THE RELATIONSHIP BETWEEN CORE STABILITY AND ATHLETIC PERFORMANCE

HUMBOLDT STATE UNIVERSITY

By

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ABSTRACT

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Angela M. Dendas

PURPOSE: To investigate the relationship between athletic performance and core stability. A secondary purpose was to test the reliability of core stability measures in an athletic population.

METHODS: Over a 2-week period, 21 collegiate Division II football players (height 184.70 ± 5.75 cm, weight 114.31 ± 18.30 kg) had core power (Medicine Ball Explosive Sit-up Throw Test [MBESTT; developed for this research] and a 60-s maximum sit-up test with a built-in 30-s test), core endurance (McGill protocol [McGill, 2007]), and a standardized testing battery for athletic performance measured. Athletic performance was assessed with 3-repetition maximums for the power clean, back squat, and bench press, as well as vertical jump height, and 40-m sprint time with a 20-m split time. Pearson correlations were used to determine relationships between core stability and athletic performance. Dependent T-tests and Pearson correlations were used to determine reliability.

RESULTS: The 60-s and 30-s maximum sit-up tests and the McGill trunk flexion test best related to athletic performance. The 60-s test was significantly correlated ($p < .05$) with the relative power clean (1.09 ± 0.17; $r = .836$), relative squat (1.64 ± 0.28; $r = .608$), relative bench press (1.24 ± 0.19; $r = .590$), vertical jump height (29.11 ± 3.70 in; $r = .721$), 40-m sprint time (5.26 ± 0.37 s; $r = -.680$), and 20-m sprint time (3.23 ± 0.27 s; $r = -.803$). The MBESTT was only significantly correlated to the absolute bench press (139.64 ± 18.55 kg; $r = .496$). There were no significant correlations
between athletic performance and trunk extension, right flexion, and left flexion of the McGill protocol. Most of the core stability measures had acceptable field-based test reliability. DISCUSSION: The timed sit-up tests are specific to the measures of athletic performance in terms of being: (a) multiple repetitions; (b) explosive movement patterns; (c) under a minute in length; and (d) similar in trunk muscle activation intensities. CONCLUSION: The 60-s and 30-s sit-up tests were reliable and moderately correlated to measures of athletic performance, making them the best field-based core stability measures investigated.
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CHAPTER ONE

Introduction/Literature Review

In order for an athlete to perform optimally, an adequate base of support is needed for upper and lower extremity movements. This base of support comes from the more than 20 pairs of muscles that make up the musculature of the lumbo-pelvic-hip complex (i.e., the core or trunk) (Tortora & Grabowski, 2003). During dynamic movements, such as sprinting or weight lifting, this musculature is expected to support the lumbo-pelvic-hip complex in order for the body's kinetic chain to function efficiently and effectively (Fredericson & Moore, 2005). Without the core muscles attached, the integrity of the spine would be unable to sustain external loads as little as two kilograms (kg) or 20 Newton's (N) (Briggs, Greig, Wark, Fazzalari, & Bennell, 2004; McGill, 1998). The complexity of the lumbo-pelvic-hip complex has caused numerous researchers to attempt to describe its musculature and explain the multifaceted, integrated parts that work synergistically to bring stability and mobility to the spine (Akuthota & Nadler, 2004; Bergmark, 1989; Richardson, Jull, Hodges, & Hides, 1999).

Anatomy of the Core

Researchers have described the core as being a “power-house” for initiating limb movement (Akuthota & Nadler, 2004) or as a double-walled cylinder or box (Richardson et al., 1999). In any of the aforementioned analogies, the abdominals act as the front of the house, the paraspinals serve as the back as the house, the diaphragm serves as the roof, and the musculature of the hip girdle and pelvic floor create the
basement of the house (Akuthota & Nadler, 2004; Richardson et al., 1999). Through its ability to contract, the core musculature creates a foundation for the naturally unstable spine, and allows for the transfer of forces between body segments during dynamic movements (Briggs et al., 2004; Essendrop & Schibye, 2004; Faries & Greenwood, 2007; Hodges, Holm, Holm, Ekstrom, Cresswell, Hansson, & Thorstensson, 2003; Stanford, 2002). According to Briggs et al. (2004), spinal stability is needed for the production of movement and relies on the musculature of the core to possess adequate strength, power, and endurance.

Classic literature classified the musculature of the core as being controlled by “local” and “global” muscular systems (Bergmark, 1989). The “local” system consists of all the muscles that originate and insert at the vertebrae, with the exception of the psoas muscles which flex the hip joints (Bergmark, 1989). The role of the “local” system is to control the curvature of the lumbar spine, aid in the coordination and control of motion segments, and provide sagittal and lateral stiffness to maintain mechanical spinal stability (Bergmark, 1989). On the other hand, the “global” system acts to transfer forces from the thoracic cage and the pelvis out to the extremities (Bergmark, 1989). The muscles of the “global” system have longer moment arms of force, as well as larger cross-sectional areas than the muscles of the “local” system, making them ideal for force production (Arokoski, Kaaukaanpaa, Valta, Juvonen, Partanen, & Taimela, 1999). Since Bergmark’s original classifications, some researchers have made slight modifications to which trunk muscles are in each system (Akuthota & Nadler, 2004; Norris, 2001; Richardson et al., 1999; Stanford, 2002).
"Local" system. The “local” system consists of the stabilizing muscles of trunk, primarily the transverse abdominis (TrA) and multifidi (Norris, 2001). These muscles are primary stabilizers because they do not generate enough force to create movements in the joints through which they pass (Norris, 2001). The internal oblique, medial fibers of the external oblique, quadratus lumborum, diaphragm, pelvic floor muscles, iliocostalis and longissimus (lumbar portions) all play a secondary role in the “local” stabilizing system (Norris, 2001). All of these muscles attach at, or near, the vertebrae of the spine and have short muscle lengths, which make them ideal for generating enough force for spinal stability (Briggs et al., 2004; Stanford, 2002).

Transverse abdominis. The TrA compresses the abdomen by utilizing the horizontally running fibers with origin points at the iliac crest and inferior six ribs, and insertion points at the xiphoid process and pubis (Tortora & Grabowski, 2003). According to Miller and Medeiros (1987), the TrA is a primary stabilizer because the fibers run from the anterior trunk to the lumbar region. In theory, the activation of the TrA before limb movement is to aid in the stabilization of the lumbar spine (Hodges & Richardson, 1996). Hodges and Richardson (1996), found the TrA to have delayed activation time in people with low back pain compared to healthy individuals, who had TrA activation before lower and upper limb movement. The activation of the TrA preceded the movements of the arms by 30 milliseconds, and the legs by 100 milliseconds, within the healthy individuals (Hodges & Richardson, 1996).

Multifidi. The multifidi originate at the sacrum, ilium, transverse processes of the lumbar, thoracic, and inferior four cervical vertebrae, and insert together
at the spinous process of a vertebra that is superior to the origin sites (Tortora & Grabowski, 2003). According to Akuthota and Nadler (2004), the multifidi work as segmental stabilizers. Working together, the multifidi extend the vertebral column (Tortora & Grabowski, 2003). Numerous researchers have examined the role of the multifidi in maintaining spinal stability within the lumbar region (Valencia & Munro, 1985; Wilke, Wolf, Claes, Arand, & Weisend, 1995). Wilke et al. (1995) reported that the multifidi contributed to an increase in spinal stiffness upon contraction. Valencia and Munro (1985) also witnessed multifidi activation and observed stiffness of the lumbar spine and pelvis.

*Quadratus lumborum.* The quadratus lumborum originates at the iliac crest and inserts at two points: the outermost parts of the transverse processes of the lumbar vertebrae and the lowest floating ribs (Tortora & Grabowski, 2003). Since the quadratus lumborum has two distinct insertion points, it also has two roles within the "local" and "global" systems (Bergmark, 1989). The "local" responsibility of the quadratus lumborum is to provide lateral stability to the spine (Bergmark, 1989). The "global" role of the quadratus lumborum is to counteract the activity of the diaphragm (Bergmark, 1989). McGill (2007) states that the quadratus lumborum acts as a spinal stabilizer because it plays an active role in tasks that predominately require movements of flexion, extension or lateral bending.

"Global" system. The “global” system is responsible for providing movement of the trunk (Berkmark, 1989). The muscles that provide the movements are the rectus abdominis, lateral fibers of the external obliques, psoas major, and erector spinae
(Norris, 2001). These muscles are ideal for creating movement and producing torque, with an emphasis on speed and power, because of their large moment arms and long levers (Faries & Greenwood, 2007).

**Rectus abdominis.** The rectus abdominis (RA) originates at the pubic crest and pubic symphysis, and inserts at the cartilage of the fifth to seventh ribs and the xiphoid process (Tortora & Grabowski, 2003). When contracted, the RA flexes the vertebral column and compresses the abdomen (Tortora & Grabowski, 2003). The RA is believed to have a high recruitment threshold, which is important in bracing the spine for high-load activities such as when pushing and lifting heavy objects (Scott, Comerford & Mottram, 2006). According to Fredericson and Moore (2005), the RA is primarily activated in traditional back and abdominal exercises, and assists with more gross spinal movements.

**Lateral fibers of the external obliques.** The external obliques have origin points on the inferior eight ribs and attach to the iliac crest (Tortora & Grabowski, 2003). The lateral fibers of the external oblique compress the abdomen and flex the vertebral column (Tortora & Grabowski, 2003). When there is unilateral contraction of the external oblique, the vertebral column is laterally flexed and rotated (Tortora & Grabowski, 2003).

**Psoas major.** The psoas major originates at the transverse processes and bodies of all of the lumbar vertebrae, and inserts, along with the iliacus, into the lesser trochanter of femur (Tortora & Grabowski, 2003). Acting together with the iliacus, the
psoas major flexes the thigh at the hip joint, rotates the thigh laterally, and flexes the trunk onto the hip (Tortora & Grabowski, 2003), such as when performing a full sit-up.

**Erector spinae.** The erector spinae consists of three groups of grouped muscles that originate on the ribs, transverse and spinous processes of the vertebrae, and iliac crest, and insert on the ribs, transverse and spinous processes, occipital bone, and mastoid process of temporal bone (Tortora & Grabowski, 2003). The erector spinae are responsible for extending the vertebral column (Tortora & Grabowski, 2003). The major muscles of the erector spinae are the longissimus and iliocostalis, which are primarily thoracic muscles, but act on the lumbar region by way of a long tendon that attaches to the pelvis (Akuthota & Nadler, 2004). According to McGill (2007), this long tendon creates a moment arm that is ideal for lumbar extension production.

The core is made up of the musculature of the lumbar, pelvic, and hip regions (Tortora & Grabowski, 2003). Therefore, it is safe to say then that all muscles that attach at the hip or cross the lumbo-pelvic region, such as the gluteals or hamstrings or quadriceps, play some kind of contributing role in spinal stability. Many researchers have examined the activation of these core muscles to determine their role in core stability (Beckman & Buchanan, 1995; Bobbert & van Zandwijk, 1999; Devita, Hunter, & Skelly, 1992; Elphinston, 2004; Wilson, 2005).

**Gluteals.** The gluteals consist of the maximus, medius, and minimus (Tortora & Grabowski, 2003). The gluteus maximus, which extends the thigh at the hip joint, originates at the iliac crest and sacrum, and attaches at the linea aspera, inferior to the greater trochanter of the femur (Tortora & Grabowski, 2003). The gluteus medius and
minimus both abduct the thigh at the hip joint, and have origin and insertion points at the ilium and greater trochanter of the femur, respectively (Tortora & Grabowski, 2003). Researchers have noted that instability in the lower extremity is partly due to poor muscular endurance and delayed firing of the gluteus maximus, as well as the gluteus medius (Beckman & Buchanan, 1995; Devita et al., 1992). Others claim that the gluteus maximus plays a significant role in core stability and hip control (Bullock-Saxton, Janda, & Bullock, 1993; Elphinston, 2004; Wilson, 2005). Many investigators have found the hip musculature to play a significant role in the transferring of the forces from the lower extremity to the pelvis and spine and out to the upper extremities (Akuthota & Nadler, 2004; Leetun, Ireland, Willson, Ballantyne & Davis, 2004; Lyons, Perry, Gronley, Barnes, & Antonelli, 1983). Insufficient strength of the maximus can influence the alignment of the lower leg and lower leg joints, which can predispose an individual to injury (Akuthota & Nadler, 2004). Bobbert and van Zandwijk (1999) have identified the importance of hip muscle activation when trying to improve core strength and when analyzing the stability of the spine.

**Defining Core Stability**

According to Hibbs et al. (2008), researchers from both areas of rehabilitation and sport performance have not provided clear distinctions between the terms “core stability” and “core strength”, which conceptually could be interpreted differently. The terms “core stability” and “core strength” are commonly interchanged throughout literature (Hibbs et al., 2008; Liemohn, Baumgartner, & Gagnon, 2005; Nesser, Huxel, Tincher, & Okada, 2008). The focus of the rehabilitation research is on improving the
quality of life of non-athletic people who are suffering from low back pain, leaving them unable to perform simple everyday tasks (Hibbs et al., 2008). According to Hibbs et al. (2008), general everyday tasks, such as walking, require much less core strength and stability as compared to dynamic athletic movements, due to their low load nature. Quite the reverse is true in the athletic setting, which is focused on enhancing performance through training that involves heavily loaded and dynamic movements (i.e., athletic movements) (Hibbs et al., 2008). Leetun et al. (2004) noted that athletes must have adequate strength in the lumbo-pelvic-hip complex in order to provide spinal stability throughout athletic movements. They continued with saying that motor control and muscular capacity create core stability (Leetun et al., 2004). Others have referred to core stability as being comprised of components such as core strength, endurance, power, balance, as well as the coordination of the spine, abdominal, and hip musculatures (Liemohn et al., 2005; Cowley & Swensen, 2008). Therefore, it is necessary to describe the multifaceted components of core stability.

