly in an attempt to improve strength rather than performing the same volume throughout the study, which was seen in the study by Stanton et al. They attribute the improved performance to a higher training volume, which possibly provided a strong enough stimulus to elicit strength gains and improve running performance [30]. Although a conditioning effect on the core musculature was not measured, after the 6-week core strength training intervention, the experimental group reported that they were more conscious of body position and the importance of good posture while running [30], which may have also led to improved performance.

Roetert et al. [29] measured the relationship between isokinetic and functional trunk strength of 60 male and female elite junior tennis players between the ages of 13-17 (mean: 14.95; standard deviation: 1.3). Isokinetic trunk flexion and extension strength were measured using a Cybex 6000 dynamometer at speeds of $60°s^{-1}$ and $120°s^{-1}$. Functional trunk strength was measured using forehand, backhand, overhead, and reverse overhead medicine ball throws for maximal distance using a 6 lb. medicine ball. Correlations ranged from 0.52 – 0.67 (p value ≤ 0.01) when peak torque extension at both speeds was correlated with the four functional throws. Correlations ranged from 0.67 – 0.76 (p value ≤ 0.01) when peak torque flexion at both speeds was correlated with the four functional throws. The authors did not provide a detailed description of how the functional throws were performed. Therefore, it is not known to what extent the core musculature was isolated or how much influence force production from the limbs had on performance. However, they concluded that there is a positive relationship between isokinetic trunk strength testing and functional movement patterns in elite junior tennis players.

A possible reason for the authors of the previously mentioned studies [12, 14-16] to use tests that were endurance in nature rather than dynamic core tests is because there exists no gold standard for field tests that measure core strength when performing everyday tasks and sport movements [3]. Isometric and isokinetic core fitness testing both have their limitations. Isometric tests only assess muscle performance at one muscle length while isokinetic tests require expensive equipment. Currently, isokinetic trunk testing is the standard measure of core stability due to its reliability [31].

Due to the complex interaction between lumbo-pelvic-hip musculature, finding a single test to evaluate core fitness remains difficult. Not only this, but field tests that measure the strength and power component of core fitness are sparse, which is why

Cowley and Swensen [20] developed the front abdominal power test (FAPT) and side abdominal power tests (SAPT). These tests may be useful in sport performance testing because they can be performed in an explosive manner similar to sport. It is also possible that these tests are able to identify athletes who may be at higher risk of low back or lower extremity injuries due to a weak core, being that strength tests are better predictors of back and lower extremity injuries than endurance tests [20, 32]. Not only does a weak core diminish performance [33] but it can also increase the likelihood of low back and lower extremity injuries, especially in females [32].

The FAPT and SAPT, which were adapted from plyometric medicine ball exercises that are designed to improve core power, are performed by explosively contracting the core musculature and using the arms as a lever to maximally project the ball. Using 24 untrained women, they performed three trials of the FAPT and SAPT on non-consecutive days. They found that there was a 3% increase in mean distance between the trials, but this was not significant and indicates that there was not a learning effect between the trials. In order to test reliability, an interclass correlation (ICC) of 0.95 was reported for the FAPT and 0.93 for the SAPT, which indicates excellent test-retest reliability [20]. The authors concluded by stating that their findings on the FAPT and SAPT were reliable tests that may be used for assessing the strength and power component of the core.

To the author's knowledge, the ability of the FAPT and SAPT as valid measures of functional core strength has not been verified in the literature. Limitations of these tests include the release height and angle of the medicine ball as well as unintended muscular involvement. All things being equal, a participant who is taller and releases the medicine ball from a height greater than that of a shorter participant will project the ball further. The angle at which the ball is released could also affect test performance. During both tests, the medicine ball is to be projected directly out of the hands of the participant, not at an upward angle. Although this is monitored for and results in a failed attempt, the possibility of a slight upward release remains.

In addition, Kumar et al. [34] found that females recruit the contralateral pectoralis muscles to generate rotational torque in order to make up for weaknesses in the abdominal and back muscles. Ikeda et al. [35] analyzed differences in the side medicine ball throw between males and females and found that they differed significantly in test execution, possibly due to the difficulty of women to recruit the trunk rotators. Thus, the FAPT and SAPT do not isolate the core musculature and the results can be confounded by the contribution of other muscle groups. The lack of reliable and valid field tests of core strength is an issue in the field testing of athletes. The unavailability of isokinetic trunk testing led to the FAPT and SAPT being used to quantify functional core strength in the current study. Future research should better establish the validity of the FAPT and SAPT with electromyography to ensure that these tests are measuring what they are intended to measure.

The tests used to quantify isometric core strength were adapted from Daniels and Worthingham's *Muscle Testing: Techniques of Manual Examination* 7th Ed [19]. Pilot testing prior to actual participant involvement established that these tests were highly reliable (Table 4.2). Tests of isometric trunk flexion and bi-lateral rotation were performed in the exact manner as tests used for manual muscle testing used by physical therapists. A dynamometer was used to measure the maximal amount of force the participants could produce during an isometric contraction. The position of the participant and testing apparatus were set up in a manner so that measurement of the isometric contraction occurred along the correct angle of pull relative to the intended muscle. The movements performed and test design helped to establish these tests as valid measures of strength for an isometric contraction.

In summary, various reasons exist as to why previous research has not been able to firmly establish the role that the core plays in sport performance. Both the study by Nesser et al. [14] and the study by Nesser and Lee [15] used testing that measured core endurance and the studies by Tse et al. [12] and Stanton et al. [16] used core training that was designed to improve endurance of the core. All of these studies attempted to correlate endurance-oriented core tests with highly dynamic tests of sport performance. Knowing what we know about the core muscles, their fiber types, and their capabilities, it should be no surprise that there was a weak correlation between the core and sport performance testing in these studies [12, 14-16]. Previous research examining the relationship between the strength and power component of core fitness is still lacking. However, the work done by Roetert et al. demonstrates that the relationship between core strength and functional movement patterns similar to sport does exist [29]. More research is warranted in order to better explain the role between core fitness and sport performance. Using tests that evaluate the strength component of the core, a better relationship between the core and sport performance should be found than what has been seen in previous studies [12, 14-16].

