The Association between Measures of Trunk Neuromuscular Control Using Clinical Screening Tools and an Unstable Sitting Device

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ABSTRACT

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(Under the direction of Darin A. Padua)

Objective: To determine the association between clinical screening tools and a laboratory screening tool of trunk neuromuscular control (NMC). **Subjects:** Thirty recreationally active males and females free from current low back pain. **Methods:** Three clinical screening tools including the human arrow, side plank and seated ball task and one laboratory screening tool for trunk NMC were completed. Correlations were run between the laboratory measure and each clinical measure. **Results:** A significant relationship between the laboratory measure of trunk NMC and the seated ball task was found ($r_{(22)}$=0.498, p=.013). No significant relationship was found between the laboratory measure of trunk NMC and the human arrow ($r_{(28)}$=-0.029, p=0.894) or side plank ($r_{(28)}$=-0.114, p=0.595). **Conclusions:** The seated ball task may be an accurate indicator of trunk NMC in addition to the human arrow and side plank tasks, but the tasks assess components of trunk NMC that are independent of one another.

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CHAPTER I

INTRODUCTION

Low back pain (LBP) is a prominent health problem facing individuals (Standaert, Herring, & Pratt, 2004). Up to 85% of the general population will experience LBP in their lifetime, and LBP is the most frequent cause of disability for individuals younger than 45 years of age (Cleland, 2002; Martin et al., 2008). Low back pain alone accounts for 2% of all doctors visits, and imaging, injections, surgery and the use of opiates in the treatment and diagnosis of LBP has increased substantially over the past decade. In 1997, polling showed that the average health care cost for an individual with LBP was $4695, compared with $2731 for those without LBP (Martin et al., 2008). Low back pain is also a very common problem among athletes, and up to 85% of all athletes will experience LBP in their careers (Standaert et al., 2004). Athletes are more susceptible to these injuries because of the dynamic physical demands placed upon them, and commonly receive treatment for LBP (Nadler, Wu, Galski, & Feinberg, 1998). Nadler et al (Nadler et al., 1998) followed athletes for one year and found that 9.3% of subjects received treatment for LBP. Adolescent athletes report LBP lasting longer than one week substantially more frequently than a matched control group of non athletes (45% vs. 18%) over 3 years (Kujala, Taimela, Erkintalo, Salminen, & Kaprio, 1996). Wrestlers and gymnasts have been found to be more susceptible to LBP than other athletes, with incidence up to 59% in wrestlers (Granhed & Morelli, 1988) and 79% in gymnasts (Sward, Hellstrom, Jacobsson, Nyman, & Peterson, 1991b). Studies have shown that athletes with a history of LBP are nearly three times more likely to sustain a future low back injury (LBI) (Cholewicki et al., 2005) indicating the need for an accurate screening tool. The identification of factors lending to LBP are important for the treatment and future prevention of similar injuries (Kujala et al., 1996; Nadler et al., 1998; Standaert et al., 2004; B. T. Zazulak, Hewett, Reeves, Goldberg, & Cholewicki, 2007).

Because the rate of re-injury to the low back is so high, preventing the initial injury is most important in the treatment of LBP in the athlete. The average athlete loses 4-6 weeks of playing time to recover from a low back injury, and with recurrence rates so high, large amounts of playing time may be lost in an athlete's career due to LBP (Trainor & Wiesel, 2002). The spine is an inherently unstable structure and becomes stable through proper activation, referred to as trunk neuromuscular control (NMC), of trunk musculature (Bergmark, 1989). Trunk NMC may be composed of multiple components (B. Zazulak, Cholewicki, & Reeves, 2008). Neuromuscular control is what allows a dynamic system like the human body to be stable. Poor NMC of the trunk and core muscles is thought to be one of the most common predisposing factors for LBP in the athlete (B. Zazulak et al., 2008). The activation and strength of the transverse abdominis muscle (TrA) (Trainor & Wiesel, 2002), a main trunk stabilizer (Trainor & Wiesel, 2002) plays a large role in NMC (Hides, Wong, Wilson, Belavy, & Richardson, 2007; Hodges & Richardson, 1999; B. Zazulak et al., 2008). Activation of both the TrA and the multifidus, a deep back muscle, is thought to provide stability to the low back (Eriksson Crommert & Thorstensson, 2008; Wilke, Wolf, Claes, Arand, & Wiesend, 1995). There is evidence of delayed activation of the TrA muscle in patients with LBP as well as abnormal activation of the multifidi muscles in patients with LBP (Hides et al., 2008). As clinicians, the goal of our treatment in preventing LBP should be targeted on strengthening and training the TrA and multifidi to properly activate in response to perturbations to the trunk. In order to achieve this, we must be able to identify the athletes who have poor trunk NMC prior to participation in their sport. There have been several attempts to quantify trunk NMC, including mathematical models, force release systems and unstable sitting devices. Mathematical modeling and in vivo measurements of the lumbar spine were developed by Vera-Garcia (Vera-Garcia, Elvira, Brown, & McGill, 2007) and Brown (Brown, Vera-Garcia, & McGill, 2006). These models are very complicated and require a great deal of skill and time to execute. Brown et al (Brown et al., 2006) developed a force release apparatus in which subjects sat in a semi-seated position with a fixed amount of weight held to the torso by an electromagnet. The force was suddenly released and the time it took subjects to return to a neutral spine position was recorded and interpreted as their trunk NMC score. This procedure is not an accurate measure of trunk NMC as we wish to define it. The force release measure is a more appropriate measure of overall abdominal strength and lumbo-pelvic stability, rather than global trunk NMC. Postural control is a relatively simple and more accurate way of quantifying a subject's NMC based on their center of pressure (CoP) measurement (Cholewicki, Polzhofer, & Radebold, 2000). Cholewicki et al (Cholewicki et al., 2000) developed an unstable sitting device in which subjects were seated on a hemisphere atop a forceplate with the lower body secured to allow for sole trunk motion. An initial study was conducted with this device to ensure it was a proper measure of lumbar postural control (Cholewicki et al., 2000). The study involved several different hemisphere sizes and had healthy subjects performed trials on each hemisphere. Results showed an inverse relationship with hemisphere size and CoP trajectories. Trajectories were larger as the hemisphere size decreased, indicating an increase in difficulty in maintaining appropriate posture. Studies have been conducted to measure CoP in subjects with LBP and controls without LBP (Radebold, Cholewicki, Polzhofer, & Greene, 2001). All CoP data from the forceplate was significantly greater, representing poorer trunk NMC, in subjects who had LBP. This indicates that the unstable sitting device is able to differentiate between those with LBP and those without LBP. This is a simple task that doesn't take more than a few seconds to execute, and is simple to quantify when compared to the mathematical equations and in vivo measurements required in other tests.

Clinical measures of trunk NMC including the unstable sitting device are not accessible to most athletic trainers in the clinical setting however (B. Zazulak et al., 2008). The unstable sitting device requires some sophisticated and costly instrumentation that may limit many athletic trainers. The device also requires a fairly substantial amount of space, and often times an area for the device is not readily available in athletic training rooms. Because of these setbacks, there exists a need for a simpler, reliable way of assessing trunk NMC with little instrumentation and difficulty (B. Zazulak et al., 2008). Clinical measures of trunk NMC are commonly used in the athletic training setting during preseason screenings and injury assessments (B. Zazulak et al., 2008). Adequate endurance of the trunk muscles is thought to contribute to spinal stability, decreasing the likelihood of sustaining a low back injury (Panjabi, 1992a;

Willson, Dougherty, Ireland, & Davis, 2005). Isometric contractions of the deep low back muscles, thought to be important contributors to spinal stability, are hypothesized to be most beneficial at educating the stabilizing role of these muscles (Richardson & Jull, 1995). Men with good low back extensor muscle endurance have been reported to have fewer low back problems (Biering-Sorenson, 1984). Trunk extensor muscle fatigue has been shown to reduce postural control and increase CoP variance in healthy individuals, implying increased susceptibility to LBP (Vuillerme, Anziani, & Rougier, 2007). Commonly used tests include the single leg stance, visual observation of neuromuscular deficiencies through athletic maneuvers (B. Zazulak et al., 2008), the Sorenson back extension test (Moreau, Green, Johnson, & Moreau, 2001), the double leg lowering task (Smidt, Blanpied, Anderson, & White, 1987; Zannotti, Bohannon, Tiberio, Dewberry, & Murray, 2002), the human arrow and side plank stance (Willson et al., 2005), and the abdominal hollowing and brace maneuvers (Hides et al., 2008; Hodges, Gandevia, & Richardson, 1997). The double leg lowering task and the Sorenson back extension test are among the two most popular tests for trunk NMC. Studies show several draw backs to their methods however (Moreau et al., 2001; Smidt et al., 1987; Zannotti et al., 2002). The double leg lowering task appears to be a challenge to abdominal strength in all subjects, however there are multiple grading systems that have been shown to be inconsistent between studies. Identifying the onset of pelvic tilting is the main focus of the grading scale. It is hypothesized however that pelvic tilting cannot be observed as soon as it occurs (Zannotti et al., 2002). Zannotti et al (Zannotti et al., 2002) demonstrated low reliability of initial grading of the double leg lowering task. Smidt et al (Smidt et al., 1987) looked at differences in back extension endurance and double leg lowering scores in healthy control subjects and subjects affected by chronic LBP. Trunk extension scores were shown to be poor indicators of trunk strength, and showed no significant differences across groups. Double leg lowering scores showed moderate differences between groups, but scores were thought to be affected by anatomic variations including gluteal mass size and length of hip flexors (Smidt et al., 1987). A literature review revealed that controversy exists as to the amount of involvement that the hip extensors play in the Sorenson extension test. It has been shown that there is more EMG activity from the biceps femoris than the back extensors during this task (Moreau et al., 2001). Therefore, these two tests are not included in this study. Many of these clinical measures of trunk NMC are very subjective, and there is little evidence demonstrating the validity of these measures. A major limitation to the research assessing clinical measures of trunk NMC is that they have not been validated against a laboratory measure of trunk NMC (Willson et al., 2005; B. Zazulak et al., 2008). In the case of this study, the clinical measures of trunk NMC that will be used include the human arrow, the side plank and a seated balance task on a stability ball in which errors will be scored. We are going to introduce a novel task in the case of the seated ball test. Verifying the validity of these clinical measures against a laboratory based measure will give clinicians' the ability to properly screen athletes and identify those that may be at risk for injury. Athletic trainers may then take the appropriate preventative measures to decrease likelihood of initial or recurrent injury.

Clinical measures of overall postural stability, such as the balance error scoring system, have been developed and validated against laboratory based instrumentation. The balance error scoring system is a clinical tool that identifies the number of errors during balance tests. These measures have been shown to be valid and reliable methods of assessing overall postural control (Broglio, Zhu, Sopiarz, & Park, 2009). More recently, clinical movement assessment tools such as the landing error scoring system and the overhead squat test have been shown to be valid and reliable clinical tests for movement quality during functional tasks (Padua et al., 2009). These clinical measures of balance and movement quality are based on the underlying process of identifying pre-defined movement errors during different tasks. Clinical measures of trunk stability that focus on identifying movement errors during tasks which attempt to isolate trunk motion may also be valid clinical tests. Unsupported sitting on a physioball is a commonly used exercise to train trunk NMC. Identification of movement errors during such a task may be a good indication of overall trunk NMC; however, previous research has not investigated this task.

There is a lack of evidence indicating that laboratory measures of trunk NMC are associated with clinical measures. Therefore, the purpose of this study is to identify a reliable clinical screening tool of trunk NMC that correlates to the laboratory measure of CoP so that clinicians may be able to identify individuals susceptible to injury. The purpose of this study is to determine the association between clinical screening tools and a laboratory screening tool of trunk NMC.

Independent Variables

1. Sway area

CoP will be represented as sway area obtained from the unstable sitting apparatus for each subject.

Dependent Variables

1. Human Arrow Test

   Time to failure during one trial

2. Side Plank Test

   Time to failure during one trial

3. Seated Ball Test

   Mean number of errors committed during 3, 60 s trials

Research Questions

1. Is there a correlation between sway area and the score obtained from the seated ball test in subjects?

2. Is there a correlation between sway area and the score obtained from the human arrow test in subjects?

3. Is there a correlation between sway area and the score obtained from the side plank test in subjects?

Research Hypotheses

1. The seated ball scores will be significantly and positively correlated with the subjects' sway area.

2. The human arrow scores will be significantly, negatively correlated with the subjects' sway area.

3. The side plank scores will be significantly, negatively correlated with the subjects' sway area.

Null Hypotheses

1. H_o: The human arrow, side plank and seated ball scores will not be significantly correlated with the subjects' sway area.