Core stability is produced by the coordinated efforts of the core musculature, mainly the TrA and multifidi (Cholewicki & VanVliet, 2002, Bergmark, 1989; Lehman, 2006). Kibler, Press, and Sciascia (2006) in reference to dynamic movement patterns defined core stability as being “the ability to control the position and motion of the core over the pelvis to allow optimum production, transfer, and control of force and motion to the terminal segment”. Akuthota and Nadler (2004) view spinal stability as the product of passive stiffness, which is provided by the osseous and ligamentous structures, and active stiffness, which is produced by muscular contraction.
Core strength can be defined using the traditional concept of strength; that is, the maximal force a muscle or muscle group can generate at a specific velocity (Knuttgen & Kraemer, 1987). Since researchers are continuously looking for ways to enhance the contraction abilities of a muscle, not a muscle’s ability to stabilize, Faries and Greenwood (2007) reference core strength as being the ability of the core musculature to contract and bring stability to the spine, even though they define strength as “the ability of a muscle to exert or withstand force.” Cholewicki, Simons, and Radebold (2000), confirm that core strength is more “active control of spine stability achieved through the regulation of force in the surrounding muscles”. It can then be suggested that core strength is a necessity for core stability, meaning that there cannot be one without the other; the core musculature has to posses both.

Muscular endurance, whether referring to the muscles of the core or the extremities, can be defined as the ability of a group of muscles to execute repeated contractions over a given time that is sufficient enough to cause muscular fatigue (Baechle & Earle, 2008). Lehman (2006) has suggested that muscular endurance is more influential to spinal stability than muscular strength. Researchers have supported this notion by showing correlations between poor trunk muscular endurance and the occurrences of low back pain (McGill, Grenier, Bluhm, Preuss, Brown, & Russell, 2003; Rissanen, Heliovaara, Alaranta, Taimela, Malkia, Knekt, Reunanen, & Aromaa, 2002).

Power has been defined across many non-scientific areas as "force, energy, strength, and/or might" (Baechle & Earle, 2000). Scientifically though, power is "the product of muscular force and the velocity of muscle shortening" (Hall, 2007, p. 172). In
other words, power is the amount of mechanical work done over a certain amount of time. In reference to the core, power can be thought of as explosive concentric contractions of the musculature over a certain amount of time against an object, such as throwing a weighted medicine ball.

Balance is maintained by keeping the body's center of gravity over its base of support. External forces have the potential to disrupt balance by altering the center of gravity (Cresswell, Oddsson & Thorstensson, 1994). While external loads are acting on the body, internal forces, particularly in the lumbo-pelvic-hip complex, are utilized to maintain equilibrium of the body (Gracovetsky, Farfan & Helleur, 1985).

Communication between the musculature of the core and the neuromuscular system is what enables the body to regain this new equilibrium state (Bullock-Saxton, Bullock, Tod, Riley & Morgan, 1991), and allow for core stability to occur. Although not a focus of the present study, research into the physiological aspect of core stability, mainly balance and coordination of the core musculature, is important to mention.

**Measurements of Core Stability and its Components**

It is very difficult to assess the core with just one test, knowing that the musculature of the core consists of complex, integrated parts that work synergistically to bring about stability to the spine (Cowley, Fitzgerald, Sottung & Swensen, 2009; Nesser & Lee, 2009; Nesser et al., 2008). Cowley et al. (2009) argue that core instability could be caused by deficiencies in muscular strength, muscular capacity, coordination of limb movement, or a combination of any of these. It is not surprising then that researchers who have investigated the relationships between core stability and performance, or the
effects of training the core musculature on performance, have used an array of tests to measure core stability and its components (i.e., strength, endurance, and power) (Durall, Udermann, Johansen, Gibson, Reineke & Reuteman, 2009; Nesser & Lee, 2009; Nesser et al., 2008; Sato & Mokha, 2009; Scibek, Guskiewicz, Prentice, Mays, & Davis, 2001; Stanton, Reaburn, & Humphries, 2004; Tse, McManus, & Masters, 2005). Methods of assessment have included everything from isokinetic machines, which measure strength and work, to isometric measures of strength and endurance, and even the use of dynamic exercises (Cowley et al., 2009). Some core measurements are more commonly performed in clinical or laboratory settings (e.g., isokinetic dynamometry, Sahrmann test of core stability [Sahrmann, 2002], McGill protocol [McGill, 2007]), whereas other measures (e.g., timed sit-ups [Baechle & Earle, 2000], front abdominal power [Cowley & Swensen, 2008], side abdominal power [Cowley & Swensen, 2008]) are more appropriate for practical settings such as training facilities where strength and conditioning professionals work closely with athletic populations.

In the clinical setting, the standard method of measuring core strength and work is through the use of an isokinetic dynamometer (Delitto, Rose, Crandell & Strube, 1991; Hislop & Perrine, 1967; Karatas, Gogus & Meray, 2002; Keller, Hellesnes & Brox, 2001; Rothstein, Lamb, & Mayhew, 1987). Researchers use isokinetic machines because of the ability to measure three different strength variables (peak torque, total work, and average power) within one testing session (Hislop & Perrine, 1967; Rothstein, Lamb, & Mayhew, 1987). When testing the musculature of the core in trunk flexion and extension, subjects typically stand in the isokinetic device with the knees slightly flexed
and the dynamometer axis aligned with the subject's iliac crest (Delitto, Rose, Crandell & Strube, 1991; Karatas, Gogus & Meray, 2002). Subjects are then verbally instructed to perform maximal concentric contractions against the device in either flexion (using the rectus abdominis and psoas major) or extension (using the erector spinae and latissimus dorsi) at selected angular velocities (e.g., 60° per second) (Delitto, Rose, Crandell & Strube, 1991; Karatas, Gogus & Meray, 2002). Even though isokinetic machines have exhibited high reliability coefficients (Delitto et al., 1991; Karatas, et al., 2002), they still remain extremely expensive, are used more as a laboratory/clinical tool to assess the progress of rehabilitation patients (Cowley et al., 2009), and do not appear to be used on athletes when investigating the effect of core training programs on core strength, endurance or power.

Another core stability measurement tool used in a laboratory/clinical setting is the Sahrmann test of core stability (Sahrmann, 2002). According to Faries and Greenwood (p. 14, 2007), the Sahrmann test assesses the "ability of the core musculature to stabilize the spine with or without motion of the lumbo-pelvic-hip complex." The test consists of five levels with each level increasing in difficulty, progressing from a static position to positions that entail active movements. The test requires the use of a biofeedback transducer to detect changes in applied pressure via an abdominal hollowing maneuver as participants lay supine. Abdominal hollowing requires an individual to actively activate the stabilizing abdominal muscles (e.g., TrA) of the "local" system via an isometric contraction (Allison, Godfrey, & Robinson, 1998). To begin the test the transducer is placed under the lumbar spine and inflated to 40 mm Hg
(Faries & Greenwood, 2007). An individual must maintain that pressure within 10 mm Hg as they progress through the stability levels (Faries & Greenwood, 2007). According to Urquhart, Hodges, Allen and Story (2005), spinal stability can be indirectly measured through changes in applied pressure to a biofeedback transducer, since individuals are required to maintain that abdominal hollowing maneuver as motion in the lumbo-pelvic-hip complex increases with each test level.

Some researchers who have investigated the effects of core training programs on athletic performance measures (Sato & Mokha, 2009; Stanton et al., 2004) have used the Sahrmann protocol to assess core stability. Sato and Mokha (2009) studied female and male runners and did not report on the reliability of the Sahrmann measures for these athletes. Stanton et al. (2004) however, did assess the reliability of the test in a prior pilot study and found a test-retest reliability coefficient of .95; the subjects for this pilot were not described. Although the Sahrmann test of core stability has repeated clinical use (Sahrmann, 2002) and established reliability (Stanton et al., 2004), its validity is currently unknown to the present investigator.

When measuring core stability and/or core strength in athletes, some researchers (Durall et al., 2009; Nesser & Lee, 2009; Nesser, Huxel, Tincher, Okado, 2008; Tse et al., 2005) have used what is known as the McGill protocol (McGill, 2007). The McGill protocol, originally developed to assess core stability in patients with low-back pain (McGill, 2007), consists of four muscular endurance tests: right lateral endurance; left lateral endurance; flexor endurance; and a modified Biering-Sorensen back extensor.
endurance test (Biering-Sorensen, 1984). These tests are scored as individually-held isometric postures for time, recorded in seconds (McGill, 2007).

According to McGill (2007), the trunk flexors, extensors, and lateral muscles of the trunk provide spinal stability during nearly every dynamic movement, and there is an obvious need to have balanced muscular capacities among them. These tests challenge the trunk musculature, even with slow trunk movements, all the while applying minimal compression loads to the spine (Juker, McGill, Kropf & Steffan, 1998; McGill, Juker & Kropf, 1996).

The McGill protocol requires no special equipment, has been shown to be reliable (McGill, Childs & Liebenson, 1999), and possesses enough validity to have been widely used by researchers (Durall et al., 2009; Nesser & Lee, 2009; Nesser et al., 2008; Tse et al., 2005). McGill et al. (1999), showed each of these muscular endurance tests to have reliability coefficients of .98 or higher when repeated over five consecutive days in untrained, healthy men and women. Furthermore, a few researchers have reported modified versions of the trunk flexion and extension tests to be highly correlated to the standard testing procedures in healthy college-aged men and women (Reiman, Krier, Nelson, Rodgers, Stuke & Smith, 2010). Reiman et al. (2010), reported correlation values of 0.84 for trunk flexion and 0.90 for trunk extension. No reliability coefficients appear to have been reported in studies of athletes.

Knowing that endurance is essential for maintaining stabilizing patterns of muscle activity (McGill, 2007), it is not surprising that athletes have been assessed for core stability using the McGill protocol (Durall et al., 2009; Nesser & Lee, 2009; Nesser
et al., 2008; Tse et al., 2005). Performing the lateral trunk endurance tests in the protocol requires the activation of "local" muscles, mainly the quadratus lumborum and abdominal wall (McGill et al., 1996). The flexor endurance portion of the McGill test targets the major trunk flexor, the rectus abdominis, which is a "global" muscle (McGill, 2007). The back extensor test, which is was modified from the classic Biering-Sorensen test (Biering-Sorensen, 1984), activates the major extensors of the spine, the longissimus and multifidi, which are part of the "local" stabilizing system (McGill, 2007).

Arguably one of the most common field tests used to assess the core musculature, specifically the rectus abdominis, is the sit-up. The sit-up has been incorporated into many physical training programs because of the ability of this exercise to effectively activate the abdominal and hip flexor musculatures at the same time. The American Alliance for Health, Physical Education, Recreation and Dance (AAHPERD) and the U.S. Army require subjects to perform a full sit-up to the upright position with elbows touching the thigh region near the knees as part of their testing batteries (AAHPERD, 1980; U.S. Army Physical Fitness Training, 1992). Sit-ups activate mainly the "global" system muscles (i.e., rectus abdominis, internal and external obliques) and also require minimal activation of the TrA to ensure sufficient spinal stiffness (Juker, McGill & Kropf, 1998; McGill, 2007). Walters and Partridge (1957) observed rectus abdominis activation in the beginning part of the sit-up when the head is lifted off a surface (e.g., exercise mat). When the feet are held down during a sit-up, the hip flexors (mainly the psoas muscles) are activated once the trunk is flexed beyond 30°, (Godfrey, Kindig & Windell, 1997; LaBan, Raptou & Johnsons, 1965); this allows the trunk to be
fully flexed (Norris, 2001). Traditionally, sit-ups were developed to test the endurance of the abdominals, whether the test lasted for 1-minute as in the AAHPERD test (AAHPERD, 1980) or 2-minutes, as in the U.S. Army Physical Fitness Test (U.S. Army Physical Fitness Training, 1992).

Though the sit-up is popular, there are concerns of possibly causing too much lumbar spinal loading, which increases the risk of injury. Researchers have shown various variations of the sit-up to produce large amounts of shear and compressive forces in the lumbar region (Axler & McGill, 1997; McGill, 1995; Nachemson & Elfstrom, 1970). McGill (1995) predicted compressive loads to be just over 3,000 Newtons during both isometrically held sit-ups and dynamic sit-ups with minimal acceleration components. Though compression forces of that magnitude seem large, when they are compared to common activities that football players encounter on a day-to-day basis, they are rather small. Gatt, Hosea, Palumbo, and Zawadsky (1997) investigated football blocking and revealed that over 8,000 Newtons of compressive forces are applied to the lumbar spine during a single blocking event.

Football players are also exposed to compressive loads in their off-field requirements (e.g., during weight-room workouts), where power lifting exercises (slow movement velocity with maximal force production) and Olympic weightlifting exercises (heavy loads moved at high movement velocity) are utilized (Burgener, 1987; Haupt, 1993; Hedrick, 1996; Hoffman, Fry, Deschenes & Kraemer, 1990; Kraemer & Gotshalk, 2000). Cholewicki, McGill, and Norman (1991) found average compressive loads of 17,000 Newtons being applied to the lumbar spine during power lifting exercises in
powerlifters. Cappozzo, Felici, Figura, and Gazzani (1985) recorded compressive loads on the lumbar spine to exceed well over six times a subject's body weight during half-squats when an external load was placed on the shoulders that was equivalent to subject's body weight. Being exposed to such excessive spinal compression loads during intensive free-weight training, athletes can increase their bone mineral content (BMC) in the vertebrae, allowing the spine to withstand such extraordinary loads (Granhed, Johnson & Hansson, 1987).

The National Strength and Conditioning Association (NSCA) has previously used a 60-second maximum sit-up test to measure local muscular endurance (Baechle & Earle, 2000). This test required that athletes lay supine on an exercise mat with knees flexed to 90° and hips flexed about 45°. Fingers were interlocked behind the neck and the feet were secured down by a test administrator. In order for a repetition to count, athletes were required to flex the trunk up far enough up to have their elbows touch their thighs. The 60-second maximum sit-up test requires no additional loads, other than body weight. Subjects must move quickly through the repetitive movement pattern because the test is scored as maximal number of correct sit-ups within the 60-second time period (Baechle & Earle, 2000).

Recently, researchers have used a test similar to the NSCA 60-second test to assess the musculature of the core in young, healthy, untrained men and women (Augustsson, Bersas, Thomas, Sahlberg, Augustsson & Svantesson, 2009). In this other test, subjects completed as many full sit-ups as possible in the 30-second time period (Augustsson et al., 2009). Unlike the NSCA test (Baechle & Earle, 2000), which is
referred to as a measure of muscular endurance, the 30-second test used by Augustsson et al. (2009) is supposedly a measure of core power. Since power is the rate of doing work and performing full sit-ups requires work to be done (due to the demand of lifting the trunk off of the floor), the more repetitions completed in a short amount of time is an indication of greater core power production. According to Sparling, Millard-Stafford, and Snow (1997) an all-out effort for one minute or less represents muscular power rather than endurance. Augustsson et al. (2009) found the 30-second timed sit-up test to be highly reliable (ICC= .93) in the untrained men and women studied.