Conclusion

From this review of literature, it is clear that the relationship between core fitness and sport performance is not fully understood. The work of Nesser et al., Stanton et al., and Tse et al. concluded that there is a weak correlation between core endurance and sport performance[12, 14-16]. However, these studies failed to measure the strength component of core stability and how it correlates with performance. Sport requires explosive and dynamic movements that travel through the kinetic chain of the core. When testing and correlating the relationship between core fitness and sport performance, testing should effectively measure the determinants of core stability and core strength relative to sport performance. With appropriate strength testing of the core, this study should determine whether the ability of the core to provide a stable base of support for optimal limb function or the ability of core concentric strength to produce and transfer force to the distal segments will correlate more strongly with soccer sport performance. Not only is it the intention of this study to better explain the relationship between the core and sport performance, but to guide future studies that improve training and sport performance.

CHAPTER 3: METHODS

Coaches and strength and conditioning professionals have prescribed core training for athletes without adequate proof that it does in fact improve sport performance. Core training is effective in the prevention and treatment of back and lower extremity injuries, but data supporting the relationship between core fitness and sport performance is lacking [2]. In order to improve sport performance training, a better understanding of the role the core plays in sport-specific movements is needed. The current study used tests of core fitness and correlated them with tests of soccer performance to better explain the role of the core during sport performance. The soccer kick and throw-in are two determinants of success in the sport of soccer [36]. Theoretically, the core musculature is the link in the kinetic chain between the lower and upper bodies and should have a direct influence on the aforementioned determinants of soccer performance.

The theoretical framework of the current study considered that since the kinetic chain encompasses local, global, pelvic/hip, and shoulder muscles, more accurate tests and correlations between core fitness and sport performance should be made. Thus, the purpose of this study was to test the core musculature for isometric and functional core strength to determine which plays a greater role in sport performance during similar movement patterns. This was examined by performing tests of similar movement patterns (trunk flexion and bi-lateral rotation) in each prescribed manner (isometrically, concentrically/functionally, and soccer performance) and correlating them with one another. Each group of tests analyzed the contributions of the same musculature in different manners. Tests of isometric core strength measured the ability of the core to provide a stable base of support for optimal limb function. Tests of functional concentric core strength measured the ability of the core to produce and transfer force to the distal segments.

Experimental Design

This was a correlational study to determine whether the ability of the core to provide a stable base of support or the ability of the core to produce and transfer force correlated more strongly with soccer sport performance. The predictive variables in this study were the isometric core strength tests of trunk flexion, right rotation, and left rotation and the functional core strength tests using the FAPT and SAPT. The criterion variables in this study were the soccer sport performance variables, which included a soccer-style kick with the dominant and non-dominant leg and a soccer style throw-in.

A stable base of support created by core isometric strength and forceful flexion created by core functional strength are both needed to maximally perform the throw-in. It was hypothesized that concentric trunk flexion would correlate more strongly with the soccer throw-in than isometric core trunk flexion. To test this hypothesis, isometric trunk flexion strength was used to quantify the ability to maintain core stability in the sagittal plane. The ability to generate/transfer force to the distal segments in the sagittal plane was quantified using the FAPT. These tests were correlated with the soccer throw-in.

During the kick, muscular activation is initiated contralateral to the kicking leg. A rigid base of support maintained by core isometric strength and the forceful rotation created by core functional strength are both necessary to maximally perform the kick. It was hypothesized that concentric trunk rotation to the right side would correlate more strongly with the left footed soccer kick than isometric trunk rotation to the right side. It was also hypothesized that concentric trunk rotation to the left side would correlate more strongly with the right footed soccer kick than isometric trunk rotation to the left side. To test these hypotheses, isometric trunk rotation strength was used to quantify the ability to maintain core stability. The ability to generate/transfer force to the distal segments in the transverse plane was quantified using the SAPT. These tests were correlated with the contralateral soccer kick.

Participants

Consistent with previous studies, a homogenous population was tested to limit any training or experience factors that may affect the data [12, 14-16]. Eleven female participants (age: 19.73 ± 0.9 y, height: 1.63 ± 0.04 m, weight: 64.41 ± 11.73 kg) from the College of Idaho soccer team who were of the same training level and had some familiarity with the testing protocols volunteered. Only participants who were free of injury and fully able to complete the testing were selected and were required to sign an informed consent. This study was approved by the Institutional Review Board at Boise State University. All participants were right foot dominant. A power analysis determined that a minimum of 16 participants had to be tested in order to produce significant results [37]. Due to some of the team members being multi-sport athletes, not all of the team was available for the testing sessions. Thus, testing was performed by 13 participants; but due to the inability of two participants to finish all of the tests, only data from 11 participants were analyzed.

Procedures

Testing took place on the campus of the College of Idaho in Caldwell, Idaho. All participants were familiarized with the tests prior to testing. The isometric core strength tests consisted of trunk flexion, right rotation, and left rotation and the functional core strength tests included the FAPT and SAPT [20]. The sport performance variables tested were soccer style kicks with the dominant and non-dominant foot as well as a throw-in, both for maximal speed. Speed was then converted to a force by multiplying the mass of the ball by the acceleration imparted by the athlete.