Operational Definitions

Trunk NMC- The ability of the abdominal and trunk musculature to maintain a stable and controlled posture while participating in dynamic athletic tasks. This involves appropriate NMC and muscular strength of the abdominal and back musculature.

Clinical Tests- Tests executed by the athletic trainer in an athletic setting, either in the clinic or on the field, to assess trunk NMC of an athlete.

Human Arrow- The subject is prone on an exam table. The subject holds their body off the table by pushing up onto his/her toes and forearms. A straight, arrow-like position is to be held in this position for as long as the subject is able. Timing will stop when the subject breaks form. This includes increasing hip flexion or extension more than 10° from neutral or increasing lumbar lordosis. The subject's trunk NMC score will be the time that he/she is able to hold proper form.

Side Plank- The task is performed on the floor and subjects will be instructed to lay on his/her dominant side and to push up off the floor (Willson et al., 2005). Subjects will hold the position supporting weight on the forearm and lateral part of the dominant leg. Subjects will hold the position for as long as possible. Timing will be stopped when the subject breaks form. Breaking form includes increasing hip adduction or abduction more than 10° from neutral, increasing hip flexion more than 10° from neutral or increasing lumbar lordosis. The subject's trunk NMC score will be the time that he/she is able to hold proper form.

Seated Ball Test- The subject is seated on a stability ball on a stable, low-friction surface. The knees are bent and the feet may grasp the sides of the ball, while the arms are crossed over the chest. The subject will be asked to maintain upright posture while seated on the ball for a total of 60 seconds. Errors committed by the subject during this test will be counted and used as the trunk NMC score. Errors include lifting the arms off of the chest, placing a foot on the floor and movement of the ball more than 10° in any direction.

Laboratory Tests- Tests executed in the laboratory setting to measure trunk NMC. These devices contain an objective measure of trunk NMC from a laboratory device typically not readily available in the clinical setting.

Unstable Sitting Device- A laboratory device involving an unstable sitting task in which the feet and legs are supported allowing solely for movement between the thorax and pelvis (Cholewicki et al., 2000; Cholewicki et al., 2005; Radebold et al., 2001). The subject is seated on a hemisphere atop a forceplate which collects data about that person's CoP measurements.

95% Ellipse Area- A measure reduced from CoP data that encompasses 95% of all points registered by the forceplate during an unstable sitting task. This is the value for trunk NMC measured by our laboratory screening tool.

Delimitations

1. All trunk NMC tests will be performed under the same conditions in the laboratory for all subjects.

2. Participants in the study will be limited to individuals who are currently physically active. This will consist of participation in a minimum of 20 minutes of aerobic activity at least 3 times each week for a minimum of 3 months.

3. Participants must be healthy enough to execute all of the clinical tests and scientific testing. Participants with debilitating a debilitating injury that would be exacerbated by testing will be excluded.

Limitations

1. The hemisphere size on the unstable sitting device won't account for the anthropometric variety of subjects that may participate in the study.

2. Because broad criteria were set for subject population, results may not be generalized to all populations, including the elite athlete or inactive populations.

Assumptions

1. Clinical tests are shown to be reliable and to measure trunk NMC.

2. Consistent grading by the administrator of all tests will be executed on all trials.

3. There will be a spread of subjects regarding trunk NMC ranging from poor to excellent as determined by the unstable sitting device.

4. The moment demands will be the same across subjects for all unstable sitting.

5. Subjects will be honest regarding activity level defined in the inclusion criteria.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Athletes are at risk for a number of different injuries in sports, including those to the low back. In certain sports, up to 85% of athletes will experience low back pain at some time in their career (Standaert et al., 2004). Due to the increased risk of LBP recurring after an initial injury, there is a need to prevent the initial onset of LBP by identifying those individuals most at risk. Individuals with poor NMC have a substantially increased risk of developing LB injuries according to research (Cholewicki et al., 2005; Radebold et al., 2001; B. Zazulak et al., 2008). One of the most common treatments for low back pain is to place the athlete on a trunk stabilization protocol (Standaert et al., 2004; Stanton & Kawchuk, 2008). Trunk stabilization, according to Standaert et al (Standaert et al., 2004), consists of improving NMC, strength and endurance of the muscles central to maintaining dynamic spinal and trunk stability. Appropriate activation of the TrA and multifidi are thought to provide stability to the lumbar spine, contributing to a decreased risk of LBI and LBP (Eriksson Crommert &

Thorstensson, 2008; Wilke et al., 1995). With such a large incidence of recurrent LBP in the athletic population, an appropriate screening tool is a necessity.

This literature review focuses on the importance of trunk NMC in reducing the athlete's risk of LBI in sport participation. Both laboratory and clinical measures of trunk NMC will be discussed, as well as mechanisms and epidemiology of LBP.

Anatomy

The spine is a complex structure which is naturally unstable (Reeves, Cholewicki, & Silfies, 2006). There are three components of structures that make up the spinal column. Twenty-six vertebrae are distributed into four regions that comprise the spinal column; cervical (7), thoracic (12), lumbar (5), sacrum (1) and coccyx (1). Four natural curves are present throughout the spine. From a sagittal view, the cervical vertebrae displays a concave (posterior) curve, the thoracic a convex curve, the lumbar spine returns to concave and the sacrum and coccyx form a convex curvature. Intervertebral disks are located between each vertebral segment and are capable of deforming in certain areas as load demands change in the spinal column. Ligaments also enhance the stability of the spine and generally fall into two categories; intersegmental and intrasegmental, connecting vertebrae to one another or connecting parts of vertebrae to themselves.

The spinal stabilizing system has been described as consisting three subsystems; the passive musculoskeletal subsystem, the active musculoskeletal subsystem, and the neural and feedback subsystems (Bergmark, 1989; Panjabi, 1992a, 1992b). The passive subsystem consists of vertebra, facet articulations, intervertebral discs, spinal ligaments and joint capsules, and passive properties of the spinal musculature. The active subsystem consists of the muscles and tendons surrounding the spine, and the neural and feedback subsystem are composed of various force and motion transducers located in the muscles, tendons and ligaments surrounding the spine (Panjabi, 1992a). Bergmark (Bergmark, 1989) developed an effective approach to modeling the spinal system by identifying a local and a global system. The global system reacts to external loads placed on the spine, while the local system reacts to postural changes within the spine, as well as reinforces the global system's adjustments. All muscles that originate and insert at the vertebra are considered local, while those that serve to transfer load from the thoracic spine to the pelvis are considered global (Bergmark, 1989). The local system is comprised of all muscles that insert and originate on the vertebra of the spine. Local musculature maintains the curvature of the spine and creates mechanical stability. The erector spinae muscles, obliques, rectus abdominus, transverse abdominus and parts of the quadrates lumborum are all considered to be global musculature. Also considered to be part of the global system is intra-abdominal pressure, which enhances the stability of the spine, and is produced by the global musculature. While intra-abdominal pressure is not completely understood, it is thought to decrease the load on the spinal column by as much as 15-30% as well as aid in flexion of the lumbar spine which allows for increased muscle re-enforcement from local musculature (Bergmark, 1989).

Epidemiology of Low Back Injury

The normal function of the spine is its ability to maintain a proper level of stability that matches the demands placed upon it from changes in posture and static and dynamic loads (Panjabi, 1992a). Eighty to 85% of the general population will experience LBP during their lifetime and LBP is the most frequent cause of disability for people younger than 45 years of age (Cleland, 2002; Standaert et al., 2004; Trainor & Wiesel, 2002). At a given time, 1% of the United States population is disabled due to LBP and 7% of patients in a primary care practice will receive medical treatment for LBP each year. It is estimated that over $26 billion is spent annually on health care costs for the treatment of LBP (Luo, Pietrobon, Sun, Liu, & Hey, 2004). Individuals with LBP are estimated to spend about 60% more on health care than those individuals without LBP (Luo et al., 2004).

In athletes, LBP is also a frequent complaint. In some sports, such as gymnastics as many as 85% of athletes will experience LBP (Standaert et al., 2004). It is estimated that 10-15% of sports injuries are related to the spine (Trainor & Wiesel, 2002). Nearly 10% of athletes followed for one year received treatment for LBP (Nadler et al., 1998). Adolescent athletes reported LBP more than twice as frequently as matched control groups (45% vs. 18%) when followed over 3 years (Nadler et al., 1998). Cholewicki et al (Cholewicki et al., 2005) demonstrated that athletes with a history of LBP are nearly three times more likely to sustain future LBI. Low back pain accounted for loss of playing time in approximately 30% of college football players in a study conducted by McCarroll et al (McCarroll, Miller, & Ritter, 1986). Hainline (Hainline, 1995) found that 38% of professional tennis players reported LBP as the reason for missing at least one tournament. Typically, LBP takes about 4-6 weeks of treatment for resolution, which is unacceptable to most scholarship athletes, placing them at increased risk for recurrence if the problem is not reported in the first place or treated properly (Trainor & Wiesel, 2002). It is reported that in both the athletic and non-athletic population, most low back injuries (LBI) are thought to be soft-tissue related; either sprains or strains (Trainor & Wiesel, 2002). However, it is also estimated that up to 85% of underlying causes for LBP are unknown (Dreisinger & Nelson, 1996). Other sources estimate that correct diagnosis of LBP is made only 2-5% of the time at presentation (Harvey & Tanner, 1991).

Athletes are placed at a greater risk of LBP for several reasons. The concept of seasons alone will place an athlete at risk of LBP. When an athlete returns to pre-season after not maintaining fitness properly, they are more likely to sustain a LBI (Trainor & Wiesel, 2002). There is a normal discrepancy between trunk flexion strength and trunk extension strength. This ratio is 1:1.3 in healthy individuals, but Foster & Fulton (Foster, 1991) showed this ratio to be substantially reduced in athletes with LBP. Lastly, many times athletes are expected to perform advanced or complex moves without proper training during weight room activities and conditioning workouts. If faulty equipment or improper technique are used, the athlete may be placed at a great risk for sustaining a LBI (Trainor & Wiesel, 2002). Recurrence is another problem that presents in the athletic population in regard to LBP. Greene et al (Greene, Cholewicki, Galloway, Nguyen, & Radebold, 2001) surveyed nearly 700 college varsity athletes on their history of LBP. Nearly 19% of athletes surveyed had a history of LBP in the last 5 years, and almost 90% of these injuries were sports related. Of these athletes, almost 7% sustained a recurrent LBI in the following season. Related factors to the initial injury including how long ago the injury occurred, time lost due to injury, presence of LBP, time taken to return to full participation, were all significant predictors for sustaining a recurrent LBI in the following season.

The athlete represents a special population in regard to LBI and LBP. Athletic trainers and other associated health care professionals must do all they can to help prevent these debilitating injuries so that recurrent injuries are less likely. If prevention of LBP can be addressed, athletes in all sports will benefit.

Mechanisms of Low Back Pain

A number of different conditions may exist or occur that cause LBP in the athlete. Most LBIs are mainly related to the intervertebral discs, ligaments and muscles (Sward, Hellstrom, Jacobsson, Nyman, & Peterson, 1991a). These injuries may occur from a variety of sudden motions involving twisting or compression of the spine, or they may have a more gradual onset involving repetitive motion placing increased stress on certain structures over time. Sward et al (Sward et al., 1991a) compared changes in the lumbar spines of elite gymnasts with those of a control group. Evidence of disc degeneration was noted in 18 of the 24 athletes, compared with five of the sixteen non-athletes. Certain athletes have been found to be more prone to disc degeneration than others. Sports including volleyball, gymnastics, golf, rowing and wrestling that place high demands on the lumbar spine tend to display more disc related low back problems (Bono, 2004).