There are many suggested ways as to how the sit-up should be modified. Most of the recommendations are from health-related associations, such as the American College of Sports Medicine (ACSM), which typically sets guidelines for exercise in non-athletic populations. Interestingly, the NSCA, which focuses on exercise in athletes, has recently changed their recommended test for abdominal muscular endurance from a timed sit-up test (Baechle & Earle, 2000) to a partial curl-up test (Baechle & Earle, 2008). The NSCA curl-up differs from the sit-up in regards to body position, cadence (i.e., speed of movement), and time. In the new test, athletes begin in a supine position with knees at 90°, arms along the sides, and fingers touching the exercise mat at a preset piece of tape. Slow, controlled curl-ups, where the fingers touch a parallel preset piece of tape that is 4.7 inches away from the first piece, are performed to a metronome set at 40 beats per minute. Though athletes are instructed to perform as many curl-ups as they can without pausing, they are limited to completing a maximum of 75 curl-ups. By extending the time period for the test and requiring that the curl-ups be done at a
predetermined cadence, this test has become more appropriate for measuring abdominal endurance as opposed power capabilities of the musculature.

Knowing the complex and synergistic parts that make up the core, knowing the various components that contribute to core stability, and since previous ways of measuring core stability and its components have been limited in regards to the type of muscular contractions and movement speeds, researchers are turning toward using new assessment tools (Liemohn, Baumgartner, & Gagnon, 2005). These newer measures mimic functional movement patterns more than previous measures. For example, extensive research has been conducted using various forms of a medicine ball throw as a field assessment tool, indirectly measuring power production (Adams, Swank, Barnard, Bering & Sevone-Adams, 2000; Cowley et al., 2009; Cowley & Swensen, 2008; Davis, Kang, Boswell, Dubose, Altman & Binkley, 2008; Gordon, Moir, Davis, Witmer & Cummings, 2009; Lyttle, Wilson & O'Strowski, 1996; Mayhew, Bemben, Piper, Ware, Rohrs & Bemben, 1993; Mayhew, Bemben & Rohrs, 1992; Mayhew, Bemben, Rohrs, Ware & Bemben, 1991; Mayhew, Bird, Cole, Koch, Jacques, Ware, Buford & Fletcher, 2005; Stockbrugger & Haennel, 2003; Stockbrugger & Haennel, 2001).

In the aforementioned studies, both athletic and non-athletic populations were used. The medicine-ball throw, whether performed from a seated or standing position, closely resembles many athletic movements because of the overall fast movement speeds of the throws, and its movement patterns progress from simple to complex. Additionally, medicine-ball throws require the summations of forces generated from either the legs (Gordon et al., 2009; Mayhew et al., 2005; Stockbrugger & Haennel,
Cowley and Swensen (2008) developed and tested the reliability of two core stability field tests that use a medicine-ball throw in untrained women (n = 24). The front abdominal power test (FAPT) and the side abdominal power test (SAPT) were adapted from plyometric exercises that caused the core musculature to be explosively contracted while using the arms as levers to propel a weighted medicine ball forward. In both tests, the subject is positioned supine on an exercise mat with knees bent at 90°. The FAPT closely resembles a timed sit-up, because subjects quickly flex the trunk up from the supine position with knees bent; hence, the "global" system muscles (i.e., rectus abdominis, internal and external oblique) are mainly activated and the TrA is minimally activated to ensure sufficient spinal stiffness (Juker, McGill & Kropf, 1998; McGill, 2007). The main difference between the FAPT and a sit-up is that the feet are not secured during the FAPT. The SAPT involves more of the obliques, because of the requirement to rotate the trunk to the side before the explosive concentric contraction. Power is inferred from the displacement of the medicine ball. Cowley and Swensen (2008) found that the FAPT (ICC = .95) and SAPT (ICC = .93) were reliable tests to assess the power component of core stability in untrained women.

Cowley and colleagues (2009) did a follow-up study in which they investigated the potential for the FAPT to predict isokinetic trunk strength and work in young, healthy, physically active men and women. The researchers first established that the
FAPT was reliable (ICC = .95) in the small group of young men (n = 3) and women (n = 5). Cowley et al. (2009) then sought to find out if the FAPT, age, and weight could predict isokinetic trunk extension strength, flexion strength and work in a larger group of young, healthy, physically active men (n = 19) and women (n = 31). Cowley et al. (2009) found that the FAPT was the only significant predictor of trunk extension strength and work in women ($R^2 = .16$ and .15, respectively). There was not a significant relationship between the FAPT and any of the flexion measures among the women. In the men, the FAPT did not predict any of the isokinetic measures (Cowley et al., 2009). Cowley et al. (2009) suggest that the FAPT could be measuring a different component of core stability (e.g., power) in men because they did not find the FAPT to be a predictor of isokinetic strength and work.

**Does Core Training Enhance Athletic Performance?**

For many strength and conditioning professionals, core stability is considered a key component in training to improve sport performance (Jeffreys, 2002; Leetun et al, 2004; McGill, 2001). The core has been shown to provide a railway for the transfer of forces from the lower extremities to the upper extremities (Behm, Leaonard, Young, Bosney, & MacKinnon, 2005). Many investigators have examined the effectiveness of core training programs on athletic performance levels (Durall et al., 2009; Sato & Mokha, 2009; Scibek, Guskiewicz, Prentice, Mays, & Davis, 2001; Stanton, Reaburn, & Humphries, 2004; Tse, McManus, & Masters, 2005); in each of these studies measures of core stability were also taken before and after training.
Durall and colleagues (2009) investigated the effects of a preseason trunk muscle training program on the occurrence of low-back pain in Division III female collegiate gymnasts (n = 15). The training program consisted of trunk extensor, flexor, and lateral flexor exercises, such as resisted upper trunk lifts and isometric side bridges, which were performed twice a week in addition to already-scheduled preseason training. The control group (n = 12) consisted of women not involved with gymnastics, which was a limitation of the study. The McGill protocol (McGill, 2007) was used before and after the 10-week training period to assess the musculature of the core. The investigators reported that the training group significantly improved their core endurance times on the tests compared to the control group. In regards to the occurrence of low-back pain, the coaching staff and the medical staff of the gymnasts reported to the researchers that there were no new incidences of low-back pain. During an informal briefing following the completion of the training, the gymnasts reported that they experienced greater general stamina in their gymnastic performances, which was attributed to the core training intervention (Durrall et al., 2009). The authors concluded that the 10-week training protocol was effective enough to stimulate increases in trunk muscular capacity, and subsequently gymnastic performances (Durall et al., 2009).

Sato and Mokha (2009) evaluated the effectiveness of core strength training on ground reaction forces (GRFs), stability of the lower extremities [measured using the Star Excursion Balance Test (Gribble, Hertel, Denegar & Buckley, 2004; Kinzey & Armstrong, 1998; Olmsted, Carcia, Hertel & Shultz, 2002)], and 5,000-meter running performance. Recreational or competitive male (n = 10) and female (n = 18) runners
were studied. Core stability was assessed with the Sahrmann test of core stability (Sahrmann, 2002) prior to the start of the training intervention in order to weed out anyone with an existing high level of core stability. Before pretesting, subjects were randomly divided into a control group (n = 8) and core strength training group (n = 12). After 6-weeks of performing stability ball exercises, such as abdominal crunches and back extensions, four times per week, only the core strength training group showed significant improvement in their average running times. Both groups improved scores on the Star Excursion Balance Test, but the improvements were not statistically significant. Core strength training did not significantly improve GRFs. Sato & Mokha (2009) concluded that a core strengthening program centered on a high training volume can improve distance run times.

Scibek and colleagues (2001) measured the effectiveness of a Swiss ball training program on dry-land performance measures. A secondary purpose was to examine the effectiveness of the same training program on swimming speed. Subjects were competitive collegiate swimmers already involved in a scheduled training program. Core stability was measured with a Swiss ball test where there were two unstable support bases and two eye conditions (open v. closed). After 6-weeks of training using Swiss Ball exercises, such as supine opposite arm and leg raises, pre-to-post test improvements were found in the training group for the forward medicine ball throw and the measures for postural control, but not in any of the other performance measures (vertical jump and backward medicine ball throw) or swim times. The authors concluded that Swiss ball training may not be specific enough to the core stability requirements of swimming, and
that the addition of the Swiss ball training program may have induced fatigue in the subjects (Scibek et al. 2001).

Stanton et al. (2004) investigated the effectiveness of a Swiss Ball training program on core stability and running economy in male athletes (n = 29). The researchers assessed core stability via the Sahrmann test of core stability (Sahrmann, 2002) and a, relatively unknown to the literature, Swiss ball specific stability test (The Swiss Ball Prone Stabilization Core Stability Test). Running-specific measurements were treadmill VO$_2$max, running economy, running posture, and trunk muscle activation. After six weeks of Swiss Ball training, investigators revealed a significant improvement in core stability via the Sahrmann test and time to failure in the Swiss Ball Prone Stabilization Core Stability Test. However, no significant improvements were revealed on any of the running performance measures in the experimental group. Stanton et al. (2004) concluded that the lack of improvements in running performance measures may be due to the light Swiss ball training program training load (which is based on number of sets and repetitions) not eliciting a significant training effect on the body.

Tse et al. (2005) examined the effectiveness of a core endurance training program on various performance measures in college-age rowers. Subjects were separated into either the control group (n = 14) or the core training group (n = 20). The McGill protocol (McGill, 2007) was used to assess core musculature endurance against various common field tests of athletic performance, such as the vertical jump and the 2,000-m rowing ergometer test. After 8-weeks of core training, the core group, who
performed trunk stability exercises that progressed from static to more dynamic, showed significant improvements in both right and left lateral endurance tests. No significant differences were observed in the core training group in terms of the performance measures; the researchers suggested that the 8-week training program was too short to elicit an effect on muscular endurance (Tse et al., 2005).

**Relationship of Core Parameters to Athletic Performance**

Nesser and Lee (2009) sought to identify the relationship between core strength and various strength and power performance measures among female collegiate soccer players (n = 16). The McGill protocol (McGill, 2007) was used to assess the muscular endurance of the core stabilizers (e.g., "local" system). Nesser and Lee (2009) chose the McGill protocol (McGill, 2007) because of its established reliability (McGill et al., 1999), but decided to combine the individual timed scores from the four tests to make a "total core" score since the core works as one system in athletic movements. To assess performance, investigators used the following strength and power variables: countermovement jump (i.e., vertical jump), 20-yard shuttle run, 40-yard sprint, one-repetition maximum (1-RM) squat lift, and 1-RM bench press. A relative-to-bodyweight score of the 1-RM squat and bench press was also analyzed. No significant correlations were observed between core strength and athletic performance variables in the female soccer players. In fact, most of the performance measures were inversely and weakly related to "total score" values from the McGill tests. Authors claimed that the results could be attributed to McGill protocol (McGill, 2007) not being specific enough to athletic performance and perhaps core strength has no role in athletic performance
The Nesser and Lee study (2009) could have been limited by the fact that only one aspect of core stability (i.e., core endurance) was measured (using the McGill protocol; McGill, 2007). It could be assumed then that this measure did not adequately capture the aspect(s) of core stability that is required in the performance measures of strength and power.

Finally, American football is a sport requiring speed and explosive power, seen by players accelerating, sprinting, jumping, and colliding at any given moment. These motor skills are made possible because of factors like strength, power, speed, and agility, that is, factors that researchers (Berg, Latin, & Baechle, 1990; Black & Roundy, 1994; Burke, Winslow, & Strube, 1980; Daniel, Brown, & Gorman, 1984; Fry & Kraemer, 1991) claim are the assumed underlying abilities of football playing ability. Commonly, football players have their playing ability assessed by performing standardized tests that evaluate strength, power, speed, and agility (Kuzmits & Adams, 2008). Test batteries typically include, but are not limited to, the power clean, the back squat, the bench press, the 40-yard dash, and the 20-yard shuttle run (i.e., Pro Agility Shuttle Run) (Berg et al., 1990; Black & Roundy, 1994; Burke et al., 1980; Daniel et al., 1984; Fry & Kraemer, 1991; Kuzmits & Adams, 2008; Nesser et al., 2008; Sawyer, Ostarello, Suess & Dempsey, 2002). Assessing players is critical, not only because test scores allow strength coaches to plan yearly training programs, but also because the aforementioned measures relate to player performance in competition (Allerheiligen & Arce, 1983).
While many strength and conditioning professionals consider core stability integral to athletic performance (Jeffreys, 2002; Leetun et al, 2004; McGill, 2001), there appears to be only one study of the relationship between core stability and football performance (Nesser et al., 2008. Nesser et al. (2008) studied the relationships between core stability and various athletic performance measurements among Division I football players (n = 29). The athletic performance variables were the vertical jump, 20-yard shuttle run, 20- and 40-yard sprint, one-repetition maximum (1-RM) squat lift, 1-RM power clean, and 1-RM bench press. A relative-to-bodyweight score for the 1-RM squat lift, power clean, and bench press were also obtained. Nesser et al. (2008) used the McGill protocol (McGill, 2007) to assess the muscular endurance of the core stabilizers, and like in the previous study of this research group (Nesser & Lee, 2009), the individual timed endurance scores of the four tests were combined to make a "total core" score. Only weak-to-moderate correlations were found between all performance measures and the "total core" scores. Moderate correlations were observed in the vertical jump \( r = .59, p < .05 \) and power clean relative to body weight score \( r = .62, p < .05 \). Authors state that results are due to the McGill protocol (McGill, 2007) not being a specific enough measure to relate to athletic performance. Alternatively, core strength may only play a minimal role in athletic performance (Nesser et al., 2008).