Prior to all testing sessions, the participants followed a series of dynamic warm-up exercises. The warm-up consisted of 20 yards of high knees, butt kickers, side shuffle, karaoke, A-skip, power skip, and walking tin soldier kicks. In order to stretch the trunk, the windmill stretch was performed 10 times to each side as well as a prone superman hold 10 times for three second stretches.

Testing took place over a 2-day period with tests on both days being performed in random order to avoid any potential interaction between tests. A random order generator was used to randomize all tests [38]. Day 1 consisted of height and weight measurements as well as the functional core strength and soccer performance testing. The FAPT and SAPT were thoroughly demonstrated and then the participants were allowed to practice the tests in order to ensure proper performance. Participants then each performed three successful attempts of each test with the best efforts recorded. The soccer kick and throw-in were also demonstrated to and practiced by the participants. Again each participant made three successful attempts with the best effort being recorded.

Participants rested 20-30 seconds between each attempt of the functional core strength and soccer performance tests.

Day 2 of testing consisted of the isometric core strength testing. A thorough demonstration was given by the test administrator. When the participants performed the isometric tests, encouragement was given and verbal cues such as “do not jerk” and “perform a smooth, maximal contraction” were used to ensure that each variation of the test was performed properly with a MVC. Each participant made three successful attempts with the best effort recorded. Participants were given 20-30 seconds to rest between each attempt of the isometric core strength tests. If a participant failed to execute either of the performance or core strength tests correctly, additional attempts were made until three correct attempts were achieved.

Isometric Core Strength Testing

The isometric core strength tests were adapted from physical therapy manual muscle tests from Daniels and Worthingham’s *Muscle Testing: Techniques of Manual Examination* 7th Ed [19]. The position of the participant and specific movement patterns of these tests allowed the intended core musculature to be evaluated for isometric strength. Strength was measured in kilograms (kg) using a dynamometer (Baseline, White Plains, NY) (Figure 3). Prior to this study, the Baseline dynamometer had not been used as a measurement tool of isometric core strength. Therefore, it was imperative to perform a pilot study prior to experimental testing to establish reliability of the testing methods and measurement device. Pilot testing consisted of seven participants who performed the testing in the exact same manner the actual participants would. Each participant made three successful attempts of an isometric MVC during tests of trunk flexion and bi-lateral rotation. The testing methods and measurement device were found to be highly reliable (Table 4.2).

A shoulder harness was used for the trunk flexion, rotation right, and rotation left tests. The center hook was used for trunk flexion. The hook behind the left scapula was used for right rotation and the hook behind the right scapula was used for left rotation (Figure 4). The hooks were positioned 12.7 cm from center near the inferior angle of the scapula. For all trunk tests, a chain was used to connect the harness to the dynamometer. Chain length was set to where there was no slack in the line while the participant was in the neutral position.

Figure 3: Baseline Dynamometer

Figure 4: Shoulder Harness

The bench used for testing was set at 62.23 cm off the ground and a center point was marked 7.62 cm out from the edge of the bench (Figure 5). From there, a measurement line was drawn 38.1 cm straight out from the center point as well as a line 45° right and left of center. The front edge of the dynamometer was set at the 38.1 cm line for all of the tests. Flexion was set at the center line while rotation right was set at 45° left of center and rotation left was set at 45° right of center (Figure 6). The dynamometer was set up in this manner so that the contraction, or pull by the participant, was in a direct line with the dynamometer, which is similar to how manual muscle testing of the trunk is performed in physical therapy [19]. The distance between the dynamometer and the hook attachment was constant so that the angle of the pull was as close as possible to being the same between participants. Due to possible torso length differences between the participants, the angle of the pull may have slightly differed; but due to the relatively small standard deviation in height (1.63 ± 0.04 m), this effect was minimal.

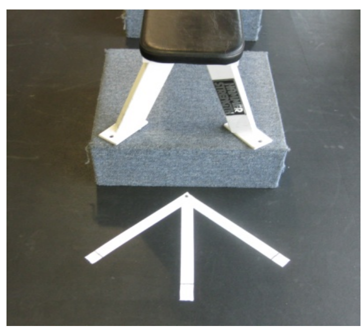

Figure 5: Isometric Core Strength Testing Setup

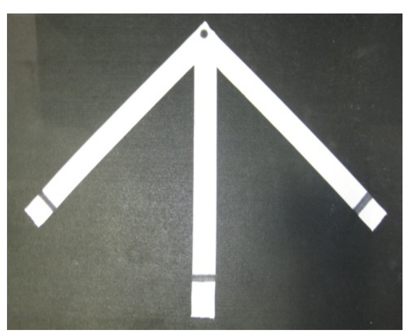

Figure 6: Locations of Dynamometer Placement

During the contraction, the participants were instructed to give a smooth and maximal effort without jerking. Once they felt like they had reached their maximal contraction, they relaxed, never giving more than a three second contraction. After a brief rest period of 20-30 seconds, the participant performed another attempt. Three successful attempts were made by each participant. Participants performed isometric flexion, rotation right, and rotation left in the same testing session with randomized test order to limit the effect of one isometric test on another.

Isometric Trunk Flexion – This test measured the maximal isometric strength of the muscles that produce trunk flexion. The participant laid supine with her legs extended and hips and feet fastened to the bench. The subject's arms were folded across her chest and the harness was connected to the dynamometer. The participant was then instructed to perform a curl up (Figure 7).

Figure 7: Isometric Trunk Flexion Strength Testing

Isometric Trunk Rotation – This test measured isometric strength of the muscles that produce trunk rotation. The participant laid supine on a bench with her legs fully extended and hips and feet fastened to the bench. The upper body harness was connected to the dynamometer, which was placed at 45° relative to the participant so she was pulling in a direct line with the involved oblique muscle. The participant was instructed to take her left shoulder to her right hip in a modified crunch (Figure 8). This was performed in the exact opposite manner to test the left side (Figure 9).