Spinal Stability

The spine is complex and due to its structure, it is inherently unstable (Reeves, Cholewicki et al., 2006). Muscles are the main components of the low back that provide spinal stability and allow the spine to bear more load than would be possible without their dynamic contribution (Panjabi, 2003). As mentioned before, these muscles make up the global and local active subsystem of the spine and their ability to function properly directly affects the spine's ability to bear loads while maintaining stability (Panjabi, 1992a). There may be a deficit in contraction of the global or local musculature. The global and local systems must work together to balance both the outer loads placed on the spine and the internal changes that occur as a result of the external load. If there is a deficit in either one of these systems, the spine will lose stability making it more susceptible to injury (Bergmark, 1989). Proper activation of these muscles in maintaining posture and in response to direct loads as well as a proper lordotic curve is necessary to maintain proper spinal stability. Because the trunk muscles are the main spinal stabilizers, de-conditioned individuals with improper trunk muscle strength are inherently unstable and thus more susceptible to LBP (Panjabi, 2003).

Neuromuscular Control

The muscles focused on in the literature contributing to spinal stability include the erector spinae muscles, TrA and the IOs (Hides et al., 2008; Hides et al., 2007; Reeves, Cholewicki et al., 2006; Renkawitz, Boluki, & Grifka, 2006; Stanton & Kawchuk, 2008; van Dieen, Cholewicki, & Radebold, 2003). The origins of LBP many times are thought to stem from spinal instability (Stanton & Kawchuk, 2008). Typically, treatment for this condition consists of a series of contractions of the trunk muscles to increase NMC of both global and local musculature and intra-abdominal pressure, although the latter concept is not thoroughly understood. These contractions are called abdominal hollowing and abdominal bracing. The abdominal hollowing consists of drawing in the lower abdomen and actively contracting the TrA in a supine position while keeping the other abdominal musculature relaxed (Richardson & Jull, 1995). The abdominal brace contraction is performed in the same position, but focuses on global abdominal muscle contraction rather than specific muscle contraction (Stanton & Kawchuk, 2008). The main muscle targeted in these contractions is the TrA. By contracting the TrA, the multifidi are consequently contracted, as well as the thoracolumbar fascia, all contributing to spinal stability (Hodges, Cresswell, Daggfeldt, & Thorstensson, 2001; Stanton & Kawchuk, 2008). Many patients with LBP display altered TrA activity, which inhibits their ability to effectively contract all of the multifidi and thoracolumbar fascia and thus contributes to instability (Stanton & Kawchuk, 2008).

Neuromuscular control is thought to play a large role in the spinal stabilizing system (Panjabi, 1992a). The neuromuscular system is responsible for continuously monitoring and controlling the forces in each of the muscles surrounding the spine. Distribution of tension and forces must be instantly altered and controlled by the neuromuscular system in order to maintain proper spinal stability in response to outside load changes (Panjabi, 1992a). Deficits in NMC are thought to play a large role in the presence of LBP (Hides et al., 2008; Hides et al., 2007; Reeves, Cholewicki et al., 2006; van Dieen et al., 2003). Several studies have been conducted that detail the effects of trunk muscle contraction patterns in subjects with LBP. Many researchers attribute this altered muscle recruitment pattern in patients with LBP to a deficiency in NMC (Hides et al., 2008; Hides et al., 2007; Reeves, Cholewicki et al., 2006; Renkawitz et al., 2006; Stanton & Kawchuk, 2008; van Dieen et al., 2003). As adults, trunk muscle activity occurs prior to limb movement during athletic tasks (Hodges & Richardson, 1999; B. Zazulak et al., 2008). Both Hides et al (Hides et al., 2007) and Hodges et al (Hodges & Richardson, 1999) determined through use of ultrasonography and EMG data, that TrA activation occurs prior to and/or simultaneously with upper and lower extremity movement. Hides (Hides et al., 2007) demonstrated automatic, bilateral and symmetrical TrA activation during a unilateral weight bearing task in subjects, and Hodges (Hodges &

Richardson, 1999) found that activation of the TrA occurred at the same time as the deltoid during movement of the arm. NMC relies on accurate feedback information to the central nervous system from external and internal cues or disturbances. These disturbances may be expected, as in preparation of performing an athletic task, or they may be unexpected, as in a collision with another athlete. In either situation, NMC of the trunk is essential in preventing injury. The central nervous system needs to be able to respond quickly to the disturbance and process the information such as velocity of movement, pain, pressure, force, and generate input to the muscle to in turn affect the joint (B. Zazulak et al., 2008). It is essential to develop appropriate levels of trunk NMC in the prevention of LBP after discussing how trunk musculature contributes to increasing spinal stability and limiting one's risk for injury. The difference noted in NMC of trunk muscles in patients with LBP is valuable information and has been studied multiple times. Hides et al (Hides et al., 2008) conducted a study that used EMG data to assess contraction of the deep abdominal muscles while subjects performed a simulated weight bearing task in the supine position. Both subjects with and without history of LBP participated in the study. Results showed altered muscle recruitment of the abdominal muscles in subject with LBP. These studies highlight the evidence that proper muscle activation is necessary to prevent initial or recurrent LBIs because improper muscle activation is seen in patients with LBP.

Addressing Deficits in Neuromuscular Control

Spinal stability has been increased in individuals with LBP by enhancing certain muscle contractions (Baratta et al., 1988). The muscular system provides protection to articular structures and can help minimize unwanted joint displacement of the spine

(Baratta et al., 1988). Trunk exercise regimens focusing on the contraction of the TrA and the multifidi, through means of the abdominal hollow or abdominal brace contractions, have been indicated in the treatment of lumbar instability in patients with LBP (Richardson & Jull, 1995). Neuromuscular factors play a large role in the onset and treatment of LBP, and by altering these factors through teaching proper muscle activation and contractions, LBP may be reduced or eliminated in symptomatic patients (Richardson & Jull, 1995).

Multiple studies have been conducted to look at how these exercises typically used in rehabilitation for patients with LBP activate trunk musculature including the TrA, IO, external obliques (EO), rectus abdominus (RA) and multifidus (Brown et al., 2006; Stanton & Kawchuk, 2008). These contractions are used in many rehabilitation settings to address deficits in NMC and instability related LBP in patients. The abdominal hollow and abdominal brace contraction are two commonly addressed exercises in the literature and in the clinic. These exercises aim to improve spinal stability by learning to create a contraction of both local and global musculature (Bergmark, 1989). Stanton et al (Stanton & Kawchuk, 2008) used EMG and ultrasound to quantify the extent to which an abdominal hollow exercise and an abdominal brace contraction increased posterior-anterior spinal stiffness as quantified by an indentation device. The abdominal hollow contraction involved the activation of both the multifidus and the TrA, more so than the brace contraction as detected by EMG. A conflicting study, by Vera-Garcia et al (Vera-Garcia et al., 2007) exists however, showing that the hollowing maneuver did not increase spinal stability or stiffness.

The brace contraction was shown to activate more superficial abdominal musculature when compared to the abdominal hollow exercise in Stanton's (Stanton & Kawchuk, 2008) study. The abdominal bracing technique was shown by Vera-Garcia (Vera-Garcia et al., 2007) to increase co-contraction of the abdominals and erector spinae muscles, and reduce lumbar displacement, contributing to increased spinal stability. Brown et al (Brown et al., 2006) found with similar methods, that as subjects tried to brace abdominally, they were typically unsuccessful in executing the exercise in a balanced way. No subject was able to increase activity in all trunk muscles in a way that increased stability while perturbed. The study concluded that most people find a natural bracing level, which if altered by a bracing technique, can decrease the stability of the spine. The effectiveness of difference exercise on increasing spinal stability is yet to be agreed upon. Both exercises were found to significantly increase P-A spinal stiffness when compared to a neutral rest position, however the abdominal brace contraction was found to provide more immediate P-A stiffness than the abdominal hollow (Vera-Garcia et al., 2007).

Laboratory Measures of Trunk Neuromuscular Control

Ways of assessing LBP related to trunk NMC have been developed in the past by various researchers (Bono, 2004; Cholewicki & McGill, 1996; Cholewicki et al., 2000; Kujala, Salminen, Taimela, Oksanen, & Jaakkola, 1992; B. T. Zazulak et al., 2007). These tests take into account center of pressure (CoP) measures, trunk force displacement measures and biomechanical modeling of the lumbar spine (Cholewicki & McGill, 1996; Cholewicki et al., 2000; B. T. Zazulak et al., 2007). Cholewicki et al (Cholewicki et al., 2000) developed an unstable sitting device to measure CoP and completed several studies to validate his apparatus (Cholewicki et al., 2000; Radebold et al., 2001; Silfies, Cholewicki, & Radebold, 2003). Eleven subjects were used in the initial study, all free of LBP for at least one year. Each subject was seated on the unstable sitting device, which consisted of a hemisphere atop a forceplate raised from the ground. The hemisphere was secured to leg and foot supports to create a 90^{o} knee angle. Having the feet supported ensured that the subject was not able to use the lower limbs for additional support or balance aid. Each subject was asked to balance while sitting on the seat with the arms crossed over the chest. Four levels of seat instability were achieved by decreasing the hemisphere sizes. Subjects completed five trials, each lasting seven seconds. Center of pressure trajectories were quantified from the forceplate data and were found to be positively correlated with body weight. Repeatability of the CoP parameters was excellent. This initial study validated the use of the unstable sitting device as an accurate measure of CoP in eleven subjects (Cholewicki et al., 2000).

A second study was conducted to determine whether patients with LBP would exhibit poorer postural control than controls without LBP (Radebold et al., 2001). The unstable sitting apparatus was used in various trials with various hemisphere sizes attached to the seat to change the level of difficulty in the task. Subjects performed five, seven second trials with eyes open and eyes closed at each seat instability level. Center of pressure trajectories were calculated and in conjunction with force displacement values from an apparatus described below, it was demonstrated that patients with chronic LBP have poorer postural control than healthy matched subjects. During the balancing tasks, only 69% of patients with LBP were able to finish the third level with eyes open and only 13% finished it with eyes closed. All healthy matched controls were able to finish level four (most difficult) with eyes open and 71% were able to finish with eyes closed. All CoP motions were greater for patients with LBP and increased significantly with increases in instability level and lack of visual feedback.

Reeves et al (Reeves, Everding, Cholewicki, & Morrisette, 2006) concluded that increased trunk muscle activity degrades postural control during the unstable sitting task. This was determined by having healthy subjects actively co-contract the abdominal and low back musculature while they performed this task. Muscle activation was measured by EMG activity, and as muscle activation increased, CoP sway velocity also increased, resulting in degraded postural control of the trunk. This suggests that individuals have their own way of activating trunk musculature in response to seat instability.

Van Daele et al (Van Daele et al., 2009) investigated the differences in postural control using an unstable sitting device between patients with non-specific LBP and healthy controls. Infrared motion analysis cameras were used to track pelvis motion in relation to the trunk in the three cardinal planes while sitting on an unstable chair. Motion in the anteriorposterior and lateral flexion and rotation directions between the trunk and pelvis were significantly ($p<0.05$) greater in the test population with LBP. This implies that patients with LBP display altered trunk motor control during an unstable sitting task in comparison to healthy controls. Radebold et al (Radebold et al., 2001) conducted a study with similar results. Sixteen patients with chronic LBP and matched, healthy controls with no history of LBP were tested on the unstable sitting device at several different seat instability levels. This was accomplished by decreasing the size of the hemisphere beneath the unstable seat. This task was also performed with the eyes closed to eliminate visual input. All CoP motion statistics were greater for patients with

LBP. Center of pressure data increased significantly with increasing seat instability level and lack of visual feedback in all subjects. Subjects with LBP demonstrated significantly poorer postural control during this task than matched controls however. The unstable sitting device is able to differentiate between subjects with LBP and those with no history of LBP (Radebold et al., 2001; Van Daele et al., 2009), which may indicate that a similar task easily executed in the clinic, such as the seated ball error scoring system, may be effective as well.

Test-retest reproducibility of postural control demonstrated during the unstable sitting task was found to be moderate by Van Daele et al (Van Daele et al., 2007) using similar procedures as the aforementioned study. Subjects performed four trials of four different postural control tasks using this device. These tasks included lifting each foot, crossing the arms in front of the chest and extending each arm one at a time. Subjects were not given practice trials. Intraclass correlation coefficients were calculated for all three planes of motion for the trunk in relation to the pelvis (flexion/extension, lateral flexion and rotation) and ranged from 0.11 to 0.73. The range suggests that there is a learning curve with this task, which may be eliminated with adequate practice trials.