**Significance/Statement of the Problem**

Although professionals in the field of strength and conditioning constantly place an emphasis on training the musculature of the core, researchers have shown conflicting findings as to the effectiveness of core training programs on athletic performance.
(Durall et al., 2009; Sato & Mokha, 2009; Scibek et al., 2001; Stanton et al., 2004; Tse et al., 2005). In most of the studies (Scibek et al., 2001; Stanton et al., 2004; Tse et al., 2005) there was not an effect of core training on athletic performance, probably due to the lack of specificity in training programs and/or assessment tools. With regards to the relationship between core stability and athletic performance, few studies have been done (Nesser et al., 2008; Nesser & Lee, 2009). In these studies, core stability was measured with the McGill protocol (McGill, 2007), which was originally developed to measure trunk muscular endurance in patients with low-back pain. Nesser et al. (2008) only showed weak-to-moderate correlations between strength/power measures of athletic performance and core stability in collegiate Division I American football players. Hibbs et al. (2008) suggest that the lack of research and the contradictory conclusions may be due to not having standard measures for core stability and its components. The next logical step, in hopes of bridging a gap in the literature, is to find relationships between measures of athletic performance and newer measures of core stability that mimic functional movement patterns more than previously used measures. Therefore, the purpose of this study will be to investigate the relationships between athletic performance and core stability measures among collegiate Division II American football players. Since very few reliability studies of core stability tests have been done in athletic populations (Cowley et al., 2009; Cowley & Swensen, 2008; McGill et al., 1999), a secondary purpose will be to test the reliability of core stability measures in an athletic population.

Hypotheses
The primary hypothesis was that core power measures (i.e., MBESTT, 30-second and 60-second maximum sit-up tests) would significantly relate to athletic performance measures. Also, measures of core power would relate to each other. Lastly, the measures of core power and core endurance (i.e., McGill protocol) would be found to be reliable.

Assumptions

For this study it will be assumed that all athletes will perform to the best of their abilities and adhere to the pre-test conditions. It will also be assumed that subjects will not participate in any outside core training other than that prescribed by the Head Strength and Conditioning Coach.

Practical Applications

Time is limited for strength and conditioning coaches when evaluating core stability of athletes. Therefore, field tests that are practical, cost effective, time saving, and specific alternatives to clinical tests, which are expensive, require a lot of time to administer, and are really not specific enough to the movement patterns of sports. Information from the current study may help guide coaches to select appropriate methods to measure core stability and its components.
CHAPTER TWO

Methodology

Research Design

A correlational design was used to investigate relationships between athletic performance and core stability measures in collegiate Division II American football players. Additionally, since very few studies have been done to determine the reliability of core stability tests (Cowley et al., 2009; Cowley & Swensen, 2008; McGill et al., 1999), particularly in athletic populations, a secondary purpose was to test the reliability of select core stability measures in this group. Core power and core endurance were the specific components of core stability that were examined. The core power measures were the Medicine Ball Explosive Sit-up Throw Test (MBESTT) (which was developed for this research), and a 60-second maximum sit-up test (with scores being recorded at both 30 and 60 seconds). Core endurance was measured with the McGill protocol (McGill, 2007), which consists of the right lateral endurance test, left lateral endurance test, flexor endurance test, and a modified Biering-Sorensen back extensor endurance test (Biering-Sorensen, 1984). Athletic performance measures consisted of the power clean, back squat, bench press, vertical jump height, and sprint times in the 40-m sprint, with split times recorded at 20 m. To establish the test-retest reliability coefficients in a male athletic population, the core power and endurance tests were performed twice by subjects on separate days.

Subjects
The principal investigator, along with the Head Strength and Conditioning Coach, received approval from the coaching staff to recruit and assess players. Assessment was selected to take place during the spring off-season training time for football. The athletes were tested during their regularly scheduled off-season testing period, so as not to disrupt their training program.

Each athlete was required to complete an informed consent form (Appendix A), as well as a screening and demographic information questionnaire (Appendix B) in order to participate in the study. To qualify for participation players had to be: (a) free from an acute injury; (b) free from chronic back pain; (c) free from any medical conditions made worse by exercise; (d) experienced in sprinting (minimum of three months); (e) experienced in Olympic-style weightlifting (minimum of three months); (f) experienced in medicine-ball throws or pushes (minimum of three months); and (g) experienced in performing full sit-ups (minimum of three months). Since performance measures and anthropometric measures were administered by the strength and conditioning staff prior to the start of the study, all athletes who completed an informed consent form allowed the release of that data to the principal investigator.

A total of 92 athletes from Humboldt State University’s football team were asked to voluntarily take part in this study. Participants were asked to complete all measurement tests within the allotted testing period set forth by the principal investigator. Due to scheduling conflicts and an unwillingness to complete two of the core measures twice, a number of athletes failed to successfully complete the entire study, so all measures were only obtained for 22 athletes.
Measurement Protocols

Demographics and athletic background. Demographic information was collected on a self-report form (Appendix B). The survey form included questions regarding: (a) date of birth; (b) ethnicity; (c) current injury status; (d) any diagnosed back or musculoskeletal injury; (e) participation year; (f) position; (g) sprint experience; (h) Olympic-style lifting experience; (i) med-ball throw experience; and (j) sit-up experience.

Mass and height. The mass and height of each participant was taken by the football strength and conditioning staff with a calibrated scale (Health-o-Meter, Illinois) four days prior to the start of testing for the current study. Subjects wore regular practice attire without shoes. Mass was measured to the nearest 0.5 lb, and then converted to kilograms (kg). Standing height was taken with participants standing, without shoes, on the Health-o-Meter weight platform with back, heels, and buttocks against scale. The measuring device was laid over the tallest point of the participant’s head. Height was measured to the nearest 0.5 inch, and then converted to centimeters (cm).

Core power measures. Core power, a component of core stability, was measured by the medicine Ball Explosive Sit-up Throw Test (MBESTT) and maximum sit-ups in 30 and 60 seconds. Scores for all core power measures were recorded on the Data Collection Sheet (Appendix C). The methods for each of the separate core power measures are described below. Verbal instructions, as well as brief demonstrations on how to perform each of the tests, were given to subjects prior to testing trials (Appendix D).
**Medicine ball explosive sit-up throw test.** The MBESTT was developed for this study as a means of measuring core power. This test is similar to the front abdominal power test (FAPT) designed by Cowley et al. (2009), involving an explosive sit-up throw. The FAPT was thought to be inappropriate for the subject group because of concern that large torques would be exerted on the small muscles of the shoulder, putting the subjects at risk for injury.

The MBESTT is a two-phase test that indirectly measures core power from the difference in distance of the medicine ball throws in the two phases. Six trials were used in each of the phases because pilot testing revealed MBESTT distances tended to remain stable after the fourth throw. To count, all throws (in both phases) had to clear a target placed four and a half feet away from the release point, which was over the knees and directly above the feet. The target that was used was modified from that used by Lyttle, Wilson, and Ostrowski (1996) and made to be adjustable so each subject could have an optimum release angle. The optimum release angle should be less than 45° according to Linthorne (2001). In order to control this optimal angle of release to be less than 45° from each subject’s shoulder joint, the horizontal low-bar was set to 19° and the horizontal high-bar was set to 36° based on the seated shoulder height of each subject. Subjects had a maximum of 30 seconds of rest between each throw, and were allowed to perform the next trial if they felt recovered enough before 30 seconds elapsed. As was done in the study by Cowley et al., (2009) (personal communication) the feet were secured. The subjects were instructed to keep feet under the handles of 140-pound dumbbells, securing feet onto the field turf, and keeping knees bent to 90° (refer to
Figure A). The distance recorded for all trials in both phases was the distance the medicine ball traveled (measured to the nearest inch, and then converted to cm) from its release point over the subject's feet to its landing spot on the field turf. The best (i.e., farthest) throw out of the six trials for each phase was used as the recorded distance for that phase. To obtain the final score of the MBESTT, the best score of the first phase was subtracted from the best score of the second phase, theoretically representing core power.

In the first phase of the MBESTT, a seated chest pass test was used, which was adopted from a test done by Mayhew et al. (1993) to measure upper body strength in collegiate Division II football players. In the MBESTT a 10-lb (4.5-kg) medicine ball was used instead of a 4.5-kg indoor shot-put ball used by Mayhew et al. (1993). Subjects performing the MBESTT completed chest passes by quickly extending forearms while sitting straight up with backs pressed firmly against a flat inverted bench. The medicine ball was placed in spread hands and had to be touching the chest before subjects were allowed to throw (refer to Figure 1).

In the second phase of the MBESTT, the subjects were instructed to perform an explosive concentric contraction of the abdominals and hip flexors, similar to the movement of the full sit-up, and release the 10-lb medicine ball once they reached an upright position (refer to Figure 2 and Figure 3). The ball again, had to clear through the target on all trials. The medicine ball placement was the same as in the first phase, in spread hands and touching the chest.
**A 60-second maximal sit-up test.** The 60-second maximum sit-up test, with a built-in 30-second test, was modified from similar tests described by Augustsson et al. (2009) and the National Strength and Conditioning Association (NSCA) (Baechle & Earle, 2000). Athletes lay supine on the field turf with knees flexed to 90° and hips flexed about 45° (Baechle & Earle, 2000). Fingers were interlocked behind the neck and the feet secured down by a fellow teammate (Augustsson et al., 2009; Baechle & Earle, 2000) (refer to Figure 4). Time started on the word "go" and athletes flexed the trunk up far enough to have their elbows touch their thighs (refer to Figure 5). Athletes had to lower their trunk back toward the turf until the scapulas came in contact with turf (as per Augustsson et al., 2009). The athletes were not permitted to touch their head or hands against the field turf during the 60 seconds (Baechle & Earle, 2000). Each up-down cycle counted as a successful repetition of the sit-up. At 30 and 60 seconds, the test administer recorded the number of successful repetitions. Subjects only performed one sit-up trial per testing session.

**Core endurance measures.** Trunk muscular endurance, a component of core stability, was assessed with a protocol developed by McGill (2007). Since spinal stability is required for nearly every dynamic movement, there is an obvious need to have balanced muscular capacities among the trunk flexors, extensors, and lateral muscles (McGill, 2007). The McGill protocol consisted of the: (a) trunk flexion test; (b) a modified Biering-Sorensen trunk extension test (Biering-Sorensen, 1984); (c) right flexion test; and (d) left flexion test. The tests were scored as individually held isometric postures for time (recorded in seconds, to the nearest .1 sec) (McGill, 2007).
Verbal instructions, as well as brief demonstrations, for all core endurance measures were given to subjects prior to testing (Appendix D). The order of tests for each subject was not controlled for, but each subject performed the core endurance tests after the core power measures during each testing session. In order to ensure recovery between the four measurements, subjects had to rest a minimum of 5 minutes between tests, but were allowed to rest longer if they felt the need to. In addition to the individually scored test, all four test times were combined to create a total core score.

**Trunk flexion test.** The flexor test started with the subjects in a sit-up position with their back resting against a wedge that was angled 55° from the floor. The knees and hips of the subjects were flexed to 90° with the arms folded across the chest and hands rested on the shoulders. The feet were held down at the top of the foot by a partner. Reiman et al. (2010) used a similar modified version of the trunk flexion test, and reported a strong correlation to the original McGill procedures. Subjects were instructed to hold the isometric posture, then the wedge was pulled back 10 cm (refer to Figure 6). Time started when the wedge was moved back and time ended when any part of the subjects' backs touched the wedge (McGill, 2007).

**Biering-Sorensen trunk extension test.** The extensor test started in the "Biering-Sorensen position", adapted from Biering-Sorenen (1984), with subjects lying prone on a workout bench with their anterior superior iliac spine (ASIS) aligned with the table's edge, leaving the upper body planked out over the edge of the bench. The knees, hips, and pelvis were secured by a partner, which was a modification from McGill, who used straps. Reiman et al. (2010), used a similar modified version of the trunk extension
test, and reported a strong correlation to the original McGill procedures. The arms were folded across the chest and hands were rested on the shoulders. Subjects were instructed to maintain a horizontal position with their body in a straight line before the time started (refer to Figure 7). Time stopped when the subjects broke that horizontal position by dropping their upper body (McGill, 2007).

**Right and left flexion tests.** The lateral musculature tests started with the subjects lying sideways (i.e., side-bridge position) on the field turf. The legs were fully extended and the subjects had to place their top foot in front of the lower foot to increase their base of support width. The subjects had to support themselves on the involved elbow while the uninvolved arm was placed on the opposite shoulder. Subjects were instructed to lift their hips off of the turf, creating a straight line with their body (refer to Figure 8). Time started once subjects were in this position. Time was stopped when the subjects could no longer maintain the straight line position and the hips lowered toward the turf (McGill, 2007).

**Athletic performance measures.** For this study, football players had their playing ability assessed by performing standardized tests that evaluate strength, power, and speed. Standardized test batteries typically include: (a) the power clean; (b) the back squat; (c) the bench press; (d) the vertical jump; and (e) the 40-yard sprint (Berg et al., 1990; Black & Roundy, 1994; Burke et al., 1980; Daniel et al., 1984; Fry & Kraemer, 1991; Kuzmits & Adams, 2008; Nesser et al., 2008; Sawyer, Ostarello, Suess & Dempsey, 2002). This standardized battery of tests is part of the Humboldt State University (HSU) Strength and Conditioning Program's regular assessment protocol, and
was used for this study. Assessing players is critical, not only because test scores allow
strength coaches to plan yearly training programs, but also because the aforementioned
measures relate to player performance in competition (Allerheiligen & Arce, 1983).
Athletes were always under the direct supervision of the football strength and
conditioning staff for all of their test trials. All rest times during testing followed those
recommended by the NSCA (Baechle & Earle, 2000).

**Power clean.** The procedures for the power clean were modified from
those suggested by Baechle and Earle (2000). One-repetition maximums (1-RM) are not
used by the HSU football strength and conditioning staff due to safety concerns; instead
3-RM tests were used. Athletes performed a warm-up protocol with an Olympic
weightlifting bar (an Ivanko [20 kg] Olympic Weightlifting Barbell model OBS-20 kg).
The warm-up consisted of two sets of 5 repetitions of overhead lunges, and two sets of 5
repetitions of high pulls. After at least 1-min of rest, athletes performed their 3-RM
power clean max test using an Olympic weightlifting bar, proper NSCA prescribed
technique (Baechle & Earle, 2000), and an initial load based on a previous recorded
estimated 1-RM by the Head Strength and Conditioning Coach. Subjects had a
maximum of 10 seconds recovery between each repetition. If the initial 3-RM test was
successful, then the athlete had an opportunity to try another 3-RM test with a heavier
load that they felt comfortable at attempting. If the participant was unsuccessful at
catching the load at shoulder height, they were allowed to retest with the current load
after 2 minutes of rest. If unsuccessful again, the load used during the previous
successful 3-RM test represented the final mass lifted. Final mass lifted was recorded in pounds then converted into units of kilograms (kg).