Figure 8: Isometric Trunk Rotation Right Strength Testing

Figure 9: Isometric Trunk Rotation Left Strength Testing

Functional Core Strength Testing

<u>Front Abdominal Power Test</u> – This test was performed with the participant lying on her back, knees bent at 90°, arms extended overhead, and feet positioned at the beginning of the measurement line. The feet were secured so that they did not come off the ground as the participant flexed her trunk. Hands were supinated with the thumbs touching and a 2kg medicine ball was placed in them. When instructed to, the participant explosively contracted the abdominal and hip flexor muscles, causing the trunk to come off the floor, and the ball was released when the hands were over the knees. Shoulder, elbow, and

wrist joints remained extended throughout the movement and the feet and buttocks remained in contact with the floor (Figure 10). The distance the ball traveled was measured in meters from the point at the tips of the feet to where the medicine ball landed. An ICC performed by Cowley and Swensen found excellent test-retest reliability of the FAPT (e.g., 0.95 at a 95% confidence interval) [20].

Figure 10: FAPT Testing

Side Abdominal Power Test – This test was performed with the participant seated, knees bent at 90°, and feet placed shoulder width apart on the ground. The left edge of the foot was placed at the beginning of the measurement line. The participant extended her arms straight out in front of her with hands supinated and her fifth digits touching. The participant then lowered her torso so that she sat 45° to the ground and a 2kg medicine ball was placed in her hands. She then slowly rotated to her right until her arms were perpendicular to the measurement line and forcefully rotated to the left by explosively contracting the core musculature and releasing the ball as her arms passed over her left knee. The countermovement rotation to the right and then explosive movement to the left was performed in a continuous manner and arms remained parallel to the ground with no upward movement while the participant's feet and buttocks remained in contact with the ground. The distance the ball traveled was measured in meters from the lateral edge of the left foot to where the ball landed (Figure 11). This test was also performed to the left side in the exact opposite manner. An ICC performed by Cowley and Swensen found excellent test-retest reliability of the SAPT (e.g., 0.93 at a 95% confidence interval) [20].

Figure 11: SAPT Testing

Soccer Performance Testing

The tests of soccer performance included in this study were the standing kick and throw-in. Reliability of the standing kick and throw-in, as depicted by an ICC at a 95% confidence interval, were 0.76 and 0.87, respectively [36]. Both of these tests measured the maximal distance the ball traveled in the air. Due to the effect that elevation angle has on distance traveled, it was suggested that a radar gun be used to measure ball speed instead. Using a radar gun to measure ball speed, a study performed by Markovic et al. [39] found the reliability of the standing kick to be 0.95 at a 95% confidence interval. Both the standing kick and throw-in were performed stationary in order to isolate the movement to the core musculature as much as possible and to eliminate any forward momentum that could aid in the amount of force produced. Due to the simplicity and reliability of these tests, they are recommended for the purpose of testing and evaluating soccer performance [36, 39]. A standard size 5 soccer ball was used for testing.

Standing Kick – This test measured the maximal force applied to project a soccer ball using a soccer-style kick. Each participant stood with their non-kicking leg beside a stationary ball. A counter movement swing was produced with the kicking leg and the ball kicked as hard as possible [36]. The ball was kicked for maximum speed (meters per second, m/s) at a Jugs radar gun (Jugs Sports, Tualatin, OR), which was placed 8.33 m from where the ball was struck. Three attempts were made.

Throw-in – This test measured the maximal force applied to project a soccer ball using a soccer-style throw-in. The ball was placed in the participant's pronated hands. She raised the ball overhead with her elbows and wrists fully extended. An extension counter movement of the trunk was produced followed by a forceful flexion of the trunk [36]. The ball was projected using movement produced only by the shoulders and trunk as extension of the elbows or wrists nor stepping were allowed. The ball was thrown for maximum speed at a radar gun, which was placed 8.33 m from where the ball was thrown. Three attempts were made.

Statistical Design

Prior to data collection, a pilot study was performed on the isometric core strength tests in order to assess their reliability. A Cronbach's alpha measured the internal consistency reliability, which is the extent to which the items of a measure assess a common characteristic [40]. A Pearson product correlation was performed to determine the strength of the relationship between the predictor and criterion variables. Correlations were run as single-tailed tests with significant correlations being found at a p-value ≤ 0.05. All data were analyzed using PASW 18.0 software package (SPSS Inc., Chicago, IL).

CHAPTER 4: RESULTS

The purpose of this study was to examine whether the core plays a greater role in providing stability or in generating and transferring forces to the limbs during sport movements. Tests of isometric core strength were used to measures the ability of the core to provide a stable base of support for optimal limb function and tests of functional core strength measured the ability of the core to produce and transfer power to the limbs.

Table 2 displays the reliability of the isometric core strength tests of trunk flexion, rotation right, and rotation left during the pilot testing. All of the tests of isometric core strength were found to have a strong reliability. Table 3 displays the mean ± standard deviation for the participant core strength and soccer sport performance tests.