There have been other methods of measuring trunk strength or stability in the lab completed first by Brown et al (Brown et al., 2006). A force release apparatus was constructed where the subject is placed in a semi-seated position with the hips and pelvis restrained. Subjects were allowed to assume the most comfortable position before they were restrained. A chest harness was worn with a cable attached at T7. The cable was attached to an electromagnet with an 8kg or a 10.3kg weight attached. Subjects were instructed to hold the load in a natural manner or to brace by activating 10%, 20% or 30%

of maximum voluntary contraction through biofeedback data. EMG electrodes were fitted to the subject's trunk and recorded muscle activation data. Muscle pre-activation patterns, spine stability and kinematic measures of trunk stiffness were quantified from the force release data. Findings showed that although individuals attempted to brace prior to force release, they were often unsuccessful in performing the bracing in a balanced manner. In situations in which the trunk is loaded, it is thought that individuals have their own separate bracing maneuvers which can be inhibited when a specific bracing technique is applied.

There are several draw backs to this apparatus for the purposes of the present study. A sudden force release does not specifically address the concept of trunk NMC. Force displacement measures may be a better representation of trunk muscle strength, rather than NMC and spinal stiffness. The focus with this device is more on lumbo-pelvic stability and stiffness rather than global stability of the trunk. Center of pressure is a much better way to assess the stability of the trunk because subjects are not restrained in any way and are better able to activate global and local musculature in order to achieve the task. Instead of a sudden perturbation that requires contraction of the abdominal musculature, a gradual contraction of the musculature can be elicited during the unstable sitting procedure. A sudden perturbation would be much more difficult to reproduce in the clinical setting, and not many clinical tests of trunk NMC use this approach. Most clinical test measures involve isometric contraction of the trunk musculature, rather than a sudden isotonic contraction in response to an outside perturbation.

Cholewicki & McGill (Cholewicki & McGill, 1996) established a model in which stability of the lumbar spine in vivo could be established during various three-dimensional tasks. The model consisted of several components including a rigid pelvis, ribcage, five vertebrae, 90 muscle fascicles, and lumped parameter discs, ligaments and facets. The method involved three models: A moment muscle model for estimating muscle force and stiffness from EMG, a rigid link segment body model for estimating moments and external forces acting on the lumbar spine, and a lumbar spine model for estimating moments produced by 90 muscle fascicles and lumped passive tissues. Relative stability was calculated from the data from each of these models for three subjects. Results showed that ample stability safety margin was present during tasks that demand a high muscular effort; however, lighter tasks present a potential hazard of spine buckling. This method allows the researcher to analyze the overall stability of the lumbar spine in vivo under a wide variety of dynamic three-dimensional loads and postures. Implications of decreased stability contributing to LBP and injury exist. This method also explains how injuries may occur from simple, light tasks which one would typically not consider when explaining LBP.

While several methods of measuring trunk NMC have been identified and explained, the first lab measure has been the most validated (Cholewicki et al., 2000; Radebold et al., 2001; Reeves, Cholewicki, Lee, & Mysliwiec, 2009). Multiple trials and studies have been conducted with this device. Also, the construction of this device is relatively simple, and easily interpreted. For these reasons, the unstable sitting device to measure CoP will be used as the lab measure of trunk NMC in this study.

Clinical Measures of Trunk Neuromuscular Control

Previous research has seldom demonstrated reliability and validity of clinical measures of trunk NMC (B. Zazulak et al., 2008). Various clinical tests exist that claim to quantify trunk NMC, including the single leg squat, postural sway on stabilometers and visual observation of neuromuscular deficits during athletic tasks (B. Zazulak et al., 2008). Mcgill et al (S. M. McGill, Childs, & Liebenson, 1999) identified mean endurance times for three commonly used trunk stabilizing exercises, including an isometric trunk extension test, an isometric trunk flexion test, and a side bridge test. Women held the trunk extension test longer, for an average of 189 seconds and men held it for an average of 146 seconds. Men held both the side bridge and the trunk flexion test longer than women, with a mean of 94 and 144 seconds respectively, and women held these tests for 72 and 149 seconds (S. McGill, Juker, & Kropf, 1996). Average times from this study may help the athletic trainer determine if an athlete should begin a trunk strengthening program in order to help prevent injury. These tests challenge the different trunk stabilizers that have been found to be main supports for the spine (Juker, McGill, Kropf, & Steffen, 1998; S. McGill et al., 1996). McGill et al (S. McGill et al., 1996) determined that the side bridge test activates the abdominal wall the best out of a variety of tasks, including various types of sit-ups, curl-ups and push-ups. This indicates that the side bridge is not only a valuable training tool for those to improve trunk NMC, but that it could be a useful screening tool to identify those with deficits in trunk strength and stability.

Tse et al (Tse, McManus, & Masters, 2005) aimed to develop a core training protocol and implemented it in college age rowers. A group of subjects received specialized training which consisted of trunk muscles stability exercises, postural stability exercises, static-dynamic exercises, and controlled mobility exercises. All other training methods were the same between the two groups and after eight weeks a series of trunk strength tests were executed. These tests included the side bridge, the back extension test and the abdominal fatigue test in which the subject is instructed to hold a flexed position for as long as possible. The side bridge showed to be the only test that showed significant differences at the end of the testing period between test and control groups. This suggests that the side bridge is an effective way of quantifying trunk NMC, as it was able to differentiate between groups (Tse et al., 2005), which is why it will be included in the present study.

The back extension test is commonly used in the clinic to assess trunk strength in athletes (Moreau et al., 2001). Including the aforementioned study, there are several other studies that found no relationship between the occurrence of LBP and back extension endurance, or differences in test times after trunk training protocols have been implemented (Moreau et al., 2001; Renkawitz et al., 2006; Tse et al., 2005). Renkawitz et al (Renkawitz et al., 2006) studied 82 tennis players with and without LBP to determine the relationship between occurrence of LBP and back extension strength, and if a trunk strengthening program improved back extension strength. Results showed no association between back extension endurance times and LBP and no significant difference was found in test scores after the trunk strengthening program. Controversy exists as to the amount of endurance that is provided by the lumbar extensors during this task (Moreau et al., 2001). A literature review of published articles using this method of quantifying back extension endurance stated that most authors believed the hip extensors contributed a large amount to this test. Results from various EMG studies of activated muscles range from a strong contribution from the hip extensors to not significant. Studies show varied results as to whether the back extension test is able to discriminate between those with LBP and those without LBP (Moreau et al., 2001). Such varied results exist with the back extension test and its ability to test the appropriate muscles that it was excluded from the present study.

Six other clinical tests were executed in an attempt to establish inter and intra-observer reliability. Weir et al (Weir et al.) used a four-point visual evaluation scale to score 40 male subjects during six clinical tasks. These task included the unilateral squat, the lateral step-down, frontal plane testing in which the subject was asked to lightly touch the wall with their shoulder without moving their body, sagittal plane testing in which subjects were asked to touch the wall with the back of their heads, transverse plane testing in which subjects were asked to touch the wall with their shoulders by rotating to each side while holding the trunk and pelvis in neutral, and a bridge test. Six experience observers consisted of four sport physicians and two sport physical therapists. Results showed that all six clinical tests for trunk NMC showed poor inter and intra-observer reliability using the four-point scoring system. The four-point scoring system consisted of a poor, moderate, good and excellent rating, each attempting to assess the amount of movement out of a neutral position and the frequency of segmental oscillation (Weir et al.). This indicates a need to develop more reliable clinical tests for clinicians to implement in the athletic training room, and the purpose of the present study.

This study will look at three different measures of trunk NMC that involve equipment readily available to most clinicians. These tests are typically used in pre-season screenings and evaluation of trunk NMC after a low back or hip injury.

A human arrow test will be included where subjects will be asked to hold a plank position for as long as possible. Trials will be timed and scores recorded as maximum time the position can be held. The side plank test will be conducted in the same manner. Subjects will be asked to lie on the dominant side and push off the floor onto the elbow and feet. The opposite arm will be crossed over the chest or held on the hip. This position will also be held for maximum time. The last clinical test being used is a seated balance test using a stability ball. The subject will be asked to sit with the knees together and lift the feet off the floor with the arms across the chest. This position is maintained for 60 seconds and the number of errors (i.e. putting a foot on the ground, increasing forward and lateral hip flexion or hip extension) is recorded. The goal of this test is to mimic the unstable sitting device developed by Cholewicki et al (Cholewicki et al., 2000).

Conclusion

Once an athlete sustains a LBI, that person is nearly three times more likely to sustain a future injury than any other active individual (B. Zazulak et al., 2008). The link between trunk NMC and NMC and occurrence of LBP is strong according to the literature (Hides et al., 2008; Hides et al., 2007; Reeves, Cholewicki et al., 2006; Renkawitz et al., 2006; Stanton & Kawchuk, 2008; van Dieen et al., 2003). To date, there is no strong evidence that a proper assessment tool for trunk NMC exists that is readily available to clinicians. Therefore, the likelihood of identifying individuals with poor trunk NMC that are most susceptible to LBP is low. If an athlete exhibits poor trunk NMC initially, it is our job as athletic trainers to implement an exercise program as a preventative measure. If we are not able to do this as clinicians, substantial risk for athletes sustaining initial and recurrent LBIs exists, which is why it is so important to identify a proper screening tool for deficits in trunk NMC in the athletic population.

CHAPTER III

METHODS

Experimental Design

A correlational analysis was performed to determine if there is a relationship between sway area during an unstable sitting task and three clinical tests of trunk NMC. Subjects completed the unstable sitting task first, followed by the three clinical tests in a pre-determined, alternating order.

Subjects

Thirty physically active individuals between the ages of 18 and 35 were recruited from physical education, anatomy and exercise and sport science classes to participate in the study. Subjects were eligible for participation if they currently participate in 20 minutes or more of aerobic activity at least three times per week. Subjects were excluded if they currently had lumbar or thoracic pain or have previously had abdominal wall surgery. Subjects were not excluded for any other injury if it did not inhibit his or her ability to complete the tasks included in the study.

Instrumentation

Unstable Sitting Device

The unstable sitting device was composed of a 30 cm polycarbonate hemisphere beneath a wooden seat. The hemisphere served as the seat, and was attached to wooden foot supports to prohibit lower extremity involvement in the task **(Figure 1)**. A 60 cm high box supported a metal forceplate (Bertec Engineering corp., Columbus, OH). Safety rails surrounded the box and the hemisphere that sat on the forceplate to ensure subject safety during testing. All data during this task was collected via the forceplate.

Clinical Testing Equipment

A 55cm stability ball was used during the seated ball test, as well as a stop watch to time the trials. Ball pressure was taken prior to each session and was measured at 9.5 PSI (pounds per square inch). The size of the stability ball was decided during pilot testing, and seemed to be the most appropriate size for a varied population.

Procedures

Height and weight were collected before testing began for each subject. Subjects performed a five minute warm-up at a moderate intensity on a stationary bike before testing. The order of clinical tests was pre-determined by the administrator for each subject. The order of clinical tests alternated between subjects.

Unstable sitting task

While maintaining an upright posture, the subject was instructed to cross their arms over their chest and keep their balance while remaining in this position for 60 seconds. Subjects were able to grasp the railings if balance was lost and resumed the position for the remainder of the trial. Subjects were allotted practice trials until they felt comfortable with the task. Once subjects completed the practice trials they were given 30 seconds of rest and asked to repeat five trials of 60 seconds each. Subjects were given 30 seconds of rest between trials. Sway area was collected during the unstable sitting task (Cholewicki et al., 2000; Cholewicki et al., 2005; Radebold et al., 2001) which represented the subject's trunk NMC score for data analysis.

Human Arrow

Subjects were instructed to push up off of the floor on to their elbows with shoulders and elbows bent to 90°. The subject was asked to push up on their toes and maintain a straight posture, keeping their back flat with mild lordosis, legs straight, and shoulders retracted **(Figure 2)**. From this position, the subject was asked to raise the hips into 10^o of flexion, and a marker was placed on the wall. Timing began when the subject pushed up into the correct position. Timing stopped and the trial ended when the subject broke form including increased lumbar lordosis, increased hip flexion more than 10^o from neutral, or the subject could no longer hold the position. One trial was performed to failure. Subjects performed one practice trial for up to ten seconds. Pilot testing performed in our laboratory demonstrates a moderate intersession reliability (ICC (3, 1) 0.624).