**Back-squat.** The procedures for the back squat were modified from those suggested by Baechle and Earle (2000). Due to safety concerns 3-RM tests were used instead of 1-RM tests. Athletes performed five sub-maximal warm-up sets (consisting of 5-10 repetitions) of the back squat, which were assigned by the Head Strength and Conditioning Coach. The initial load used in the 3-RM back squat test was based on a previous recorded estimated 1-RM by the Head Strength and Conditioning Coach. Subjects had a maximum of 10 seconds of recovery between each repetition. If the athlete successfully completed the 3-RM test load with proper technique, at the discretion of the overseeing strength coach, they were allowed to attempt a heavier load. The strength coach and the athlete decided if the next load lifted accurately represented their successful 3-RM test. If the participant was unsuccessful at the prescribed load at a depth suitable to the overseeing strength coach, the athlete was allowed to retest with the current load after 2 minutes of rest. If unsuccessful again, the load used during the previous successful 3-RM trial represented the final mass lifted. Final mass lifted was recorded in pounds then converted into units of kilograms (kg).

**Bench press.** The procedures for the back squat were modified from those suggested by Baechle and Earle (2000). Due to safety concerns 3-RM tests were used instead of 1-RM tests. Athletes performed five sub-maximal warm-up sets (consisting of 1-6 repetitions) of the bench press with a light load, which was assigned by the Head Strength and Conditioning Coach. The initial load used in the 3-RM bench
press test was based on a previous recorded maximum by the Head Strength and Conditioning Coach. Subjects had a maximum of 10 seconds between each repetition. If the athlete successfully completed the initial 3-RM test load with proper technique, at the discretion of the overseeing strength coach, they were allowed to attempt a heavier load. The strength coach and the athlete decided if the load lifted represents a successful 3-RM. If the participant was unsuccessful at lowering and fully pressing up the load, the athlete was allowed to retest with the current load after 2 minutes of rest. If unsuccessful again, the load used during the previous successful 3-RM test represented the final mass lifted. Final mass lifted was recorded in pounds then converted into units of kilograms (kg).

*Vertical jump height.* Vertical jump height was measured with a Vertec (Sports Imports, Columbus, OH) using modified procedures from Baechle and Earle (2000). The Vertec was positioned in the back of the training facility. Participants had their standing reach measured first with their dominant arm against the Vertec. The standing reach height marker was adjusted to the tip of the athlete’s middle finger on their dominant hand. Once the Vertec was properly adjusted, participants stood approximately a foot and a half away from the apparatus (measured from the outside edge of their dominant foot), so not to touch the apparatus during their jump, and performed a standard countermovement jump (CMJ).

The CMJ was performed by having the participants first standing straight up with feet shoulder width apart and flat on the ground. Participants then quickly moved their hips down and backwards into a semi-squat position and immediately exploded upwards
to jump. As this movement was happening, the arms were moving back during the downwards phase, and then moved upwards during the explosion phase. When the participant was at the peak of their upward phase of the jump they extended their dominant hand into the air in attempt to displace the Vertec measuring vanes. The displacement of the vanes was used as the vertical jump height (per ½-inch increment) of each participant (Baechle & Earle, 2000). Each athlete continued at attempting jump trials until they were unable to displace measuring vanes on two consecutive jumps. The vertical jump height on the Vertec is measured as the difference between the standing reach and the jumping reach of each participant. The vertical jump test was performed under the supervision of the football strength and conditioning staff.

A 40-m sprint. Sprint testing took place in the University’s indoor facility on turf that is comprised of rubber-pellets and artificial grass. Prior to the sprint testing, each athlete was taken through a general dynamic warm-up protocol administered by the Head Strength and Conditioning coach that lasted for approximately 20 minutes. The dynamic warm-up protocol consisted of: (a) jogging; (b) backwards jogging; (c) side-to-side shuffles; (d) carioca; (e) high skips; (f) skip-kicks; (g) high knees; (h) butt-kicks; (i) forward lunges; (j) side lunges; (k) step-pulls; and (l) A-march. The warm-up protocol is typically done over a distance of 40 m.

For the sprint trials, an electronic timing device (Brower Wireless Sprint System, model 175) was used. A timing hand pad was placed at the 0-m mark (i.e., the start), with infrared detectors at the 20-m and 40-m marks. Before the sprint testing, the group got an explanation and a brief demonstration of how the timer starts (e.g., as soon as
their hand leaves the pad). The infrared detectors took the athletes' time at the 20-m mark (to the nearest 0.01 second) and the 40-m mark (to the nearest 0.01 second) as they sprinted by.

The procedures for sprint trials were modified from those suggested by Baechle and Earle (2000). Athletes started in a three-point stance position, with their dominant hand over the hand pad. Two 40-m sprint trials were taken for each subject. There was a minimum 2-min recovery between sprint trials for each athlete. Athletes were encouraged to sprint as quickly as possible during their two 40-m sprint trials. The final time was the time recorded at the 40-m mark. The 20-m split sprint time was the time recorded at the 20-m mark during each 40-m all out sprint, as opposed to simply performing both 20- and 40-m sprints. The final score for the 20-m split sprint was the best recorded time (i.e., fastest) in the two trials. The final score for the 40-m sprint was the best recorded time (i.e., fastest) out of the two time trails.

**Procedures**

Once approved by the Institutional Review Board at HSU, testing took place over a 2-week period (February 24th - March 8th, 2010). The mass and height of each participant was taken by the football strength and conditioning staff with a calibrated scale (Health-o-Meter, Illinois) four days prior to the start of testing for the current study. Informed written consent and the demographic and athletic background information was obtained first from all participants as they entered the training facility on their assigned first day of testing (February 24th or February 25th, 2010). All participants, who meet the inclusion criteria, were asked to participate in the rest of the
study. A detailed testing schedule for this study can be found in Appendix E. Prior to each testing day, all subjects had their current health state assessed with the same questions from the screening questionnaire. For the core power and endurance measurements the same testing administrators (e.g., principal investigator, assistant strength coaches) tested all of the subjects over the multiple testing days. For the athletic performance and anthropometric measurements, the football strength and conditioning staff tested all of the subjects prior to the start of this study (February 22-23, 2010). Adhering to the National Strength and Conditioning Association (NSCA) prescribed order of testing (Baechle & Earle, 2000), all core power measures preceded the core endurance measures on all testing days. All core power and endurance measures were completed twice by subjects for reliability purposes.

Since athletes were already divided into their assigned off-season training groups (i.e., Heavy Group 1, Heavy Group 2, and Skill Group) during the first week of testing, only those participants from the Skill Group had their core power assessed with the first phase (i.e., chest pass) of the MBESTT and the 60-s maximum sit-up test on Wednesday February 24, 2010. The other participants from the other two groups performed the first phase of the MBESTT and the 60-s maximum sit-up tests on the next day (Thursday February 25, 2010), because that was their assigned day. All subjects performed their second test of maximum sit-ups on Friday February 26, 2010, as well as having their core endurance measured for the first time with the McGill right and left lateral protocols.
Due to scheduling conflicts, all subjects had their third day of testing on Monday March 1, 2010. On this day, subjects completed their first trials of the second phase (i.e., explosive sit-up with medicine ball throw) of the MBESTT, as well as the second trials of the McGill right and left lateral protocols. Subjects also finished their first trials of the McGill flexion and extension protocols. The next testing session did not commence until the next Monday, March 8, 2010. On that day, all subjects completed their second trials of both of the MBESTT phases, and the second trials of the McGill flexion and extension protocols.

**Statistical Analyses**

The relationships between core stability and athletic performance were established using Pearson Product Moment Correlations (i.e., Pearson r). The test-retest reliability of the core stability measure trials was determined using Pearson Product Moment Correlation Coefficients. Realizing the limitations of a Pearson r (e.g., bi-variate), the group means of each core stability test between the different testing days was analyzed using a dependent t-test. The data was analyzed with PASW Statistics (formally SPSS, IBM Corp., Chicago, IL, USA) version 17.0.2. The criterion for significance was set at an alpha level of $p \leq .05$.

**Operational Definitions**

1) *Core Stability* - Comprised of components (e.g., core strength, core power, balance, coordination).
2) **Core Power** - The MBESTT and 60-second sit-up tests. Out of two trials, the best difference in distance between the best (i.e., the furthest) of the six throws for the MBESTT's two phases was used as an indirect measure of core power. The most successfully completed repetitions of sit-ups during 60 seconds, as well as at 30 seconds from the two trials of each were used as measures of core power.

3) **Core Endurance** - The McGill protocol (McGill, 2007) was used to measure core endurance. Four muscular endurance tests were given: (a) trunk flexion; (b) back extension (modified from Biering-Sorensen, 1984); (c) right flexion; and (d) left flexion. All four test times were combined to create a total core score.

4) **Power Clean 3-Repetition Maximum (3-RM)** - Successful completion of three repetitions of the power clean (i.e., starting with dropped hips and flat back position, quickly pulling loaded bar from platform and catching loaded bar upon the shoulders in a semi-squat position) (load measured in pounds then converted to kilograms).

5) **Back Squat 3-RM** - Successful completion of three repetitions of the back squat (i.e., starting with balanced loaded bar across posterior deltoids and slowly flexing hips and knees until thighs are below parallel to floor, and then returning to starting position) (load measured in pounds and converted to kilograms).
6) **Bench Press 3-RM** - Successful completion of three repetitions of the bench press (i.e., starting with a closed, pronated grip on a loaded bar at over the chest with the elbows fully extended and slowly lowering the bar to the chest, touching the chest and returning to staring position) (load measured in pounds then converted to kilograms).

7) **Sprint Time** - The best 40-m sprint time, as well as the best 20-m split time, of the two trials for the 40-m sprint (rounded to the nearest .01 second).

8) **Vertical Jump Height** - Vertical height jumped by the participant measured in inches (rounded to the nearest .5 inch).

**Limitations**

The following limitations are noted as they may have affected the outcomes of this study:

1) The athletes may have experienced a carry-over effect because of the regularly scheduled off-season training during this testing period of the study.

2) Attempts to standardize recovery periods between testing measures and training were made, but were impossible to fully control.

3) Athletes had varied experience and skill levels for each of the core stability and athletic performance tests.

4) The order of all athletic performance measures were not controlled for.

5) The MBESTT phases and McGill tests had to be split across multiple days, instead of being completed all at once.
Delimitations

The following delimitations are noted as they may have affected the outcomes of this study:

1) Only male student-athletes playing NCAA Division II American football were used as subjects.
2) Only 21 athletes comprised the final subject group that was used for analysis.
3) The other components of core stability (e.g., strength, balance, neuromuscular control, coordination) were not examined.
4) Athletic performance was only assessed with selective standardized measurements for football.
Figure 1. The first phase of the MBESTT.
Figure 2. The starting position of the second phase of the MBESTT.
Figure 3. The second phase of the MBESTT.
Figure 4. The start and end position for the 30-second and 60-second maximum sit-up tests.
Figure 5. The "up" position of the 30-second and 60-second maximum sit-up tests.
Figure 6. The trunk flexion test of the McGill protocol.
Figure 7. The trunk extension test of the McGill protocol.
Figure 8. Right lateral flexion test of the McGill protocol.
CHAPTER THREE

Results

This study was designed to determine the relationships between core stability and athletic performance measures in American football players. Core power measures (the MBESTT, and 60-second maximum sit-up test), core endurance measures (McGill protocol), and athletic performance measures (3-RM power clean, 3-RM squat, 3-RM bench press, vertical jump height, and 40-meter sprint) were taken. A secondary purpose of the study was to determine the test-retest reliability for all core stability measures in this group of athletes. Statistics were analyzed using PASW Statistics (formally SPSS, IBM Corp., Chicago, IL, USA) version 17.0.2, with the criterion for significance set at an alpha level of $p \leq .05$. All measurements were obtained for 22 athletes, but primary results showed an extreme outlier on the MBESTT test-retest reliability data. The outlier was removed, the statistical analyses were run again with 21 total subjects, and those results are presented below.

Subject Descriptive Characteristics

The descriptive characteristics of the 21 male subjects who successfully completed the entire study are presented in Table 1. In regards to football playing position, subjects represented multiple positions including offensive linemen ($n = 10$), defensive linemen ($n = 4$), wide receivers ($n = 2$), tight ends ($n = 2$), line backers ($n = 2$), and a quarterback.
Table 1

Subject Characteristics \((N = 21)\)

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (years)</td>
<td>20.05</td>
<td>1.43</td>
<td>18-23</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>184.70</td>
<td>5.75</td>
<td>170.2-195.60</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>114.31</td>
<td>18.30</td>
<td>83.46-143.79</td>
</tr>
<tr>
<td>Med-Ball experience (months)</td>
<td>33.76</td>
<td>20.61</td>
<td>3-84</td>
</tr>
<tr>
<td>Sit-up experience (months)</td>
<td>71.71</td>
<td>49.07</td>
<td>3-180</td>
</tr>
<tr>
<td>Sprint experience (months)</td>
<td>76.19</td>
<td>51.89</td>
<td>7-180</td>
</tr>
<tr>
<td>Olympic-lifting experience (months)</td>
<td>49.95</td>
<td>26.52</td>
<td>7-96</td>
</tr>
</tbody>
</table>

Reliability of Core Stability Measures

As the reliability of the core stability measures will influence the relationships between these measures and measures of athletic performance, these results are presented first. The test-retest reliability coefficients for all core stability measures are shown in Table 2. All of the core stability correlation coefficients, with the exception of trunk extension, were statistically significant \((p \leq .01)\). The mean values for trial 1 and trial 2 for all core stability measures were compared using dependent t-tests; the results of these analyses, along with descriptive statistics for all core stability measures, are presented in Table 3. No significant difference were found between mean scores from the two trials of the MBESTT \((p = .118)\) (refer to Figure 9). Similarly, no significant
differences were found between scores on the trials of the 30-second maximum sit-up test \((p = .051)\), between the first testing trial of 60-second maximum sit-ups and the second trial \((p = .108)\) (refer to Figure 10), or between the two testing trials of the McGill trunk extension \((p = .317)\). However, there was a significant improvement in scores from the first to the second trials for all remaining core stability tests (i.e., trunk flexion, right flexion, left flexion, and total core).