Table 2: Reliability of Isometric Core Strength Pilot Testing

	Cronbach's alpha
Flexion	0.966
Rotation Right	0.972
Rotation Left	0.986

Table 3: Mean ± Standard Deviation for Isometric Strength, Functional Strength, and Soccer Performance Tests

	Mean ± Std Dev
Iso Flex (kg)	34.504 ± 19.704
Iso Right (kg)	25.620 ± 10.951
Iso Left (kg)	26.654 ± 12.202
Funct Flex (m)	1.600 ± 0.336
Funct Right (m)	2.612 ± 0.439
Funct Left (m)	2.771 ± 0.412
Throw-in (N)	7.250 ± 0.784
Kick Right (N)	16.508 ± 1.959
Kick Left (N)	14.296 ± 2.011

Table 4 displays the Pearson product correlation coefficients found between the isometric core strength and soccer performance tests. Significant and meaningful correlations were found between isometric flexion and throw-in (r = 0.526) and isometric left rotation and right footed kick (r = 0.622). Significant correlations were also found between isometric right rotation and right footed kick (r = 0.753) and isometric flexion and left footed (r = 0.615). Significant correlations between isometric rotation right and isometric rotation left (r = 0.784) and soccer kick right and soccer kick left (r = 0.549) indicate that there were no major differences between the dominant and non-dominant sides of the participants in the execution of these tests.

Table 4: Correlation between Isometric Core Strength and Soccer Performance Tests

	Iso Flex	Iso Right	Iso Left	Throw-in	Kick Right	Kick Left
Iso Flex	1	0.667*	0.803*	0.526*	0.486	0.615*
Iso Right		1	0.784*	-0.030	0.753*	0.459
Iso Left			1	0.124	0.622*	0.348
Throw-in				1	-0.253	0.415
Kick Right					1	0.549*
Kick Left						1

* indicates significance at $p \leq 0.05$.

Table 5 displays the Pearson product correlation coefficients between the functional core strength and soccer performance tests. There were no significant and meaningful correlations found between these tests. Significant correlations were found between functional rotation right and functional rotation left strength (r = 0.891), which indicates that there were no major differences between the dominant and non-dominant sides of the participants in the execution of these tests.

Table 5: Correlation between Functional Core Strength and Soccer Performance Tests

	Funct Flex	Funct Right	Funct Left	Throw-in	Kick Right	Kick Left
Funct Flex	1	-0.311	-0.353	-0.036	0.246	0.440
Funct Right		1	0.891*	0.255	0.017	0.102
Funct Left			1	0.108	0.260	0.032
Throw-in				1	-0.253	0.415
Kick Right					1	0.549*
Kick Left						1

* indicates significance at $p \leq 0.05$.

Table 6 displays the Pearson product correlation coefficients between the isometric core strength and functional core strength tests. The only significant correlation between the core fitness measures was isometric rotation right with functional flexion ($r = 0.655$).

Table 6: Correlation between Isometric Core Strength and Functional Core Strength Tests

	Iso Flex	Iso Right	Iso Left	Funct Flex	Funct Right	Funct Left
Iso Flex	1	0.667*	0.803*	0.348	0.325	0.361
Iso Right		1	0.784*	0.655*	-0.071	0.165
Iso Left			1	0.402	-0.033	0.173
Funct Flex				1	-0.311	-0.353
Funct Right					1	0.891*
Funct Left						1

* indicates significance at $p \leq 0.05$.

It was hypothesized that the tests of functional core strength would correlate more strongly with the tests of soccer sport performance than the tests of isometric core strength. Therefore, correlations were run separately between all three sets of these tests.

1. The hypothesis that functional core strength during trunk flexion will correlate more strongly with the soccer throw-in than isometric core strength during trunk flexion was rejected. It was found that there was a significant correlation between isometric core strength during flexion and the throw-in ($r = 0.526$) compared to a

non-significant correlation between functional core strength during trunk flexion and the throw-in (r = -0.036).

2. The hypothesis that functional core strength during trunk rotation to the right side will correlate more strongly with the left footed soccer kick than isometric core strength during trunk rotation to the right side was rejected. It was found that there was a greater correlation between isometric core strength during trunk rotation to the right side and the left footed kick (r = 0.459) compared to a non-significant correlation between functional core strength during rotation to the right side and the left footed kick (r = 0.102).
3. The hypothesis that functional core strength during trunk rotation to the left side will correlate more strongly with the right footed soccer kick than isometric core strength during trunk rotation to the left side was rejected. It was found that there was a significant correlation between isometric core strength during trunk rotation to the left side and the right footed kick (r = 0.622) compared to a non-significant correlation between functional core strength during trunk rotation to the left side and the right footed kick (r = 0.260).

CHAPTER 5: DISCUSSION

Core training has become a staple of sport-specific training as a means of improving performance; however, the link between core fitness and sport performance has not yet been fully elucidated [2]. Sport performances are determinant upon the capacity of the neuromuscular system to achieve a desired movement and the quality of the postural support that is given during this movement [41]. Increasing core stability and strength has been shown to improve spinal stability and increase force production of the core musculature [2], which theoretically should improve sport performance. Yet previous studies [12, 14-16] have failed to show a positive correlation between core fitness and sport performance. The purpose of this study was to examine whether the core plays a greater role in providing stability or in generating and transferring of forces to the limbs during sport movements.

It was hypothesized that there would be a stronger correlation between the functional core strength tests and soccer performance variables than between the isometric core strength tests and soccer performance variables. The reasoning for this was that the functional tests could be performed in a dynamic manner, which better mimics sport [20, 32] as compared to the isometric tests. The tests of isometric core strength measured the ability of the core to provide a stable base of support to allow for optimal limb function. The tests of functional core strength measured the ability of the core to generate and transfer force during a dynamic movement. The current study measured the isometric and concentric strength components of the core, which were absent in previous studies, with the hopes of better explaining the role the core plays during soccer sport performance. The statistical analysis indicated that there were significant differences between these two measures of core fitness and soccer sport performance.

It has been shown that only 10% of a MVC by the multifidi and abdominal muscles is needed to perform movements of rigorous activity [25]. Only 25% of a MVC of the back muscles is needed to provide maximal joint stiffness [42]. The contraction strength required to maintain core stability is not constant and is typically submaximal based on the difficulty of the movement performed. Thus, once spinal stability has been provided for a given movement, there is no greater need for the core musculature to produce more force to improve performance. The main role of the core is spinal and trunk stability for the purpose of providing a base of support for limb function and to reduce the risk of injury to the spine and upper and lower extremities. Therefore, exceedingly greater levels of strength beyond what is required during a movement to provide stability may not be necessary.