Side Plank Test

The side plank test was performed on the floor and subjects were instructed to lie on their dominant side and to push up off the floor. Subjects held the position supporting weight on the forearm and lateral part of the dominant leg (Figure 3). From this position, the subject was asked to raise the hips into 10^{o} of flexion, and a marker was placed on the wall. Subjects were instructed to hold the position for maximal time. Time stopped when the subject broke form including increasing hip adduction or abduction more than 10° from neutral, increasing hip flexion more than 10° from neutral, increasing lumbar lordosis or until they could no longer hold the position. One trial was performed to failure. Subjects performed one practice trial for up to ten seconds. Pilot testing performed in our laboratory demonstrates a good intersession reliability (ICC (3, 1) 0.828).

Seated Ball Test

The aim of the seated ball test is to mimic the unstable sitting task in the clinical setting. Prior to each testing session the pressure of a 55cm stability ball was taken and measured at 9.5 PSI. The subject was asked to maintain the same upright posture while seated on a stability ball with the hips and knees flexed to approximately 90°. With arms crossed over the chest the subject was instructed to lift their feet three inches off the ground. The subject was asked to maintain proper posture, including mild lumbar lordosis, neutral shoulders and head and neck with feet and knees together while moving as little as possible **(Figure 4)**. The subject maintained this position for 60 seconds and the total numbers of errors committed was counted **(Figures 4a-d)**. Subjects were allotted two practice trials of 30 seconds each before errors were recorded. Each trial was completed with 30 seconds of rest between each testing session. Errors counted during the test trial included touching one or both feet to the floor, uncrossing the arms, increasing lumbar lordosis or decreasing hip flexion more than 10° (i.e. rolling back and forth on the ball). The subject was asked to get in the position on the ball and to say "go," at which point the administrator began the time. Two administrators scored the test simultaneously to assess inter-rater reliability (ICC (2, k) 0.981, SEM 0.801). The subject performed a total of five trials and errors were averaged across trials two, three and four. All trials were video-taped and re-scored to determine intersession reliability (ICC (3, k) 0.911, SEM 1.606).

Data Processing and Reduction

Data from the unstable sitting device was recorded via a metal forceplate and the middle three trials were averaged to reduce the likelihood of a learning or fatigue effect. Center of pressure data were collected at 100 Hz using the Motion Monitor Software (Innovation Sports Technology Inc., Chicago, IL). The signal was filtered with a 4^{th} order Butterworth filter at a frequency of 20 Hz (Silfies et al., 2003) and the measures were calculated using a customized Matlab (The Mathworks Inc., Natick, MA). All data were exported to a 95% ellipse area was used to determine the subjects' CoP sway area score that was interpreted as the laboratory measure of trunk NMC. Many previous studies that have looked at CoP measures have exported data to a 95% ellipse area (Salavati et al., 2009; Slota, Granata, & Madigan, 2008; Swanenburg, de Bruin, Favero, Uebelhart, & Mulder, 2008). Sway area may also be a better indicator of global trunk NMC rather than local trunk NMC, which is what we are aiming to quantify with our clinical testing.

Statistical Analysis

Multiple correlational analyses were performed to determine the association among mean sway area during the unstable sitting task, and measures for the seated ball task, human arrow task, and side plank task. Pearson product moment correlation coefficients were calculated for each of the six analyses and an alpha level of 0.05 was set a priori. All analyses were performed using Statistical Package for the Social Sciences (SPSS) version 17.0 (SPSS Inc., Chicago, IL).

CHAPTER IV

RESULTS

The purpose of this study was to determine the association between clinical screening tools and a laboratory screening tool of trunk stability. There is lack of evidence indicating that laboratory measures of trunk NMC are associated with clinical measures, and this study looked at CoP measures from an unstable sitting device and three different clinical screening tools. Testing procedures involved subjects participating in a series of four tasks including the unstable sitting task, a human arrow, a side plank and a seated ball task, aimed to mimic the unstable sitting task.

Measures of Trunk Neuromuscular Control

Fifteen females (age=20.07 yrs ± 1.91, height=169.49 cm ± 8.43, weight=59.92 kg ± 8.11) and 15 males (age=20.87 yrs ± 2.72, height=178.06 kg ± 8.24, weight=75.08 kg ± 8.94) participated in the study. The laboratory measure of trunk NMC was assessed through an unstable sitting device first introduced by Cholewicki et al (Cholewicki et al., 2000), and compared against three clinical measures of trunk NMC (See **Table 1**). Sway area for six subjects was eliminated either because of the subject's inability to complete the unstable sitting task without touching down, or because their scores were more than two standard deviations away from the mean for all subjects. We observed a significant correlation between the average errors committed during the seated ball task over three trials and the sway area ($r_{(22)}$=0.498, p=.013), with a moderate positive linear relationship between these two variables **(Figure 5)**. Time to failure during the human arrow task and sway area were not significantly correlated ($r_{(28)}$=-0.029, p=0.894) **(Figure 6)**, and time to failure during the side plank task and sway area were not significantly correlated ($r_{(28)}$=-0.114, p=0.595) **(Figure 7)**. Human arrow and side plank time to failure were significantly correlated with each other, displaying a strong linear relationship ($r_{(28)}$=.0841, p=0.001) as expected, and neither the human arrow nor side plank were significantly correlated with average errors committed during the seated ball task over three trials ($r_{(28)}$=-0.213, p=0.258, $r_{(28)}$=-0.176, p=0.352). These results indicate that the seated ball task is a reliable and accurate clinical measure of lumbar postural stability as measured by the unstable sitting device. Since endurance tasks were not correlated with sway area, they may not be good indicators of lumbar postural stability, but may play a separate role in stabilizing the spine that could be useful to clinicians. All Pearson correlation and significance values are located in **Table 2.**

CHAPTER V

DISCUSSION

The purpose of this study was to determine if a previously developed measurement of trunk NMC was related to clinical tests commonly used to assess trunk NMC. The primary findings of this investigation showed that there was a positive relationship between measures from the unstable sitting device and average errors committed during a seated ball task. This means that those who had smaller sway areas during the unstable sitting task generally also had a lower number of average errors during the seated ball task. Ways of assessing trunk NMC and individuals susceptible to LBP have been developed in the laboratory using forceplates, EMG and other expensive and intricate equipment (Bono, 2004; Cholewicki & McGill, 1996; Cholewicki et al., 2000; Kujala et al., 1992; B. T. Zazulak et al., 2007). The unstable sitting device was shown to differentiate between subjects with LBP and those without, indicating that this is an accurate assessment tool to identify those with poorer trunk NMC (Radebold et al., 2001). Subjects with LBP had larger sway areas than those without. Literature has looked at several different clinical tests (Hodges et al., 2001; Juker et al., 1998; S. McGill et al., 1996; Moreau et al., 2001; Tse et al., 2005), but none have been compared to a laboratory measure of trunk NMC as this study did.

The present study found no statistical significance between sway area and the side plank or the human arrow however, which may indicate that this test is not an accurate assessment of trunk NMC or that it measures a different aspect of trunk NMC. Because trunk endurance tasks have been found to differentiate between subjects with LBP and those without, there is evidence that endurance of the trunk musculature plays an important role in stabilizing the spine which helps in preventing injury. We also know that lumbar postural stability, as assessed by the unstable sitting device, can differentiate between subjects with LBP and those without (Radebold et al., 2001). These kinds of tasks may play roles independent of each other in stabilizing the spine, which is why we observed no significant relationship between endurance tasks and lumbar postural stability tasks in the present study.

The seated ball task and sway area were found to have a significant, positive relationship. This indicates that the seated ball task is able to asses some aspect of spinal stability as is the unstable sitting device. The unstable sitting device is not readily available to most clinicians, and is not a feasible way of screening athletes for poor trunk NMC. The seated ball test appears to be a good option for clinicians, and this study demonstrated that it was a valid and reliable tool. The seated ball task was a novel task that was developed in this study, and has not been investigated in the literature. A major gap in the literature is identification of a clinical screening tool for lumbar postural stability, and the present study was able to identify a valid test for this. Because previous studies have also identified that trunk endurance is important in stabilizing the spine and preventing low back injuries, the addition of the seated ball task seems to form a more comprehensive assessment of spinal stability.

It was hypothesized that sway area would be correlated with scores from the seated ball task, which was shown to be true. It was also hypothesized that scores from the human arrow and the side plank task would be correlated with sway area. Neither of these variables was significantly correlated with sway area however. Values from the side plank were fairly consistent with values found during this task by Tse et al (Tse et al., 2005) and McGill et al (S. M. McGill et al., 1999). Our mean side plank times are located in **Table 1.** We found a mean time of 88.66 seconds compared to 81 seconds with McGill et al (S. M. McGill et al., 1999) and 75 seconds with Tse et al (Tse et al., 2005).

Low back pain was not controlled for in this study. All subjects completed the Oswestry Disability Questionairre, which scores an individual's disability due to LBP as a percentage. Only eleven of the thirty subjects reported any kind of low back disability, with an average score of 6.7%. The average score for all subjects was 2.4%. Zero to 20 percent is considered minimal disability, and of the subjects reporting LBP, all fell into this category. Because no individuals were experiencing significant LBP, we can be confident that LBP was not driving our results, because the unstable sitting device has been shown to be able to differentiate between individuals with LBP and those without (Radebold et al., 2001).

We chose to use the unstable sitting device as our laboratory measure of lumbar postural stability because it has been shown to be able to differentiate between subjects who are currently experiencing or have a history of LBP (Radebold et al., 2001) and those who are not, indicating that it is an accurate assessment of one's postural stability, which influences one's risk of suffering from LBP (Baratta et al., 1988; Panjabi, 2003; Richardson & Jull, 1995; Stanton & Kawchuk, 2008). The seated ball task was developed to mimic the unstable sitting device with equipment readily available in the athletic training room. Both tasks involve similar positions and movements. Both tasks require lumbar postural control and were performed for the same amount of time. The association of these two tasks is not surprising, however only a moderate relationship was found. Reimann et al (Reimann, 1999) completed a study with similar methodology comparing clinical measures with forceplate measures. Postural stability was scored using the BESS and also using a forceplate with the same balance conditions. The balance tasks were performed on a forceplate that recorded the subjects' sway area while an administrator scored the task using the BESS simultaneously. In this case, sway area was used as a gold standard of postural stability, and BESS as a clinical measure of postural stability. All conditions showed a significant relationship between the laboratory and clinical measure, with Pearson r values ranging from 0.3077 to 0.7887. These values indicate moderate relationships between laboratory and clinical measure of postural stability, similar to the relationship found between the seated ball task and sway area.

Intersession scoring of the seated ball task showed excellent reliability with an ICC (3, k) 0.911 and SEM 1.606. Inter-tester scoring also showed excellent reliability with an ICC (2, k) 0.981, and SEM 0.801. Subjects reported that the seated ball task was significantly more challenging than the unstable sitting device, and that they felt increased fatigue in the hamstrings and hip flexors while completing the task. The unstable sitting device involved a hemisphere, with a flat surface on which subjects sat. This makes the task less difficult than sitting on a full sphere, as in the seated ball task. Future clinical tests may be developed involving a similar hemisphere as the unstable sitting device. This would be a fairly inexpensive and simple apparatus to obtain in most athletic training rooms. A BOSU ball was used during pilot testing and appeared to be too easy of a task in comparison to the unstable sitting device.

The human arrow and the side plank tasks were completed only one time and were held to fatigue by subjects. No relationship was found between either of these measures and sway area from the unstable sitting device. Several factors might explain the lack of correlation between these measures. First, both tasks involve isometric contractions of multiple muscle groups, including global and local trunk musculature important in stabilizing the spine (Tse et al., 2005). While the seated ball task and the unstable sitting task require lumbar postural control and balance, the side plank and human arrow do not challenge the trunk musculature in the same way. Muscle endurance appears to play a more important role in these tests rather than postural control of the trunk and hips. Individuals may have performed better on the endurance tests, which were highly correlated with each other, than the stability tests simply because they possessed more trunk muscle endurance than lumbar postural stability. Because subjects were asked to hold both of these tests until they fatigued, there may have been a lack of effort in performing the tasks as well. On the other hand, subjects may have performed poorer on the endurance tests due to fatigue from completing the other tasks first, or simply because they lack trunk muscle endurance. Since the unstable sitting tasks were associated with each other, it indicates that many individuals did not possess both lumbar postural stability and trunk muscle endurance. Although no relationship exists between the unstable sitting task and both the human arrow and side plank task, these tests may still be important clinically for measuring spinal stability (Tse et al., 2005). Research in other areas of the body has shown no relationship between muscular endurance and balance as well (Hung-Maan Lee, 2009). Hung-Maan Lee et al (Hung-Maan Lee, 2009) looked at patients with unilateral ACL deficiency without surgical intervention and compared quadriceps and hamstring strength, proprioception, and standing balance in both the injured and uninjured knee. In the injured knee, hamstring and quadriceps strength were not significantly correlated with standing balance. We know that muscle strength is important for the stability of any joint, but in this case it did not contribute to standing postural stability, similar to our results for the endurance tasks and the unstable sitting task.