The intercorrelations between scores of core stability for all measures are presented in Table 4. Scores on the MBESTT were not related to scores on any of the other measures of core stability. As expected, 30-s and 60-s sit-up scores were highly related to each other. The 30-sec and 60-sec maximum sit-up tests were moderately related to trunk flexion and total core scores from the McGill protocol. Finally, there were moderate to high correlations between the component tests for core muscular endurance (i.e., trunk flexion, trunk extension, right flexion, and left flexion) with the total core score. The highest correlation was between the trunk flexion test and the total core score.
Table 2

Test- Retest Reliability (using Pearson Product Moment Correlation Coefficient) for all Measures of Core Stability ($N = 21$)

<table>
<thead>
<tr>
<th>Measure</th>
<th>$r$</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBESTT (cm)</td>
<td>.734**</td>
</tr>
<tr>
<td>30-s Max Sit-up</td>
<td>.758**</td>
</tr>
<tr>
<td>60-s Max Sit-up</td>
<td>.862**</td>
</tr>
<tr>
<td>Trunk flexion (s)</td>
<td>.828**</td>
</tr>
<tr>
<td>Trunk extension (s)</td>
<td>.421</td>
</tr>
<tr>
<td>Right flexion (s)</td>
<td>.621**</td>
</tr>
<tr>
<td>Left flexion (s)</td>
<td>.742**</td>
</tr>
<tr>
<td>Total Core (s)</td>
<td>.911**</td>
</tr>
</tbody>
</table>

Note. *$p \leq .05$. **$p \leq .01$. 
### Table 3

Comparison of Trial 1 with Trial 2 Measures of Core Stability ($N = 21$)

<table>
<thead>
<tr>
<th></th>
<th>Trial 1</th>
<th></th>
<th>Trial 2</th>
<th></th>
<th>95% CI</th>
<th></th>
</tr>
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<tbody>
<tr>
<td></td>
<td>$M$</td>
<td>$SD$</td>
<td>$M$</td>
<td>$SD$</td>
<td>$t(20)$</td>
<td>$p$</td>
</tr>
<tr>
<td>MBESTT (cm)</td>
<td>122.16</td>
<td>42.93</td>
<td>133.16</td>
<td>41.67</td>
<td>-1.63</td>
<td>.118</td>
</tr>
<tr>
<td>30-s Max Sit-up</td>
<td>22.19</td>
<td>4.21</td>
<td>23.52</td>
<td>4.23</td>
<td>-2.08</td>
<td>.051</td>
</tr>
<tr>
<td>60-s Max Sit-up</td>
<td>38.71</td>
<td>8.67</td>
<td>40.33</td>
<td>7.85</td>
<td>-1.68</td>
<td>.108</td>
</tr>
<tr>
<td>Trunk flexion (s)</td>
<td>132.28</td>
<td>52.28</td>
<td>162.80</td>
<td>70.47</td>
<td>-3.50</td>
<td>.002</td>
</tr>
<tr>
<td>Trunk extension (s)</td>
<td>98.04</td>
<td>26.14</td>
<td>105.71</td>
<td>35.67</td>
<td>-1.03</td>
<td>.317</td>
</tr>
<tr>
<td>Right flexion (s)</td>
<td>66.00</td>
<td>15.94</td>
<td>79.85</td>
<td>20.40</td>
<td>-3.89</td>
<td>.001</td>
</tr>
<tr>
<td>Left flexion (s)</td>
<td>67.66</td>
<td>19.97</td>
<td>79.23</td>
<td>23.82</td>
<td>-3.29</td>
<td>.004</td>
</tr>
<tr>
<td>Total Core (s)</td>
<td>364.00</td>
<td>90.38</td>
<td>427.61</td>
<td>128.94</td>
<td>-4.88</td>
<td>.000</td>
</tr>
</tbody>
</table>

*Note.* CI = confidence interval; $M =$ mean; $SD =$ standard deviation; $LL =$ lower limit; $UL =$ upper limit.
Table 4

Inter-relationships among Various Core Stability Measures \((N = 21)\)

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
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<tbody>
<tr>
<td>1. MBESTT (cm)</td>
<td>-</td>
<td>.021</td>
<td>-.156</td>
<td>-.013</td>
<td>-.017</td>
<td>.333</td>
<td>.105</td>
<td>.053</td>
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<tr>
<td>2. 30-s Max Sit-up</td>
<td>-</td>
<td>.914**</td>
<td>.556**</td>
<td>.142</td>
<td>.383</td>
<td>.252</td>
<td>.467*</td>
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<tr>
<td>3. 60-s Max Sit-up</td>
<td>-</td>
<td>.615**</td>
<td>.280</td>
<td>.278</td>
<td>.221</td>
<td>.511*</td>
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<td>4. Trunk flexion (s)</td>
<td>-</td>
<td></td>
<td>.751**</td>
<td>.544*</td>
<td>.502*</td>
<td>.498*</td>
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<tr>
<td>5. Trunk extension (s)</td>
<td>-</td>
<td></td>
<td></td>
<td>.498*</td>
<td>.332</td>
<td>.812**</td>
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<tr>
<td>6. Right flexion (s)</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td>.830**</td>
<td>.728**</td>
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<td>7. Left flexion (s)</td>
<td>-</td>
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<td>.679**</td>
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</table>

*Note. *\(p \leq .05\), **\(p \leq .01\).*

Relationships between Core Stability and Athletic Performance

The descriptive statistics for all best core stability measures and athletic performance measures are presented in Table 5. The primary hypothesis of the current study was that the core power measures of the MBESTT and 30-sec and 60-sec maximum sit-ups would be significantly related to the measures of athletic performance. Pearson Product-Moment Correlations were used to examine the relationships between core stability and athletic performance. The intercorrelations between measures of core stability and measures of athletic performance are presented in Table 6.
Table 5

<table>
<thead>
<tr>
<th>Measure</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>MBESTT (cm)</td>
<td>138.61</td>
<td>40.62</td>
<td>68.58-210.82</td>
</tr>
<tr>
<td>30-s max sit-up</td>
<td>24.00</td>
<td>4.21</td>
<td>15-30</td>
</tr>
<tr>
<td>60-s max sit-up</td>
<td>41.33</td>
<td>8.36</td>
<td>23-54</td>
</tr>
<tr>
<td>Trunk flexion (s)</td>
<td>163.38</td>
<td>69.74</td>
<td>62-305</td>
</tr>
<tr>
<td>Trunk extension (s)</td>
<td>111.76</td>
<td>30.10</td>
<td>60-199</td>
</tr>
<tr>
<td>Right flexion (s)</td>
<td>80.38</td>
<td>20.00</td>
<td>49-125</td>
</tr>
<tr>
<td>Left flexion (s)</td>
<td>80.85</td>
<td>22.86</td>
<td>50-126</td>
</tr>
<tr>
<td>Total Core (s)</td>
<td>429.61</td>
<td>126.25</td>
<td>242-642</td>
</tr>
<tr>
<td>Power clean (kg)</td>
<td>122.79</td>
<td>15.35</td>
<td>83.91-142.88</td>
</tr>
<tr>
<td>Power clean/BW</td>
<td>1.09</td>
<td>0.17</td>
<td>0.77-1.40</td>
</tr>
<tr>
<td>Squat (kg)</td>
<td>184.89</td>
<td>30.64</td>
<td>138.35-251.74</td>
</tr>
<tr>
<td>Squat/BW</td>
<td>1.64</td>
<td>0.28</td>
<td>1.06-2.26</td>
</tr>
<tr>
<td>Bench press (kg)</td>
<td>139.64</td>
<td>18.55</td>
<td>111.13-183.70</td>
</tr>
<tr>
<td>Bench press/BW</td>
<td>1.24</td>
<td>0.19</td>
<td>0.93-1.56</td>
</tr>
<tr>
<td>Vertical jump (in)</td>
<td>29.11</td>
<td>3.70</td>
<td>21-38.50</td>
</tr>
<tr>
<td>20-m sprint (s)</td>
<td>3.23</td>
<td>0.27</td>
<td>2.83-3.97</td>
</tr>
<tr>
<td>40-m sprint (s)</td>
<td>5.26</td>
<td>0.37</td>
<td>4.65-6.41</td>
</tr>
</tbody>
</table>

*Note.* 3-RM values for the power clean, squat, and bench press are presented. BW = body weight.
Table 6

Intercorrelations between Core Stability and Athletic Performance \((N = 21)\)

<table>
<thead>
<tr>
<th></th>
<th>Best MBESTT</th>
<th>Best 30-sec Sit-up</th>
<th>Best 60-sec Sit-up</th>
<th>Best Trunk Flexion</th>
<th>Best Trunk Extension</th>
<th>Best Right Flexion</th>
<th>Best Left Flexion</th>
<th>Best Total Core</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clean</td>
<td>.383</td>
<td>.406</td>
<td>.291</td>
<td>-.082</td>
<td>-.096</td>
<td>-.124</td>
<td>-.388</td>
<td>-.134</td>
</tr>
<tr>
<td>Clean/BW</td>
<td>-.129</td>
<td>.821***</td>
<td>.836**</td>
<td>.560**</td>
<td>.342</td>
<td>.343</td>
<td>.189</td>
<td>.520*</td>
</tr>
<tr>
<td>Squat</td>
<td>.365</td>
<td>.185</td>
<td>.085</td>
<td>-.150</td>
<td>-.237</td>
<td>-.108</td>
<td>-.292</td>
<td>-.182</td>
</tr>
<tr>
<td>Squat/BW</td>
<td>-.092</td>
<td>.588***</td>
<td>.608**</td>
<td>.443*</td>
<td>.162</td>
<td>.285</td>
<td>.171</td>
<td>.404</td>
</tr>
<tr>
<td>Bench</td>
<td>.496*</td>
<td>.020</td>
<td>-.077</td>
<td>-.215</td>
<td>-.205</td>
<td>-.195</td>
<td>-.247</td>
<td>-.194</td>
</tr>
<tr>
<td>Bench/BW</td>
<td>-.029</td>
<td>.550**</td>
<td>.590**</td>
<td>.452*</td>
<td>.237</td>
<td>.296</td>
<td>.318</td>
<td>.473*</td>
</tr>
<tr>
<td>Vertical jump</td>
<td>-.194</td>
<td>.631*</td>
<td>.721*</td>
<td>.476*</td>
<td>.261</td>
<td>-.001</td>
<td>-.066</td>
<td>.354</td>
</tr>
<tr>
<td>20-m Sprint</td>
<td>.155</td>
<td>-.690**</td>
<td>-.803**</td>
<td>-.542*</td>
<td>-.267</td>
<td>-.226</td>
<td>-.171</td>
<td>-.446*</td>
</tr>
<tr>
<td>40-m Sprint</td>
<td>-.063</td>
<td>-.611**</td>
<td>-.680**</td>
<td>-.418</td>
<td>-.239</td>
<td>-.225</td>
<td>-.108</td>
<td>-.359</td>
</tr>
</tbody>
</table>

Note. 3-RM values for the power clean, squat, and bench press are presented. BW = body weight. *\(p \leq .05\). **\(p \leq .01\).
Figure 9. The scatter diagram of the test-retest reliability of the MBESTT test.

$r = .734, p \leq .01$
Figure 10. The scatter diagram of the test-retest reliability of the 60-second maximum sit-up test.

\[ r = .862, \ p \leq .01 \]
American football is a sport that requires athletes to be explosive at any given moment. Athletes are constantly transferring forces between the extremities and are in need of support from the musculature of the core to keep the kinetic chain of the body intact. Researchers have failed to show that training the core is effective for enhancing athletic performance in sports (Durall et al., 2009; Sato & Mokha, 2009; Scibek, Guskiewicz, Prentice, Mays, & Davis, 2001; Stanton, Reaburn, & Humphries, 2004; Tse, McManus, & Masters, 2005). Furthermore, only a few researchers appear to have even attempted to determine the inherent relationship between core stability and athletic performance (Nesser & Lee, 2009; Nesser et al., 2008). Therefore, this study was designed to investigate the relationships between measurements of core stability and measurements of athletic performance in collegiate American football players. The components of core stability that were examined were core power and endurance. In addition, the reliability of all core stability measures was examined in this group of athletes.

Statistically significant, moderately strong correlations between many, but not all, core stability measures and measures of athletic performance were found. The core stability measures that related the most to the athletic performance measures were the 60-second and 30-second maximum sit-up tests and the trunk flexion test. Overall, the 60-second sit-up test was the measure that best related to athletic performance. The subjects that performed a high number of sit-ups in 60 seconds: (a) power cleaned a
larger load relative to body weight \((r = .836)\); (b) squatted a larger load relative to body weight \((r = .608)\); (c) benched pressed a larger load relative to body weight \((r = .590)\); (d) jumped higher in the vertical jump \((r = .721)\); (e) ran faster in the 20-m sprint \((r = -.803)\); and (f) ran faster in the 40-m sprint \((r = -.680)\). Furthermore, the majority of the core stability measures were found to have "acceptable" reliability coefficients for field-based tests (Baumgartner, Jackson, Mahar & Rowe, 2007). The McGill total core had the highest reliability coefficient out of the eight core stability measures \((r = .911, p = .000)\), although there was a statistically significant improvement in the McGill total core score (measured in seconds) from trial to trail \((\text{trial 1 } M = 364.00, SE = 19.72; \text{trial 2 } M = 427.61, SE = 28.13; t(20) = -4.88, p = .000)\). Perhaps the most reliable measurement was the 60-sec maximum sit-up test; it had a test-retest correlation of .862 \((p = .000)\) and there was no significant difference in the mean number of completed sit-ups from the first trial to the second \((\text{trial 1 } M = 38.71, SE = 1.89; \text{trial 2 } M = 40.33, SE = 1.71; t(20) = -1.68, p = .108)\).