The results of the current study indicated that isometric core strength correlated more strongly with soccer sport performance than the tests of functional strength. Various reasons exist as to why this may have been the case. One reason is that the ability of the core to produce strength and provide stability is dependent upon the difficulty of the task being performed [26, 27]. Cholewicki et al. found that stability of the lumbar spine is at its greatest during the most demanding of tasks and decreases during periods of low muscular activity [26]. This indicates that the abdominal muscle force required to perform a sport-specific task is not necessarily the maximal amount of force that these muscles can produce [41]. Thus again, once stability is established for a given movement, additional force from the core musculature would be energy inefficient and potentially counterproductive.

The muscular activation required to perform a task is dependent upon muscle capacity, muscle morphologic characteristics of the antagonist co-activations, and external perturbations, which are all dependent on learning, intensity, and external factors of the motor task [41]. Ikeda et al. [35] found that there were greater correlations with isometric maximal trunk rotation torque and the side medicine ball throw using a 4kg and 6kg ball than there were using a 2kg ball in females. Possible reasons for this could be that a heavier load using the 4kg and 6kg medicine ball required a greater muscle contraction from the trunk rotators than what was required to project the 2kg medicine ball. A 2kg medicine ball was used in the current study because Cowley and Swensen had confirmed the reliability of the FAPT and SAPT using a medicine ball of this weight [20]. The use of a heavier ball would have elicited greater muscular activations of the core, however, it is unknown whether this would have resulted in stronger correlations between functional core strength and sport performance in the current study. Using a lighter ball was also more sport specific being that it more closely mimicked the mass of a soccer ball.

During tests of trunk flexion, the isometric core strength and concentric functional core strength differed significantly in the difficulty of task performance. During an isometric contraction, there is no change in muscle length due to the muscular force being equal to the external load, whereas during a concentric contraction, muscle length shortens because the muscular force is greater than the external load [43]. In the current study, the external load applied during the isometric test was much greater than the external load of the functional tests. Due to the force-velocity relationship of muscular contraction, an isometric contraction is always greater than a concentric contraction; therefore, the isometric tests elicited greater muscular activation than the functional tests. Difficulty of the task effects the amount of muscular activation, which in turn has a direct influence on the amount of strength and stability that is provided [26, 27].

Difficulty of the task is also dependent upon the direction of the external load that is placed on the musculature. During the isometric strength tests of trunk flexion, there was a large, dorsally-directed sagittal load placed on the trunk flexors. During the functional strength tests as measured by the FAPT, there was a minimal load and the load shifted from sagittal to being axially directed. Cholewicki et al. found that a dorsally-directed sagittal load creates a large bending moment about the spine, which requires a significant muscular activation to counteract via trunk flexion. During trunk flexion a axially-directed load was found to decrease muscular activation due to the vertical forces being anterior to the center of gravity, which reduces the amount of force needed to produce this movement [27].

In the current study of tests that involved trunk flexion, the hypothesis that functional core strength would correlate more highly with the throw-in than isometric core strength was rejected (Table 4.4 and 4.5). In other words, the ability of the core musculature to provide a stable base of support correlated more highly with the soccer throw-in than the ability to generate and transfer force to the limbs. The size and direction of the load placed on the core musculature during the isometric test led to increased muscular activation, which provides a better representation of the maximal performance of the core musculature during the isometric strength tests than the functional strength tests.

A second factor that may have led to weak correlations between functional core strength during trunk flexion and the soccer throw-in has to do with antagonistic muscular activations. Granata and Orishimo found that antagonistic muscular contraction of the trunk flexor muscles increases in response to a need for greater stability [44]. The tests of isometric core strength, functional core strength, and soccer sport performance differed in the amount of stability required to perform them maximally. During the isometric tests, the participant's trunk was supported by the bench, which reduced the amount of muscular stabilizing required. During the functional strength and soccer performance tests, the participant had to maintain trunk stability as they performed the intended task.

Previous work on females found that a decreased MVC torque and neuromuscular efficiency of the rectus abdominis during trunk flexion resulted in greater difficulty in maintaining trunk stability [41, 45]. Similarly, the same could possibly be said for the muscles that produce trunk rotation. When instability is present, antagonistic activations increase, which could take away from the production of external forces to the limbs [3]. Therefore, it is possible that antagonistic muscular activation, which was needed to provide stability, decreased the external forces that were produced and transferred to the limbs during the functional strength and sport performance tests. Had maintaining stability not been a factor in performance of the task, as was the case during the isometric tests, improved performance and stronger correlations may have been found between the tests that involved functional movements.

The hypotheses that functional right and left strength measured by the SAPT would correlate more strongly with the contralateral soccer kick than would isometric rotation was rejected (Table 4.4 and 4.5). The correlations between the isometric rotational strength and soccer kick tests were not completely unexpected due to the role the contralateral oblique muscle plays in stabilizing the core during the soccer kick. A 2002 study performed by Hirashima et al. [1] found that when throwing a baseball, there is a pattern of muscle activity that begins in the lower body followed by activation of the contralateral oblique muscle. Strong similarities exist in the patterning of force generation along the kinetic chain during throwing and kicking motions, which allows them to be compared [8].