Clinicians have many ways of trying to quantify trunk NMC to help prevent LBP, but very few studies have been able to determine an accurate screening tool for poor trunk NMC. The present study shows promise for validating a clinical screening tool to assess trunk NMC and identify those individuals susceptible to LBP. The seated ball task involves very little equipment and is a fairly simple error scoring system that could be added to a standard screening protocol. The BESS and LESS are similar tools that have been accepted by clinicians for identification and definition of cognitive function and lower extremity biomechanics that may promote injury. Implementing the seated ball task may be a beneficial addition to the athletic trainer's testing that may help prevent injuries in susceptible individuals. While the human arrow and side plank were not found to be accurate screening tools for trunk NMC according to the definitions in the present study, they may hold a place in the screening process. The side plank has been shown to activate the muscles of the trunk important in stabilizing the spine (S. M. McGill et al., 1999; Tse et al., 2005), which may indicate that the task has a place in the treatment of poor trunk NMC as well.

We recognize that the present study has several limitations. First, the subject population consisted of recreationally active people, not necessarily athletes or inactive people. Our subject pool may not represent the athletic population or the inactive population. Athletic trainers generally have the best opportunity to implement prevention programs with the individuals they work with, which is generally the athletic population. The results of the study may be generalized to the recreationally active population, but no conclusions can be drawn in regard to the athletic or inactive populations. The unstable sitting task and the seated ball task involved a standard size hemisphere and physioball. Therefore, anthropometric differences between subjects were not accounted for during these tasks. A correlation was run between height and weight and all measures of trunk NMC, and revealed a significant correlation between height and sway area ($r_{(22)}$=0.553, P=0.005). No significance was found between weight and this task ($r_{(22)}$=0.358, P=0.086). Height was not significantly correlated with the seated ball task, the human arrow or the side plank task ($r_{(28)}$=0.354, P=0.055, $r_{(28)}$=0.027, P=0.889, $r_{(28)}$=0.080, P=0.674). Weight was also not significantly correlated with the seated ball task, the human arrow or the side plank task ($r_{(28)}$=0.055, P=0.773, $r_{(28)}$=-0.007, P=0.972, $r_{(28)}$=0.073, P=0.700). Taller individuals may have experienced a more difficult time performing the unstable sitting task than did other individuals because of their increased trunk moment.

Future research warrants further investigation between clinical measures of trunk NMC and laboratory measures of trunk NMC. Muscle activation patterns between clinical tests and laboratory tests involving EMG information may help to give us further knowledge about the relationship between these measures. Only three clinical measures of trunk NMC were looked at in this study, and many more exist that are commonly used in the clinic. Investigation of additional clinical measures may reveal a stronger relationship than the tests included in the present study.

Further research may develop a battery of tests used to assess trunk strength in the clinic including measures of lumbar postural stability as well as trunk muscle endurance. Both kinds of activities have been found to activate the spinal stabilizing musculature (Radebold et al., 2001; Tse et al., 2005) important in reducing one's risk of suffering from LBP, which suggests that both trunk stability and endurance are important in the prevention of LBP. More testing needs to be done involving the seated ball task in order to establish a feasible and reliable protocol. We had individuals complete 60 second trials, which may be excessive as other studies have had subjects complete as little as seven second trials. The present study did not include individuals with significant LBP, and future studies are warranted to determine the sensitivity of the task. A cut-off value should also be established to determine the number of errors that may indicate poor trunk NMC versus adequate trunk NMC. Studies that compare the role of lumbar postural stability versus trunk muscle endurance and how each type of exercise contributes to spinal stability may also be warranted.

This study investigated the relationship between three clinical measures of trunk NMC commonly used in the athletic training clinic and a laboratory measure of trunk NMC that represented the gold standard. Based on the results of this study it can be concluded that:

1. Sway area from the unstable sitting device shows a significant correlation with the seated ball task in recreationally active individuals, with a moderate, positive relationship.

2. Sway area from the unstable sitting device shows no significant correlation with the human arrow task in recreationally active individuals.

3. Sway area from the unstable sitting device shows no significant correlation with the side plank task in recreationally active individuals.

APPENDIX A: FIGURES

Figure 1: Unstable Sitting Device. Subjects stabilized themselves on the apparatus and completed 5 trials of 60 s.

Figure 2: Human arrow position. Subject maintained this position until failure for 1 trial.

Figure 3: Side plank position. Subject maintained this position until failure for 1 trial.

Figure 4: Seated ball task. Subject maintained this position for 60 s for 5 trials during which errors committed were scored.

Figure 4a: Error committed during seated ball task; increased lateral trunk flexion.

Figure 4b: Error committed during seated ball task; increased forward trunk flexion.

Figure 4c: Error committed during seated ball task; foot touch down.

Figure 4d: Error committed during seated ball task; lifting of arms from start position.

Figure 5: Seated Ball and CoP Scatter

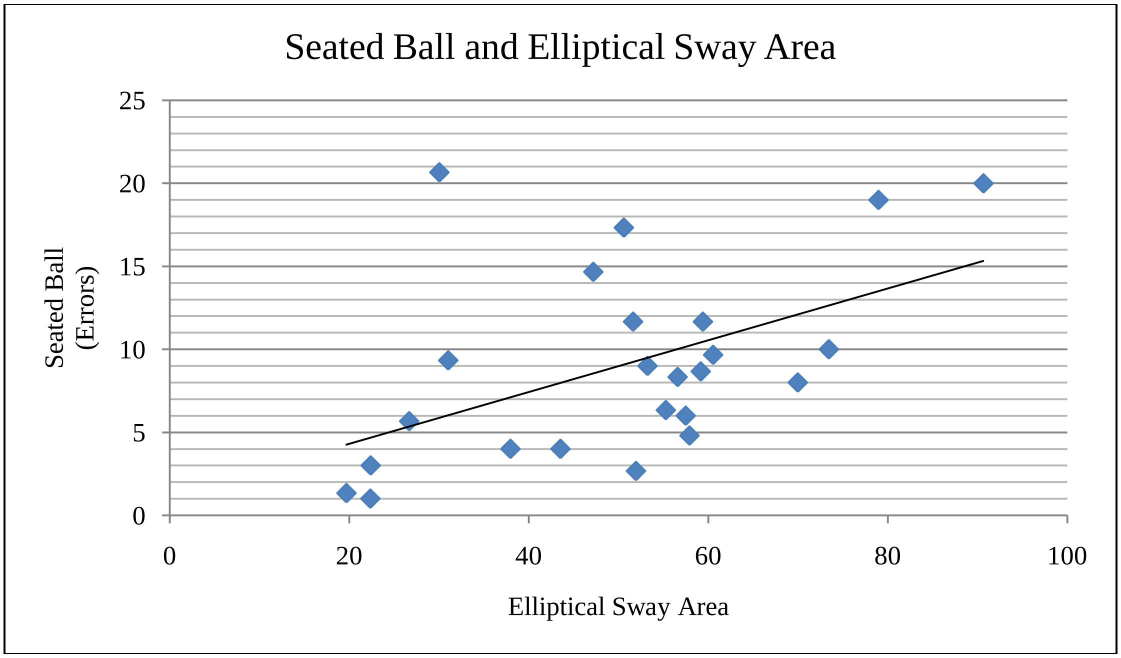


Figure 6: Human Arrow and Sway area Scatter

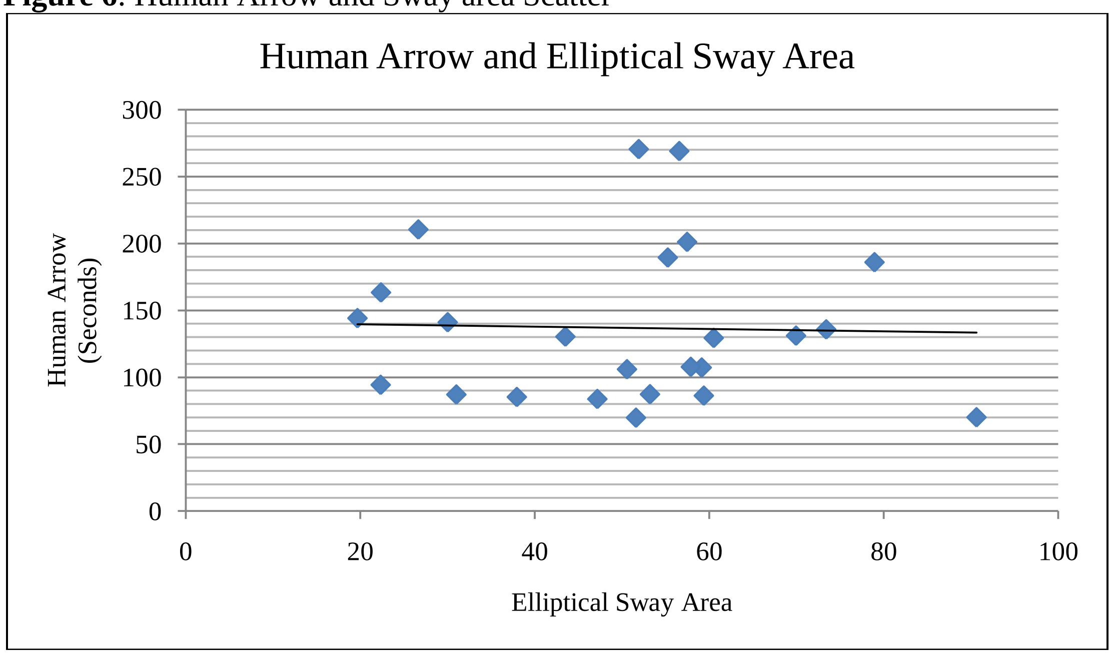
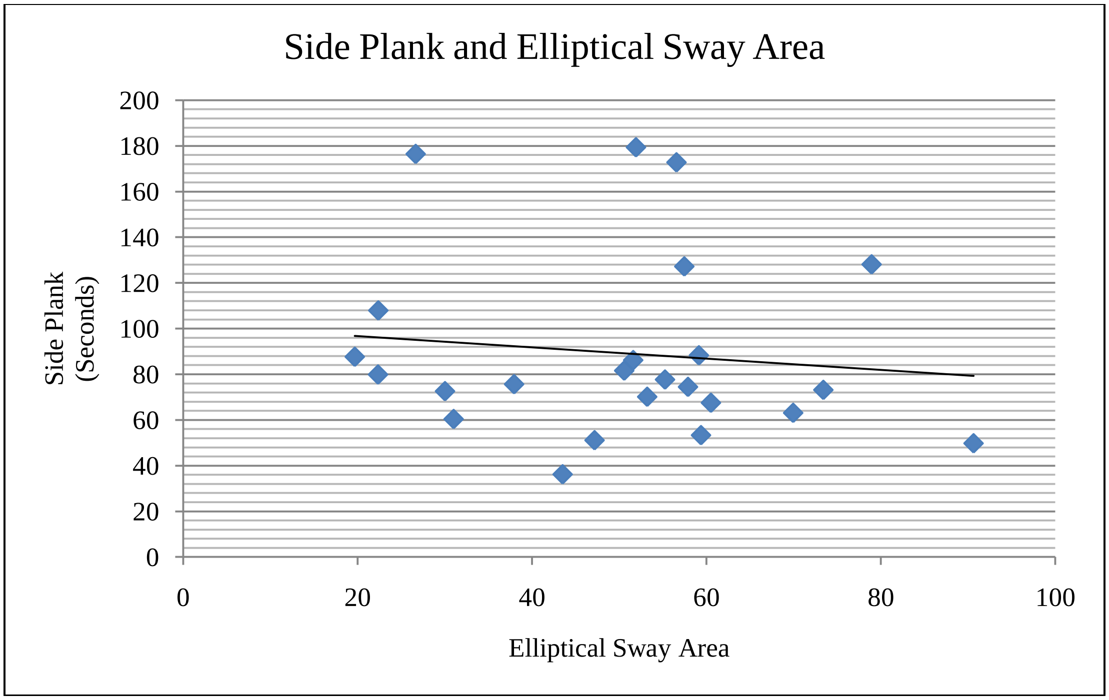