The participating football players in this study had means of height \((184.70 \text{ cm})\) and weight \((114.31 \text{ kg})\) that were similar to other Division II football players \((185.0 \text{ cm} \text{ and } 105.3 \text{ kg}, \text{respectively})\) (Garstecki, Latin & Cuppett, 2004). The subjects in the current study had greater means (e.g., superior performance scores) to other Division II football players (Garstecki, Latin & Cuppett, 2004) with regard to athletic performance measures (power clean; power clean relative to body weight; back squat; back squat relative to body weight; bench press; bench press relative to body weight) even when 3-RM testing was done (used in this study) instead of 1-RM. To the author's knowledge,
the only other researchers to investigate the relationships between core stability and athletic performance in collegiate football players were Nesser et al. (2008). The players in the current study were similar in terms of anthropometric measures to those studied by Nesser et al. (2008); surprisingly the measures of core stability and athletic performance for the subjects of the current study were also comparable to the Division I football players studied by Nesser et al. (2008).

**Reliability of Core Stability Measures**

Although researchers have reported on the reliability of the core stability measures that were used in this study in non-athletic populations (Augustsson et al., 2009; Cowley et al., 2009; Cowley & Swensen, 2008; McGill, 2007), and researchers have tested athletes using these measurements of core stability (Durall et al., 2009; Nesser & Lee, 2009; Nesser et al., 2008; Tse et al., 2005), it does not appear that the reliability of these tests have been investigated in an American collegiate football population. Hence, to the author's knowledge, this is the first study in which reliability coefficients are reported for a number of core stability measures in the same collegiate football population. To determine the reliability coefficients, test-retest correlation coefficients were obtained to determine stability of measures for the athletes relative to the group; in addition, dependent t-tests were used to compare the means of the two test trials of each core stability measure. Most of the core stability tests (excluding the trunk extension and right flexion tests) were found to have acceptable (Baumgartner et al., 2007) reliability (based on magnitude of the test-retest correlation coefficients). The highest test-retest correlations were reported for total core ($r = .911, p = .000$), 60-sec
maximum sit-up \((r = .862, p = .000)\), and trunk flexion \((r = .828, p = .000)\). Out of these tests, only the 60-sec maximum sit-up test did not show a significant improvement in means (as demonstrated in dependent t-test). A reason for the test-retest improvements in scores for the trunk flexion, right flexion, left flexion, and total core could be due to miniature neuromuscular adaptations from performing the tests twice (J. Ortega, personal communication, May 7, 2010).

The MBESTT was a new test developed for this study. The MBESTT was modeled after the Front Abdominal Power Test (FAPT) described by Cowley and Swensen (2008), and the seated shot put test used Mayhew et al. (1993). Both of these other tests have been shown to be repeatable. Cowley and Swensen (2008) reported an intraclass correlation coefficient (ICC) of .95 for the FAPT and Mayhew et al. (1993) reported the seated shot put to be reliable based upon a validity and reliability analysis study by Gillespie and Keenum (1987). Gillespie and Keenum (1987) reported Fisher's intraclass reliability coefficients of .96 and .97 for the seated shot put test and retest in a group of healthy, untrained males. Though the MBESTT was found to be reliable \((r = .734, p = .000)\) ("acceptable" reliability according to Baumgartner et al., 2007), and there was no significant difference between trials (trial 1 \(M = 122.16, SE = 9.36\); trial 2 \(M = 133.16, SE = 9.09\); \(t(20) = -1.63, p = .118\)), it exhibited the lowest r-value out of all the other "acceptable" reliability tests. The low r-value of the MBESTT in the current study could be due to the learning effect and/or the skill technique acquisition that maybe required to perform the MBESTT consistently. Another possible explanation for the low reliability may have been that the two phases of the first trial of the test were completed
on separate days (introducing day-to-day variability). Furthermore, the athletes tested were much less experienced in the throwing of a medicine ball ($M = 33.76 \pm 20.61$ months) when compared with their experience level in sit-ups ($M = 71.71 \pm 49.07$ months). In fact, the athletes were much less experienced in throwing a medicine ball than in performing sit-ups, sprinting, and in Olympic-style lifting.

The 60-second maximum sit-up test, with a built in 30-second test, was used to measure core power and was found to have a high reliability coefficient ($r = .862, p = .000$). In addition, there was not a statistically significant improvement of scores from trial to trial. The procedures for the sit-up test were adopted from Augustsson et al. (2009) and Baechle and Earle (2000). Reliability for these tests has previously been established in healthy, young men. Augustsson et al. (2009) reported an ICC of .93 with a 95% confidence interval of .77-.98 for the 30-second maximum sit-up test. In the current study, the 30-second test had a reliability coefficient of .758, which is "acceptable" reliability according to Baumgartner et al. (2007). The subjects of the current study were very experienced in performing sit-ups ($M = 71.71 \pm 49.07$ months), which could explain why the current study was able to show both of the sit-up tests to be reliable in these subjects.

In the current study, core endurance was measured with the McGill protocol (McGill, 2007). Previously established reliability coefficients of greater than .98 have been found for the components (trunk flexion, trunk extension, right flexion, left flexion) of this protocol in young, healthy men and women (McGill, Childs & Liebenson, 1999). In collegiate gymnasts, Durall et al. (2009) reported ICC ranging
from .89 to .92 for the McGill protocol. Reiman et al. (2010) used modified versions of the trunk flexion and extension tests, similar to the versions used in the current study, and reported strong correlations between standard methods of the tests (\( r = .84 \) for trunk flexion, \( r = .90 \) for trunk extension). In the current study, only two out of the four individual tests were considered to have "acceptable" reliability, based on the magnitude of the correlation coefficient (Baumgartner et al., 2007). The trunk flexion test had the highest reliability coefficient at .828 (\( p = .000 \)) and the left flexion test had the only other acceptable value (\( r = .742, p = .000 \)). The other two tests of the protocol, trunk extension and right flexion, had "unacceptable" reliability (i.e., \( r \leq .70 \)) according to Baumgartner et al. (2007). The reliability coefficients in the current study were lower than the values reported by others (Durall et al., 2009; McGill, Childs & Liebenson, 1999; Reiman et al., 2010). Though Nesser et al. (2008) used the four core endurance tests, reliability coefficients were not reported for their collegiate football subjects.

Reasons for the lower reliability in the current study could have been due to the tests of the protocol being split-up and completed on separate days (introducing day-to-day variability). Another reason for the low reliability of these tests could be due to the variability in when the testers stopped the test (i.e., subjective judgment of when subjects deviated from the start position during the isometric holds). Reasons for the poor and "unacceptable" reliability in the trunk extension and right flexion tests specifically, could be due to design flaws in the methods of these two tests. The trunk extensor test was performed on a bench press bench, which may have been too narrow for the subjects to keep their lower half of the body on while their upper body was
projected out over the edge. When compared to previous studies (Durall et al., 2009; Nesser & Lee, 2009; Nesser et al., 2008), the subjects of the current study had larger body masses which could have influenced their ability to hold their projected-out upper body over the edge of the bench press bench. For the right flexion test, subjects could have deviated from the start position due to possibly becoming fatigued from performing the left flexion test first, or by being allowed to correct the dropping of the hips toward the field turf instead of having the test stopped once the body broke the straight-line starting position.

Consistent with what was done by Nesser et al. (2008), the four tests of the McGill protocol were combined to create the total core score. Since the muscles of the core work synergistically together to bring stability the spine during movements, the total core score was considered a measure of core stability in the current study. The total core score had the highest reliability coefficient \( r = .911, p = .000 \) (based on magnitude of the test-retest correlation coefficient) out of any of the other core stability measures, even though there was a statistically significant improvement in means from trial to trial. To the author's knowledge, this is the first study to report on the reproducibility of the total core score in collegiate football population.

One of the research questions in this study was concerned with the relationships between the core stability measures themselves. It was expected that the core power measures of the MBESTT and 30-sec and 60-sec maximum sit-up tests would significantly relate to each other, but not to the core endurance measures (i.e., McGill protocol). Even though the MBESTT closely resembled the sit-up in terms of movement
patterns (i.e., subjects quickly flexing the trunk up from the supine position with knees bent) and there was "global" system muscle activation (i.e., rectus abdominis, internal and external oblique), the MBESTT was not correlated to the 30-sec and 60-sec maximum sit-up tests ($r = .021$; $r = -.156$, respectively). The strength of these relationships may have been hindered by the less-than-perfect reliability of either test. These results suggest that either the MBESTT or the sit-up tests are not actual measures of core power, and therefore could be measuring a different component of core stability, such as core endurance. The individual movements of the MBESTT were explosive and quick (i.e., lasting only a few seconds) compared to the movements of the sit-ups, which were repetitive in nature and lasted for 60 seconds. Researchers have reported greater trunk muscle activation duration when sit-ups are performed quickly compared to slowly (Godfrey, Kindig & Windell, 1977; Vera-Garcia, Parodi, Elvira & Sarti, 2008). This longer activation of the trunk muscles during quickly performed sit-ups is thought to provide stability to the spine (Vera-Garcia et al., 2008). Providing stability to the spine implies the trunk muscles during quick sit-ups are sustaining prolonged contractions, which is essentially muscular endurance. These differences in trunk muscle activation duration during different types of sit-ups (e.g., quickly vs. slowly) may explain why the MBESTT scores did not highly relate to the maximum sit-up scores for these athletes.

Furthermore, the sit-up tests had significantly moderate correlations to the McGill trunk flexion, and total core score tests. The 60-second test had higher correlation values than the 30-sec test to the trunk flexion test ($r = .615$, $p = .003$) and the total core score ($r = .511$, $p = .018$). These relationships could be due to similar
muscle activations patterns in the two movements. These two measures of core stability involve flexion of the spine, which requires activation of the rectus abdominis (RA) and internal and external obliques (Juker, McGill & Kropf, 1998; McGill, 2007).

Researchers have reported abdominal activation to be over 100% of isometric Maximal Voluntary Contraction (MVC) for the RA during the flexion of the spine portion of the sit-up (Axler & McGill, 1997). The core power and core endurance measures were not expected to be correlated to each other based on the fact that the core power measures were more explosive and dynamic in movement patterns than the core endurance measures, but these results, along with the electromyographical research on the core muscles (Axler & McGill, 1997; Godfrey et al., 1977; Juker, McGill & Kropf, 1998; McGill, 2007; Vera-Garcia et al., 2008), suggest that the sit-up tests, mainly the 60-second test, may be a measure of core endurance rather than core power.

The measures of core endurance (i.e., McGill protocol) in the current study had low to moderate significant correlations to each other, which were expected. The tests that had the greatest correlation were the right and left flexion tests ($r = .830, p = .000$). The correlations between the tests of the McGill protocol in the current study were higher than those reported by Nesser et al. (2008). Nesser et al. (2008) only reported significant correlations for the left flexion test to the trunk flexion test ($r = .468, p \leq .05$) and the right flexion test ($r = .617, p \leq .01$). The results of the current and Nesser et al. (2008) confirm that there are relationships between the four components tests of the McGill protocol, possibly because they all are measuring core muscular endurance in their targeted muscle groups.
Intercorrelations between Measures of Core Stability and Measures of Athletic Performance

The primary hypothesis of the current study was that the core power measures (i.e., MBESTT, 30- and 60-second sit-up tests) would relate to the measures of athletic performance, while the measures of core endurance (i.e., McGill protocol) would not. There was only one significant correlation between the MBESTT and the athletic performance measures. The MBESTT was moderately correlated to the absolute bench press ($r = .496, p = .022$), a measure of upper body strength and power (Mayhew et al., 1993). Furthermore, the MBESTT was derived from the scores from the two phases that were subtracted from one another to create the end score, which is theoretically capturing just the involvement of the core. The first phase of the MBESTT was done to measure upper body power (Mayhew et al., 1993), while the second phase was thought to capture both upper body power and the power of the core musculature. While it was thought that the MBESTT represented the contribution of the core, in other words core power, other factors might explain the MBESTT scores and the failure of the MBESTT to relate to performance measures. These factors include, but are not limited to: (a) timing of the movements of the phases; (b) technique of throwing the medicine ball; and (c) a low level of experience in throwing medicine balls for these subjects ($M = 34.41 \pm 20.34$ months).

Out of all the core stability measures, the maximum sit-up tests had the highest correlations to the athletic performance measures. Both of the sit-up tests had moderate to strong relationships to measures of athletic performance, with the 60-second test...
having slightly higher coefficients on average than the 30-second test. The sit-up tests were only related to the weightlifting score measures that were expressed relative to body weight. That the sit-ups related to most of the athletic performance measures is not surprising, since both sit-up tests were found to be reliable and because they were timed tests, theoretically capturing core power production. Furthermore, the sit-up tests seem to require more activation of the "global" muscles (i.e., rectus abdominis, internal and external obliques) than the "local" muscles because of the rapid, explosive movements of the tests and because of the maximal effort that the tests demand from the subjects. Researchers have reported greater trunk muscle coactivation between the abdominals, which act as the primary movers of the trunk, and the erector spinae, which are considered to be the antagonists, when the speed of sit-ups increase (Godfrey et al., 1977; Vera-Garcia et al., 2008). Hence, it makes sense that timed sit-up tests would relate to the measures of athletic performance (i.e., squat, power clean, bench press, vertical jump, 40-m sprint) all of which are performed quickly (e.g., under 6-seconds). Furthermore, researchers have reported abdominal activation (specifically, the rectus abdominis) during squats (Hamlyn, Behm & Young, 2007; Nuzzo, McCaulley, Cormie, Cavill & McBride, 2008), bench press (Uribe et al., 2010), jumping and landing (Kulas, Schmitz, Shultz, Henning & Perrin, 2006), and running (Behm, Cappa & Power, 2009; Saunders, Rath & Hodges, 2003). Additionally, the 30-sec and 60-sec sit-up tests seem to be specific to the measures of athletic performance in terms of being: (a) multiple repetitions; (b) explosive movement patterns; and (c) lasting under a minute. This specificity, together with the practicality of the measures, and the apparent (yet still
unclear) relationships to measures of athletic performance, seems to make the sit-up tests ideal for measuring core stability in a collegiate football population.

The 60-second maximum sit-up test explained approximately 69% of the variance in the power clean score (expressed relative to body weight). The power clean is a complex Olympic-style lift that requires precise timing of the musculature and movement patterns, mainly hip extension, knee extension, and plantar flexion (Baechle & Earle, 2000), which makes proper technique a limiting factor in the outcome of the power clean score. Explaining a large portion of the variance in the power clean scores, the 60-second maximum sit-up test is deemed a good measure of core stability with regard to relating to this key measure of athletic performance in support of the primary hypothesis of this study. Furthermore, the 60-second sit-up test explains more of the variance in almost all of the performance measures than does the McGill test scores in the current study and in the study by Nesser et al. (2008).