Striking and throwing movements follow a sequential motion of segments through a linked system, which progresses from the most proximal to the most distal segment [8]. This sequencing of body segments was described earlier as proximal stability for distal mobility [5]. The soccer throw-in and kick used in the current study followed this same patterning of proximal to distal segment motion in the kinetic chain. The most proximal segment in this kinetic chain, the core, provides the stability and strength required for optimal distal segment function. The distal end is any point on the distal segment for which the direction and speed of motion are useful in describing the outcome of the skill: e.g., the point of release during the throw-in and point of impact during the soccer kick [8]. The current study indicated that the contralateral external oblique plays a greater role in providing stability rather than in producing/transferring force to aid in kick performance.

Results of this study showed that there was no correlation between the tests of functional core strength and soccer performance (Table 4.5). Various reasons for this may exist. Although the FAPT and SAPT were found to be reliable tests by Cowley and Swensen [20], the validity of these tests measuring functional core strength has not been established. Both the FAPT and SAPT have their limitations as far as unwanted muscular involvement and ball release angle, which can both affect results. There seemed to be a high degree of difficulty in maintaining stability and producing force simultaneously during performance of this task. It has already been established that when instability is present, there is a reduced amount of external force development [9].

The ability of the female subjects to forcefully contract the core musculature in order to produce enough force to project a 2 kg medicine ball without the use of shoulder, elbow, or wrist flexion in this study and the Cowley and Swensen study remains in question. Although this was controlled for as best as possible during participant testing of the FAPT and SAPT, observation alone cannot determine unintended muscular activation. A 2001 study by Kumar et al. [34] found that females recruit the contralateral pectoralis muscles to generate rotational torque in order to make up for weakness in the abdominal and back muscles. Ikeda et al. [35] analyzed differences in the side medicine ball throw between males and females as well as comparing the throw against isometric maximal trunk rotation torque. The findings of this study emphasized that there were significant differences between males and females in the execution of the side medicine ball throw, possibly due to female's inability to recruit the trunk rotators.

The lack of valid and reliable field tests for the purpose of testing core strength remains a problem in the sport performance field. It is imperative that field tests are reliable and valid measures of performance for the core musculature, while at the same time being as sport specific as possible. Isokinetic trunk testing remains the gold standard for measuring core stability in clinical sports medicine due to its reliability [31]. But isokinetic testing is not efficient for rapidly testing large samples due to the size and high cost of the equipment. The isometric trunk testing used in this study used a Baseline dynamometer and movements that were adapted from manual muscle tests used by physical therapists for trunk flexion and bi-lateral rotation [19]. The pilot data used to determine the reliability of these tests of isometric trunk stability found them to be highly reliable (Table 4.2). If future work were to find a strong positive correlation between the measures of isometric trunk strength used here and isokinetic trunk strength, these isometric core strength tests could become an acceptable field standard.

Results from the current study indicate that the core plays a greater role in providing a stable base of support rather than producing/transferring force during tests of soccer sport performance. The main role of the core is in providing a stable base of support that protects the spine and allows for optimal limb function. The core provides stability based on the difficulty of the movement produced, thus exceedingly greater forces will not be produced by the core musculature to aid in movement performance. The reliability of the isometric strength tests has been established but future research should look to establish validity to ensure these tests are true measures of the muscles that produce trunk flexion and bi-lateral rotation.

The role that core fitness plays in sport performance is still yet to be clearly understood as evidenced by the current and previous studies. Even in studies [12, 16] where improved core stability and strength indices were found, they still did not demonstrate an improvement in sport performance. However, this does not mean that core stability and strengthening programs should not be an integral piece of a training program. The positive influence that core training has on reducing the risk of lower extremity injury and low back pain cannot be underestimated [2, 3, 13]. The benefit of core training on sport performance may not necessarily be a clearly defined improvement in performance itself, but the ability to allow athletes to train and compete with a reduced risk of injury may be the greatest influence of core training on sport performance.

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APPENDIX A: RAW DATA

Table A.1: Individual participant data for isometric core strength measures

	Flexion (kg)	Rotation Right (kg)	Rotation Left (kg)
P01	36.364	18.182	22.727
P02	63.636	29.545	34.091
P03	18.182	20.455	27.273
P04	15.909	15.909	20.455
P05	25.0	36.364	25.0
P06	54.545	47.727	40.901
P07	6.818	18.182	9.091
P08	27.273	20.455	27.273
P09	63.636	38.636	52.273
P10	22.727	13.636	13.636
P11	45.455	22.727	20.455
Mean ± Std Dev	34.504 ± 19.704	25.62 ± 10.951	26.653 ± 12.201

Table A.2: Individual participant data for functional core strength measures

	FAPT (m)	SAPT Right (m)	SAPT Left (m)
P01	1.372	2.21	2.286
P02	1.676	2.896	2.972
P03	1.143	2.134	2.591
P04	1.524	2.362	2.515
P05	1.524	2.743	3.2
P06	2.286	2.134	2.515
P07	1.981	2.21	2.057
P08	1.448	2.819	2.972
P09	1.905	2.743	2.896
P10	1.448	2.972	3.048
P11	1.295	3.505	3.429
Mean ± Std Dev	1.6 ± 0.336	2.612 ± 0.439	2.771 ± 0.412

Table A.3: Individual participant data for soccer sport performance measures

	Throw-In (m/s)	Soccer Kick Right (m/s)	Soccer Kick Left (m/s)
P01	12.517	18.323	18.329
P02	12.964	17.435	16.988
P03	11.176	17.882	14.305
P04	12.517	16.54	16.093
P05	11.176	19.67	16.988
P06	12.07	18.776	17.882
P07	11.176	16.988	16.093
P08	11.623	16.988	15.199
P09	11.623	19.67	17.882
P10	11.623	17.435	16.988
P11	12.517	17.882	16.988
Mean ± Std Dev	11.908 ± 0.641	17.963 ± 1.054	16.703 ± 1.204

Table A.4: Individual participant data for soccer sport performance measures converted to Newtons of force.