Figure 7: Side Plank and CoP Scatter



APPENDIX B: TABLES

Table 1: Descriptive Statistics for Measures of Trunk NMC

Task	Mean	Std. Deviation	N
Ellipse Area	50.30	18.50	24

Human Arrow	134.90	54.50	30
Side Plank	88.66	37.50	30
Seated Ball	9.60	5.66	30

Table 2: Pearson Correlation and Significance Values for Measures of Trunk NMC

	Ellipse Area	Human Arrow	Side Plank	Seated Ball
Ellipse Area				
Pearson Correlation	1.00	-0.029	-0.114	0.498
Significance		0.894	0.595	0.013
Human Arrow				
Pearson Correlation	-0.029	1.00	0.841	-0.213
Significance	0.894		0.001	0.258
Side Plank				
Pearson Correlation	-0.114	0.841	1.00	-0.176
Significance	0.595	0.001		0.352
Seated Ball				
Pearson Correlation	0.498	-0.213	-0.176	1.00
Significance	0.013	0.258	0.352	

APPENDIX C: MANUSCRIPT

Introduction

Low back pain (LBP) is a prominent health problem facing individuals (Standaert et al., 2004). Up to 85% of the general population will experience LBP in their lifetime, and LBP is the most frequent cause of disability for individuals younger than 45 years of age (Cleland, 2002; Martin et al., 2008). In 1997, polling showed that the average health care cost for an individual with LBP was $4695, compared with $2731 for those without LBP (Martin et al., 2008). LBP is also a very common problem among athletes, and up to 85% of all athletes will experience LBP in their careers (Standaert et al., 2004). Nadler et al (Nadler et al., 1998) followed athletes for one year and found that 9.3% of subjects received treatment for LBP. Adolescent athletes report LBP lasting longer than one week substantially more frequently than a matched control group of non athletes (45% vs. 18%) over 3 years (Kujala et al., 1996). Studies have shown that athletes with a history of LBP are nearly three times more likely to sustain a future low back injury (LBI) (Cholewicki et al., 2005) indicating the need for an accurate screening tool. The identification of factors lending to LBP are important for the treatment and future prevention of similar injuries (Kujala et al., 1996; Nadler et al., 1998; Standaert et al., 2004; B. T. Zazulak et al., 2007).

Because the rate of re-injury to the low back is so high, preventing the initial injury is most important in the treatment of LBP in the athlete. The average athlete loses 4-6 weeks of playing time to recover from a low back injury, and with recurrence rates so high, large amounts of playing time may be lost in an athlete's career due to LBP (Trainor & Wiesel, 2002). The spine is an inherently unstable structure and becomes stable through proper activation of trunk musculature, referred to as trunk NMC (Bergmark, 1989). Trunk NMC may be composed of multiple components (B. Zazulak et al., 2008). NMC (NMC) is what allows a dynamic system like the human body to be stable. Poor NMC of the trunk muscles is thought to be one of the most common predisposing factors for LBP in the athlete (B. Zazulak et al., 2008). Activation of the transverse abdominis (Trainor & Wiesel) (Trainor & Wiesel) and the multifidus, a deep back muscle, is thought to provide stability to the low back (Eriksson Crommert & Thorstensson, 2008; Wilke et al., 1995). There is evidence of delayed activation of the TrA muscle in patients with LBP as well as abnormal activation of the multifidi muscles in patients with LBP (Hides et al., 2008). As clinicians, the goal of our treatment in preventing LBP should be targeted on strengthening and training the TrA and multifidi to properly activate in response to perturbations to the trunk. In order to achieve this, we must be able to identify the athletes who have poor trunk NMC prior to participation in their sport. There have been several attempts to quantify trunk NMC, including mathematical models, force release systems and unstable sitting devices. Mathematical modeling and in vivo measurements of the lumbar spine were developed by Vera-Garcia (Vera-Garcia et al., 2007) and Brown (Brown et al., 2006). These models are very complicated and require a great deal of skill and time to execute. Brown et al (Brown et al., 2006) developed a force release apparatus in which subjects sat in a semi-seated position with a fixed amount of weight held to the torso by an electromagnet. The force was suddenly released and the time it took subjects to return to a neutral spine position was recorded and interpreted as their trunk NMC. The force release measure is a more appropriate measure of overall abdominal strength and lumbo-pelvic stability, rather than global trunk NMC. Postural control is a relatively simple and more accurate way of quantifying a subject's NMC based on their center of pressure (CoP) measurement (Cholewicki et al., 2000). Cholewicki et al (Cholewicki et al., 2000) developed an unstable sitting device in which subjects were seated on a hemisphere atop a forceplate with the lower body secured to allow for sole trunk motion. Studies have been conducted to measure CoP in subjects with LBP and controls without LBP (Radebold et al., 2001). All CoP data from the forceplate was significantly greater, representing poorer trunk NMC, in subjects who had LBP. This indicates that the unstable sitting device is able to differentiate between those with LBP and those without LBP. This is a simple task that doesn't take more than a few seconds to execute, and is simple to quantify when compared to the mathematical equations and in vivo measurements required in the other tests.

Clinical measures of trunk NMC including the unstable sitting device are not accessible to most athletic trainers in the clinical setting however (B. Zazulak et al., 2008). Because of this, there exists a need for a simpler, reliable way of assessing trunk NMC (B. Zazulak et al., 2008). Clinical measures of trunk NMC are commonly used in the athletic training setting during preseason screenings and injury assessments (B. Zazulak et al., 2008). Adequate endurance of the trunk muscles is thought to contribute to spinal stability, decreasing the likelihood of sustaining a low back injury (Panjabi, 1992a; Willson et al., 2005). Isometric contractions of the deep low back muscles, thought to be important contributors to spinal stability, are hypothesized to be most beneficial at educating the stabilizing role of these muscles (Richardson & Jull, 1995). Commonly used tests include the single leg stance, visual observation of neuromuscular deficiencies through athletic maneuvers (B. Zazulak et al., 2008), the Sorenson back extension test (Moreau et al., 2001), the double leg lowering task (Smidt et al., 1987; Zannotti et al., 2002), the human arrow and side plank stance (Willson et al., 2005), and the abdominal hollowing and brace maneuvers (Hides et al., 2008; Hodges et al., 1997). The double leg lowering task and the Sorenson back extension test are among the two most popular tests for trunk NMC. Studies show several draw backs to their methods however (Moreau et al., 2001; Smidt et al., 1987; Zannotti et al., 2002). The double leg lowering task appears to be a challenge to abdominal strength in all subjects, however there are multiple grading systems that have been shown to be inconsistent between studies (Zannotti et al., 2002). Smidt et al (Smidt et al., 1987) looked at differences in back extension endurance and double leg lowering scores in healthy control subjects and subjects affected by chronic LBP. Trunk extension scores were shown to be poor indicators of trunk strength, and showed no significant differences across groups. Double leg lowering scores showed moderate differences between groups, but scores were thought to be affected by anatomic variations including gluteal mass size and length of hip flexors (Smidt et al., 1987). Controversy exists as to the amount of involvement that the hip extensors play in the Sorenson extension test (Moreau et al., 2001). It has been shown that there is more EMG activity from the biceps femoris than the back extensors during this task (Moreau et al., 2001). Therefore, these two tests are not included in this study. A major limitation to the research assessing clinical measures of trunk NMC is that they have not been validated against a laboratory measure of trunk NMC (Willson et al., 2005; B. Zazulak et al., 2008). In the case of this study, the clinical measures of trunk NMC that will be used include the human arrow, the side plank and a seated balance task on a stability ball in which errors will be scored. We are going to introduce a novel task in the case of the seated ball test. Verifying the validity of these clinical measures against a laboratory based measure will give clinicians' the ability to properly screen athletes and identify those that may be at risk for injury. Athletic trainers may then take the appropriate preventative measures to decrease likelihood of initial or recurrent injury.

Clinical measures of overall postural stability, such as the balance error scoring system, have been developed and validated against laboratory based instrumentation. The balance error scoring system is a clinical tool that identifies the number of errors during balance tests. These measures have been shown to be valid and reliable methods of assessing overall postural control (Broglio et al., 2009). Clinical measures of trunk stability that focus on identifying movement errors during tasks which attempt to isolate trunk motion may also be valid clinical tests. Unsupported sitting on a stability ball is a commonly used exercise to train trunk stability.

Identification of movement errors during such a task may be a good indication of overall trunk stability; however, previous research has not investigated this task.

There is a lack of evidence indicating that laboratory measures of trunk NMC are associated with clinical measures. Therefore, the purpose of this study is to identify a reliable clinical screening tool of trunk NMC that correlates to the laboratory measure of CoP so that clinicians may be able to identify individuals susceptible to injury. The purpose of this study is to determine the association between clinical screening tools and a laboratory screening tool of trunk stability.

Research Questions

1. Is there a correlation between sway area and the score obtained from the seated ball test in subjects?

2. Is there a correlation between sway area and the score obtained from the human arrow test in subjects?

3. Is there a correlation between sway area and the score obtained from the side plank test in subjects?

Research Hypotheses

1. The seated ball scores will be significantly and positively correlated with the subjects' sway area.

2. The human arrow scores will be significantly, negatively correlated with the subjects' sway area.

3. The side plank scores will be significantly, negatively correlated with the subjects' sway area.

Experimental Design

A correlational analysis was performed to determine if there is a relationship between sway area during an unstable sitting task and three clinical tests of trunk NMC. Subjects completed the unstable sitting task first, followed by the three clinical tests in a pre-determined, alternating order.

Subjects

Thirty physically active individuals between the ages of 18 and 35 were recruited from physical education, anatomy and exercise and sport science classes to participate in the study. Subjects were eligible for participation if they currently participate in 20 minutes or more of aerobic activity at least three times per week. Subjects were excluded if they currently had lumbar or thoracic pain or have previously had abdominal wall surgery. Subjects were not excluded for any other injury if it did not inhibit his or her ability to complete the tasks included in the study.

Instrumentation

Unstable Sitting Device

The unstable sitting device was composed of a 30 cm polycarbonate hemisphere beneath a wooden seat. The hemisphere served as the seat, and was attached to wooden foot supports to prohibit lower extremity involvement in the task **(Figure 1)**. A 60 cm high box supported a metal forceplate (Bertec Engineering corp., Columbus, OH). Safety rails surrounded the box and the hemisphere that sat on the forceplate to ensure subject safety during testing. All data during this task was collected via the forceplate.

Clinical Testing Equipment

A 55cm stability ball was used during the seated ball test, as well as a stop watch to time the trials. Ball pressure was taken prior to each session and was measured at 9.5 PSI (pounds per square inch). The size of the stability ball was decided during pilot testing, and seemed to be the most appropriate size for a varied population.

Procedures

Height and weight were collected before testing began for each subject. Subjects performed a five minute warm-up at a moderate intensity on a stationary bike before testing. The order of clinical tests was pre-determined by the administrator for each subject. The order of clinical tests alternated between subjects.

Unstable sitting task

While maintaining an upright posture, the subject was instructed to cross their arms over their chest and keep their balance while remaining in this position for 60 seconds. Subjects were able to grasp the railings if balance was lost and resumed the position for the remainder of the trial. Subjects were allotted practice trials until they felt comfortable with the task. Once subjects completed the practice trials they were given 30 seconds of rest and asked to repeat five trials of 60 seconds each. Subjects were given 30 seconds of rest between trials. Sway area was collected during the unstable sitting task (Cholewicki et al., 2000; Cholewicki et al., 2005; Radebold et al., 2001) which represented the subject's trunk NMC score for data analysis.