Since some of the measures of core endurance seem to have a relationship with some of the measures of athletic performance, the second part of the primary hypothesis (i.e., the measures of athletic performance and the measures of core endurance would not relate to each other) cannot be accepted. The McGill protocol yielded scores that were low to moderately correlated with the measures of athletic performance. Of the McGill tests, it was the total core score and trunk flexion test that had the highest correlations to athletic performance. On average the total core had lower correlations to athletic performance than the trunk flexion test, even though the total core had the highest reliability coefficient out of all core stability measures. Possible reasons behind
the trunk flexion test being related to all of the measures of athletic performance, except for the lifting scores expressed in absolute terms, is because of its specificity to the athletic performance measures, in terms of being performed in the same plane of motion, and requiring abdominal activation due to trunk flexion. Flexion of the spine requires activation of the RA, internal and external oblique (Juker et al., 1998; McGill, 2007), which most of the measures of athletic performance require as well (Behm et al., 2009; Hamlyn et al., 2007; Kulas et al., 2006; Nuzzo et al., 2008; Saunders et al., 2003; Uribe et al., 2010).

The results of the current study are somewhat consistent with what was reported by Nesser et al. (2008) (i.e., the magnitude of the correlations of the McGill tests to performance were similar), even though measures of athletic performance involving lifting were represented by 3-RM tests in the current study, rather than 1-RM tests used by Nesser et al. (2008). However, Nesser et al. (2008) did report that the trunk extension, right flexion, and left flexion tests were related to some of the measures of athletic performance, unlike the current study. The lack of correlation between athletic performance and trunk extension, right flexion, and left flexion in the current study could be due to the poor reliability of those tests, especially for trunk extension and right flexion. Furthermore, the fact that the right and left flexion tests were not significantly related to any of the measures of athletic performance further supports the idea that core measures involving movements in the sagittal plane, like the 60-second maximum sit-up, and trunk flexion tests, may be most relevant to use when trying to establish a relationship with athletic performance.
Implications

The major implication of this research is that a 30-second or 60-second sit-up test is the best field test of core stability currently available for use in relating to measures of athletic performance in collegiate football players. The 30-sec and 60-sec maximum sit-up tests are practical core stability measurements that are cost and time efficient. The 30-sec and 60-sec maximum sit-up tests were found to be reliable and moderately correlated to measures of athletic performance, making them the best field-based assessment to measure core stability out of the measures investigated in the current study in collegiate football players.

Future Research

One next step in continuing the ideas of this study would be to improve on the MBESTT or another field test like it that would better capture the measure of explosive core power. In the MBESTT, there should be only a single day of testing for each trial and only one test administrator should give the test to improve reliability. Future research should determine the interrater reliability of the MBESTT. Additionally, since experience and technique seemed to play a role in the outcome of MBESTT scores and the inherent lack of correlations to athletic performance, maybe allowing subjects more time to become familiarized with the phases of the test would improve the test as a measure of core stability. Investigating the muscle activation of the core during the MBESTT could explain what muscles are activated during the phases of the test, as well as determining the amplitude of trunk muscle activation. Also warranted is the development of another field test to measure core power that will have greater reliability.
and better relationships to measures of athletic performance than currently available measures. Additionally, future research could study athletes training with core power exercises (e.g., timed sit-ups) to determine if such training would enhance measures of athletic performance and/or measurements of core power. Furthermore, since the measures of core stability in the current study were performed either sitting or lying and researchers (Kibler et al., 2006; Willardson, 2007) have suggested that measures of core stability be performed in similar functional positions to measures of athletic performance, future research should test core stability in an athletic position (e.g., standing and weight bearing).

**Conclusion**

Statistically significant, strong to moderate correlations between many, but not all, core stability measures and measures of athletic performance were found. The core stability measures that related the most to the athletic performance measures were the: (a) 30-second maximum sit-up test; (b) 60-second maximum sit-up test; and (c) trunk flexion. Though most core stability tests related to athletic performance, the exact reasoning as to why there is a relationship still remains unclear. Furthermore, the majority of the core stability measures were found to have acceptable test-retest reliability in this athletic group. Knowing that the core is comprised of synergistic parts working together, the current study along, with the works of other researchers (Nesser & Lee, 2009; Nesser et al., 2008), supports the notion that one test of core stability is unlikely to capture all aspects of the core that might relate to measures of athletic performance.
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Appendix A: Informed Consent
The Relationship between Core Stability and Athletic Performance

INFORMED CONSENT FOR PARTICIPATION

Please read the following as it provides information about this research study. Please understand that you are being asked to volunteer in this study and it is your choice to participate. By signing this form you are indicating that you have been informed of the nature of the study including the risks and benefits of its association and want to participate.

Principal Investigator:

Angela M. Dendas, B.S., CSCS, USAW
Humboldt State University
707-616-0292
Angela.Dendas@humboldt.edu

Project Description:

The purpose of this study will be to investigate the relationships between athletic performance and core stability among collegiate Division II football players. A secondary purpose will be to test the repeatability of selected core stability measures in an athletic population. This research may help guide coaches to select appropriate methods to measure core stability and its components.

Consent:

1. You must be at least 18 years old to participate in this study.
2. Your participation in the research study is voluntary.
3. You may choose not to participate at all, or you may refuse to participate in certain procedures or answer certain questions or discontinue your participation at any time without penalty or loss of benefits.

Procedures:

If you agree to participate in this study, you will:

1. Be asked to participate in testing that will take place over a 6-day period (Approximately Feb. 19 & Feb. 22-26, 2010).
2. Complete a demographic and athletic background questionnaire. The athletic background questionnaire will determine final eligibility for the study.
3. Be assigned to your already predetermined off-season training groups (i.e., Heavy Group 1, Heavy Group 2, and Skill Group).
4. Have your core power measured with the modified Front Abdominal Power Test (mFAPT) (explosive sit-up movement with chest pass of an 8-lb medicine ball as far as you can). The 60-second maximal sit-up test. These tests will approximately take 10 minutes each to complete. These tests will not be done on the same day or on consecutive days.
5. Have your core endurance measured with the McGill protocol of four held-isometric endurance tests (upper torso extended off of weight bench and held for as long as possible, side-bridge-like-position held for as long as possible, and sit-up-like-position held for as long as possible). These tests will approximately take 5 minutes each to complete (total 20-min). These tests will be done in a single testing session with recommended rest periods in between tests, but will not be repeated on consecutive days.
6. Have your athletic performance measured with standardized 3-RM (maximal weight lifted three times) in the power clean, back squat, and bench press. These tests will be completed only once during assigned days at your normal scheduled off-season training time.
7. Have your athletic performance measured with a standardized vertical jump height protocol and 40-meter sprint test. These tests will be completed only once during the testing period on specified days.

Possible Risks:

This study involves bouts of all-out efforts in the mFAPT, 60-second Maximum Sit-up Test, and McGill protocol. Bouts of all-out efforts will also be required for the 3-RM
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power clean lift, 3-RM back squat lift, 3-RM bench press lift, vertical jump and the 40-
m sprint.

1. (   ) You may experience discomfort that is associated with this type of
strenuous, all- out bouts of exercise.
2. (   ) You may experience muscle soreness that lasts for up to 72 hours from
performing any of these activities.
3. (   ) There is a possibility of injuring yourself while performing any of these
activities. Proper supervision and instruction will be provided to avoid injury.
Standardized procedures for testing will be followed. Emergency equipment and
trained personnel will be available to respond to any unusual situations should
they arise.

Benefits:

The only direct benefits to you for participating in this study include receiving your
scores for all core power and endurance tests, as well as your scores in the athletic
performance tests that may help you determine any individual strengths or weaknesses.
The athletic performance scores can also help your strength and conditioning coach
write a more appropriate strength training regimen for you.

Confidentiality/Anonymity:

You understand that participation in this study is completely voluntary. Confidentiality
will be protected by the following ways: (a) results will be presented as group data in
any presentations and publications; (b) all testing data, once collected, will be stored in
password-protected computers that are only accessible by the Principal Investigator, and
the faculty supervisor; (c) all athletic performance data, once collected, will be made
available to the Head Strength and Conditioning coach only for training purposes; (d) all
non-electronically stored information will be kept in a locked drawer in the residence of
the P.I.; and (e) all data will be kept for five years. Five years after project completion,
data will be destroyed via a paper shredder and electronic information will be
permanently removed from computer memory. The demographic and athletic
background information collected will be treated as privileged and confidential as
described in the Health Insurance Portability and Accountability Act of 1996. The
Principal Investigator will only have access to your demographic and athletic
background information. Participation in this research project will not involve any
additional costs. You understand that no compensation will be awarded for participating in this study. Authorized persons from Humboldt State University and the Institutional Review Board have the legal right to review research records and will protect the confidentiality of those records to the extent permitted by law. Otherwise, all research records will NOT be released without your consent, unless required by law or court order. Results of testing will be confidential and will not be released unless individual participant consent is given; otherwise your name will be assigned a number to analyze data for anonymity purposes.

Institutional Contacts:

For questions regarding this study, please contact the Principal Investigator using the contact information above. If you have any additional questions concerning your rights as a volunteer or you are dissatisfied at any time with any aspect of this study you may contact Dr. Tina Manos (707) 826-5962 or The Office of Research, Graduate Studies, and International Programs; Humboldt State University; (707) 826-3949, if you wish.

Signature:

Your signature below indicates your voluntary agreement to participate in this study.

I, __________________________ have read and agree to participate in this study as described above.

(Please PRINT Your Name Here)

____________________________________  ____/____/____

(Please SIGN Your Name Here)  (Date)
Appendix B: Demographic and Athletic Background Screening Questionnaire
Demographics and Athletic Background Screening Questionnaire

1. Name: ________________________
2. Date: _________________________
3. Date of birth expressed as Month/Day/Year:____________________

Please circle/mark ONE of the following:

4. ( ) Yes or ( ) No: Are you currently injured?
5. ( ) Yes or ( ) No: Do you have chronic back pain?
6. ( ) Yes or ( ) No: Do you have any medical condition made worse by exercise?
7. ( ) Yes or ( ) No: Do you have any previous musculoskeletal injury or neurological condition that may impair your ability to perform any of the core power and endurance tests and/or athletic performance measures?
8. Which ONE of the following ethnicities BEST represents you:
   a. African American
   b. Asian
   c. Caucasian
   d. Latino
   e. Middle Eastern
   f. Native American
   g. Pacific Islander
   h. Other

9. Position on the Humboldt State University football team:______________________
10. Months of sit-up experience:__________________________
11. Months of medicine-ball throw/push experience:_____________
12. Months of Olympic weightlifting experience:_______________
13. Months of sprinting experience:_________________________
Appendix C: Sample Data Collection Sheet
<table>
<thead>
<tr>
<th>Name</th>
<th>1Max Sit-ups @30-s</th>
<th>1Max Sit-ups @ 60-s</th>
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<table>
<thead>
<tr>
<th><strong>Linebackers</strong></th>
<th>1Max Sit-ups @30-s</th>
<th>1Max Sit-ups @ 60-s</th>
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Appendix D: Verbal Instructions for Core Power and Endurance Measures
MBESTT

Phase 1 of Test
1. Sit down up against padded bench
2. Keep knees bent at 90°
3. Sit straight-up with shoulders touching padded bench
4. Place feet under Dumbbells, securing feet
5. Place hands on med-ball, no more than 6” apart
6. Hold med-ball in spread-hands against chest
7. Extended arms quickly, throwing ball as far as possible thru target

Phase 2 of Test
1. Sit down with feet by Dumbbells
2. Keep knees bent at 90°
3. Place feet under Dumbbells, securing feet
4. Place hands on med-ball, no more than 6” apart
5. Hold med-ball in spread-hands against chest
6. Lay back on turf
7. Quickly perform a sit-up and throw ball thru target as far as possible once in upright position. Keeping movements in one continuous motion

Right Flexion
1. Lay on right side with legs fully extended
2. Place top foot in front of lower foot
3. Place left hand on right shoulder
4 Support yourself on right forearm, elbow and closed hand
   (make a fist)
5 Lift hips off of turf, keeping body in a straight line

Left Flexion
1 Lay on left side with legs fully extended
2 Place top foot in front of lower foot
3 Place right hand on left shoulder
4 Support yourself on left forearm and elbow
   (make a fist)
5 Lift hips off of turf, keeping body in a straight line

Trunk Flexion
1 Sit with knees bent at 90° and back against wedge
2 Fold arms across chest with hands on shoulders
3 Feet will be secured down
4 Hold position when wedge is moved
5 Hold position as long as possible

Trunk Extension
1 Lay chest-down on bench
2 Align ASIS with edge of bench, leaving trunk planked out
3 Lower body will be secured down
4 Fold arms across chest with hands on shoulders
5 Hold upper trunk in plank position as long as possible

(adapted from McGill, 2007)

60-s Maximum Sit-up
1 Lay flat on field turf with knees bent at 90°
2 Interlock fingers behind head, but do not pull on neck
3 On "Go" command, quickly perform sit-ups
4 Make sure elbows touch thighs on up portion
5 Lower trunk down to turf, let upper back touch turf
6 Make sure hands and head DO NOT touch turf
7 Quickly perform as many sit-ups (i.e., up-down cycles) as possibly

(adapted from Augustsson et al., 2009; Baechle & Earle, 2000)
Appendix E: Testing Schedule
Wednesday February 24th (Subjects Only from the Skill Group)
1. MBESTT phase 1 (1st time)
2. 30-second and 60-second maximum sit-up test (1st time)

Thursday February 25th (Subjects Only from the Heavy Group)
1. MBESTT phase 1
2. 30-second and 60-second maximum sit-up test

Friday February 26th (All Subjects)
1. 30-second and 60-second maximum sit-up test (2nd time)
2. Right and left flexion tests of McGill protocol (1st time)

Monday March 1st (All Subjects)
1. MBESTT second phase (1st time)
2. Trunk flexion test of McGill protocol (1st time)
3. Trunk extension test of McGill protocol (1st time)
4. Right and left flexion tests of McGill protocol (2nd time)

Monday March 8th (All Subjects)
1. MBESTT (both phases) (2nd time)
2. Trunk flexion test of McGill protocol (2nd time)
3. Trunk extension test of McGill protocol (2nd time)