	Throw-In (N)	Soccer Kick Right (N)	Soccer Kick Left (N)
P01	7.991	17.134	17.134
P02	8.572	15.503	14.718
P03	6.370	16.308	10.437
P04	7.991	13.954	13.209
P05	6.370	19.733	14.718
P06	7.430	17.980	16.308
P07	6.370	14.718	13.209
P08	6.890	14.718	11.783
P09	6.890	19.733	16.308
P10	6.890	15.503	14.718
P11	7.991	16.308	14.718
Mean ± Std Dev	7.250 ± 0.784	16.508 ± 1.959	14.296 ± 2.011

APPENDIX B: INFORMED CONSENT

BOISE STATE UNIVERSITY
DEPARTMENT OF KINESIOLOGY

RESEARCH PROJECT
CONVERGENT VALIDITY BETWEEN FIELD TESTS OF ISOMETRIC CORE STRENGTH, FUNCTIONAL CORE STRENGTH, AND SPORT PERFORMANCE VARIABLES IN FEMALE SOCCER PLAYERS

A. PURPOSE AND BACKGROUND

Jeff Wagner and Shawn Simonson, Ed.D, in the Department of Kinesiology at Boise State University are conducting research to measure the correlation between tests of core stability and sport performance variables in female soccer players. The core is responsible for providing a base of support prior to limb movement so that the limbs can function to their optimal capabilities. The core is also responsible for generating and transferring forces in integrated upper and lower body movements. Previous research has failed to fully explain the relationship that the core musculature and function have on sport performance.

I understand that tests of core stability and performance relative to soccer will be conducted in order to better identify this relationship. I volunteer and consent to participate in this study because I would like to help with the research project and I would like to have my core stability and sport performance variables measured.

B. PROCEDURES

If I agree to volunteer and participate in the study, the following will take place:

1. I will complete the study contraindications questionnaire to ascertain my ability to participate in this study. If I do not meet safe study participation guidelines, I will not be selected to participate in the study.
2. If I am selected for the study and I agree to participate, I will have my height, weight, core stability tests of isometric strength, core stability tests of power and soccer sport performance variables measured. Three maximal attempts will be performed for each test described below.
3. Core stability tests of isometric strength will be measured by maximal trunk flexion and bi-lateral rotation tests. A resistance will be applied to the trunk and an isometric contraction (without movement) will be produced with the amount of force being measured by a force dynamometer.
4. Core stability tests of power will be measured by the front abdominal power test and side abdominal power test. These tests are performed by forcefully contracting the core musculature to throw a 1.81kg (4 lb) medicine ball as far as possible.
5. Sport performance relative to soccer will be measured by performing a kick and throw-in for maximal ball speed measured by a radar gun. A soccer style kick will be performed stationary with only a counter-movement of the kicking leg to be used. The throw-in will be performed standing with feet shoulder width apart.

C. RISKS/DISCOMFORTS

1. When performing tests of physical performance there is always a risk of a muscular-skeletal injury. A proper warm-up and test demonstration will be performed in order to decrease this risk of injury. If at any point I feel uncomfortable, the test will be stopped immediately.
2. Participation in research may involve loss of privacy; however, my records will be handled as confidentially as possible. Only Jeff Wagner and Shawn Simonson, Ed.D., will have access to my records. No individual's identities will be used in any report or publication that may result from this study.

D. CONSENT TO BE A RESEARCH PARTICIPANT

My permission to participate in this study is voluntary. I am free to deny consent or stop the test at any point, if I so desire. I have read the above and I understand the test procedures that I will perform. For additional questions, I can contact Jeff Wagner at 307-679-4806 or Shawn Simonson at 208-426-3973. If I have any comments or concerns about participation in this study, I should first talk with the investigators. If for some reason I do not wish to do this, I may contact the Institutional Review Board, which is concerned with the protection of volunteers in research projects. I may reach the board office between 8:00 AM and 5:00 PM, Monday through Friday, by calling (208) 426-1574 or by writing: Institutional Review Board, Office of Research Administration, Boise State University, 1910 University Drive, Boise, ID 83725-1135.

I understand that the data obtained from the results of this study will be treated as privileged and confidential and will not be released to any person without my consent. The data, however, will be used as anonymous data for publication of scientific research with my right to privacy retained.

I give my consent to participate in this study:

______________________________ _______________

Signature of study participant Date

______________________________ _______________

Signature of test supervisor Date

The Boise State University Institutional Review Board has reviewed this project for the protection of human participants in research.

APPENDIX C: CONTRAINDICATIONS

Boise State University - Department of Kinesiology

Research Project

Convergent Validity between Field Tests of Isometric Core Strength, Functional Core Strength, and Sport Performance Variables in Female Soccer Players

Study Contraindications Screening Questionnaire

Par-Q

Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?

___YES ___NO

Do you feel pain in your chest when you do physical activity?

___YES ___NO

In the past month, have you had chest pain when you were not doing physical activity?

___YES ___NO

Do you lose your balance because of dizziness or do you ever lose consciousness?

___YES ___NO

Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?

___YES ___NO

Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?

___YES ___NO

Do you know of any other reason why you should not do physical activity?

___YES **___NO**

Have you ever had any of the following:

1. Major knee injury or surgery	___Yes	____No
2. Major hip injury or surgery	___Yes	____No
3. Major ankle injury or surgery	___Yes	____No
4. Major back injury or surgery	___Yes	____No
5. Doctor say you have high blood pressure	___Yes	____No

Are you currently free of injury that could affect performance of the testing described in this study?

How many years have you been playing soccer?

Name:_____________________________ Signature:_______________________

Test Supervisor:_____________________ Signature:_______________________

Date:________