Human Arrow

Subjects were instructed to push up off of the floor on to their elbows with shoulders and elbows bent to 90°. The subject was asked to push up on their toes and maintain a straight posture, keeping their back flat with mild lordosis, legs straight, and shoulders retracted **(Figure 2)**. From this position, the subject was asked to raise the hips into 10^{o} of flexion, and a marker was placed on the wall. Timing began when the subject pushed up into the correct position. Timing stopped and the trial ended when the subject broke form including increased lumbar lordosis, increased hip flexion more than 10^{o} from neutral, or the subject could no longer hold the position. One trial was performed to failure. Subjects performed one practice trial for up to ten seconds. Pilot testing performed in our laboratory demonstrates a moderate intersession reliability (ICC (3, 1) 0.624).

Side Plank Test

The side plank test was performed on the floor and subjects were instructed to lie on their dominant side and to push up off the floor. Subjects held the position supporting weight on the forearm and lateral part of the dominant leg (Figure 3). From this position, the subject was asked to raise the hips into 10^{o} of flexion, and a marker was placed on the wall. Subjects were instructed to hold the position for maximal time. Time stopped when the subject broke form including increasing hip adduction or abduction more than 10° from neutral, increasing hip flexion more than 10° from neutral, increasing lumbar lordosis or until they could no longer hold the position. One trial was performed to failure. Subjects performed one practice trial for up to ten seconds. Pilot testing performed in our laboratory demonstrates a good intersession reliability (ICC (3, 1) 0.828).

Seated Ball Test

The aim of the seated ball test is to mimic the unstable sitting task in the clinical setting. Prior to each testing session the pressure of a 55cm stability ball was taken and measured at 9.5

PSI. The subject was asked to maintain the same upright posture while seated on a stability ball with the hips and knees flexed to approximately 90°. With arms crossed over the chest the subject was instructed to lift their feet three inches off the ground. The subject was asked to maintain proper posture, including mild lumbar lordosis, neutral shoulders and head and neck with feet and knees together while moving as little as possible **(Figure 4)**. The subject maintained this position for 60 seconds and the total numbers of errors committed was counted. Subjects were allotted two practice trials of 30 seconds each before errors were recorded. Each trial was completed with 30 seconds of rest between each testing session. Errors counted during the test trial included touching one or both feet to the floor, uncrossing the arms, increasing lumbar lordosis or decreasing hip flexion more than 10° (i.e. rolling back and forth on the ball). The subject was asked to get in the position on the ball and to say "go," at which point the administrator began the time. Two administrators scored the test simultaneously to assess inter-rater reliability (ICC (2, k) 0.981, SEM 0.801). The subject performed a total of five trials and errors were averaged across trials two, three and four. All trials were video-taped and re-scored to determine intersession reliability (ICC (3, k) 0.911, SEM 1.606). Pilot testing revealed good within-subject reliability (ICC (3,k) 0.811) when subjects were tested on two separate occasions.

Data Processing and Reduction

Data from the unstable sitting device was recorded via a metal forceplate and the middle three trials were averaged to reduce the likelihood of a learning or fatigue effect. Center of pressure data were collected at 100 Hz using the Motion Monitor Software (Innovation Sports Technology Inc., Chicago, IL). The signal was filtered with a 4^{th} order Butterworth filter at a frequency of 20 Hz (Silfies et al., 2003) and the measures were calculated using a customized

Matlab (The Mathworks Inc., Natick, MA). All data was exported to a 95% ellipse area was used to determine the subjects' CoP sway area score that was interpreted as the laboratory measure of trunk NMC. Many previous studies that have looked at CoP measures have exported data to a 95% ellipse area (Salavati et al., 2009; Slota et al., 2008; Swanenburg et al., 2008). Sway area may also be a better indicator of global trunk NMC rather than local trunk NMC, which is what we are aiming to quantify with our clinical testing.

Statistical Analysis

Multiple correlational analyses were performed to determine the association among mean sway area during the unstable sitting task, and measures for the seated ball task, human arrow task, and side plank task. Pearson product moment correlation coefficients were calculated for each of the six analyses and an alpha level of 0.05 was set a priori. All analyses were performed using Statistical Package for the Social Sciences (SPSS) version 17.0 (SPSS Inc., Chicago, IL).

Results

The purpose of this study was to determine the association between clinical screening tools and a laboratory screening tool of trunk stability. There is lack of evidence indicating that laboratory measures of trunk NMC are associated with clinical measures, and this study looked at CoP measures from an unstable sitting device and three different clinical screening tools. Testing procedures involved subjects participating in a series of four tasks including the unstable sitting task, a human arrow, a side plank and a seated ball task, aimed to mimic the unstable sitting task.

Measures of Trunk NMC

Fifteen females (age=20.07 yrs ± 1.91, height=169.49 cm ± 8.43, weight=59.92 kg ± 8.11) and 15 males (age=20.87 yrs ± 2.72, height=178.06 kg ± 8.24, weight=75.08 kg ± 8.94) participated in the study. The laboratory measure of trunk NMC was assessed through an unstable sitting device first introduced by Cholewicki et al (Cholewicki et al., 2000), and compared against three clinical measures of trunk NMC (See **Table 1**). Sway area for six subjects was eliminated either because of the subject's inability to complete the unstable sitting task without touching down, or because their scores were more than two standard deviations away from the mean for all subjects. We observed a significant correlation between the average errors committed during the seated ball task over three trials and the sway area ($r_{(22)}$=0.498, p=.013), with a moderate positive linear relationship between these two variables **(Figure 5)**. Time to failure during the human arrow task and sway area were not significantly correlated ($r_{(28)}$=-0.029, p=0.894) **(Figure 6)**, and time to failure during the side plank task and sway area were not significantly correlated ($r_{(28)}$=-0.114, p=0.595) **(Figure 7)**. Human arrow and side plank time to failure were significantly correlated with each other, displaying a strong linear relationship ($r_{(28)}$=.0841, p=0.001) as expected, and neither the human arrow nor side plank were significantly correlated with average errors committed during the seated ball task over three trials ($r_{(28)}$=-0.213, p=0.258, $r_{(28)}$=-0.176, p=0.352). These results indicate that the seated ball task is a reliable and accurate clinical measure of lumbar postural stability as measured by the unstable sitting device. Since endurance tasks were not correlated with sway area, they may not be good indicators of lumbar postural stability, but may play a separate role in stabilizing the spine that could be useful to clinicians. All Pearson correlation and significance values are located in **Table 2.**

Discussion

The purpose of this study was to determine if a previously developed measurement of trunk NMC was related to clinical tests commonly used to assess trunk NMC. The primary findings of this investigation showed that there was a positive relationship between measures from the unstable sitting device and average errors committed during a seated ball task. This means that those who had smaller sway areas during the unstable sitting task generally also had a lower number of average errors during the seated ball task. Ways of assessing trunk NMC and individuals susceptible to LBP have been developed in the laboratory using forceplates, EMG and other expensive and intricate equipment (Bono, 2004; Cholewicki & McGill, 1996; Cholewicki et al., 2000; Kujala et al., 1992; B. T. Zazulak et al., 2007). The unstable sitting device was shown to differentiate between subjects with LBP and those without, indicating that this is an accurate assessment tool to identify those with poorer trunk NMC (Radebold et al., 2001). Subjects with LBP had larger sway areas than those without. Literature has looked at several different clinical tests (Hodges et al., 2001; Juker et al., 1998; S. McGill et al., 1996; Moreau et al., 2001; Tse et al., 2005), but none have been compared to a laboratory measure of trunk NMC as this study did.

The present study found no statistical significance between sway area and the side plank or the human arrow however, which may indicate that this test is not an accurate assessment of trunk NMC or that it measures a different aspect of trunk NMC. Because trunk endurance tasks have been found to differentiate between subjects with LBP and those without, there is evidence that endurance of the trunk musculature plays an important role in stabilizing the spine which helps in preventing injury. We also know that lumbar postural stability, as assessed by the unstable sitting device, can differentiate between subjects with LBP and those without (Radebold et al., 2001). These kinds of tasks may play roles independent of each other in stabilizing the spine, which is why we observed no significant relationship between endurance tasks and lumbar postural stability tasks in the present study.

The seated ball task and sway area were found to have a significant, positive relationship. This indicates that the seated ball task is able to asses some aspect of spinal stability as is the unstable sitting device. The unstable sitting device is not readily available to most clinicians, and is not a feasible way of screening athletes for poor trunk NMC. The seated ball test appears to be a good option for clinicians, and this study demonstrated that it was a valid and reliable tool. The seated ball task was a novel task that was developed in this study, and has not been investigated in the literature. A major gap in the literature is identification of a clinical screening tool for lumbar postural stability, and the present study was able to identify a valid test for this. Because previous studies have also identified that trunk endurance is important in stabilizing the spine and preventing low back injuries, the addition of the seated ball task seems to form a more comprehensive assessment of spinal stability.

It was hypothesized that sway area would be correlated with scores from the seated ball task, which was shown to be true. It was also hypothesized that scores from the human arrow and the side plank task would be correlated with sway area. Neither of these variables was significantly correlated with sway area however. Values from the side plank were fairly consistent with values found during this task by Tse et al (Tse et al., 2005) and McGill et al (S. M. McGill et al., 1999). Our mean side plank times are located in **Table 1.** We found a mean time of 88.66 seconds compared to 81 seconds with McGill et al (S. M. McGill et al., 1999) and 75 seconds with Tse et al (Tse et al., 2005).

Low back pain was not controlled for in this study. All subjects completed the Oswestry Disability Questionairre, which scores an individual's disability due to LBP as a percentage. Only eleven of the thirty subjects reported any kind of low back disability, with an average score of 6.7%. The average score for all subjects was 2.4%. Zero to 20 percent is considered minimal disability, and of the subjects reporting LBP, all fell into this category. Because no individuals were experiencing significant LBP, we can be confident that LBP was not driving our results, because the unstable sitting device has been shown to be able to differentiate between individuals with LBP and those without (Radebold et al., 2001).

We chose to use the unstable sitting device as our laboratory measure of lumbar postural stability because it has been shown to be able to differentiate between subjects who are currently experiencing or have a history of LBP (Radebold et al., 2001) and those who are not, indicating that it is an accurate assessment of one's postural stability, which influences one's risk of suffering from LBP (Baratta et al., 1988; Panjabi, 2003; Richardson & Jull, 1995; Stanton & Kawchuk, 2008). The seated ball task was developed to mimic the unstable sitting device with equipment readily available in the athletic training room. Both tasks involve similar positions and movements. Both tasks require lumbar postural control and were performed for the same amount of time. The association of these two tasks is not surprising, however only a moderate relationship was found. Reimann et al (Reimann, 1999) completed a study with similar methodology comparing clinical measures with forceplate measures. Postural stability was scored using the BESS and also using a forceplate with the same balance conditions. The balance tasks were performed on a forceplate that recorded the subjects' sway area while an administrator scored the task using the BESS simultaneously. In this case, sway area was used as a gold standard of postural stability, and BESS as a clinical measure of postural stability. All conditions showed a significant relationship between the laboratory and clinical measure, with Pearson r values ranging from 0.3077 to 0.7887. These values indicate moderate relationships between laboratory and clinical measure of postural stability, similar to the relationship found between the seated ball task and sway area.

Intersession scoring of the seated ball task showed excellent reliability with an ICC (3, k) 0.911 and SEM 1.606. Inter-tester scoring also showed excellent reliability with an ICC (2, k) 0.981, and SEM 0.801. Subjects reported that the seated ball task was significantly more challenging than the unstable sitting device, and that they felt increased fatigue in the hamstrings and hip flexors while completing the task. The unstable sitting device involved a hemisphere, with a flat surface on which subjects sat. This makes the task less difficult than sitting on a full sphere, as in the seated ball task. Future clinical tests may be developed involving a similar hemisphere as the unstable sitting device. This would be a fairly inexpensive and simple apparatus to obtain in most athletic training rooms. A BOSU ball was used during pilot testing and appeared to be too easy of a task in comparison to the unstable sitting device.

The human arrow and the side plank tasks were completed only one time and were held to fatigue by subjects. No relationship was found between either of these measures and sway area from the unstable sitting device. Several factors might explain the lack of correlation between these measures. First, both tasks involve isometric contractions of multiple muscle groups, including global and local trunk musculature important in stabilizing the spine (Tse et al., 2005). While the seated ball task and the unstable sitting task require lumbar postural control and balance, the side plank and human arrow do not challenge the trunk musculature in the same way. Muscle endurance appears to play a more important role in these tests rather than postural control of the trunk and hips. Individuals may have performed better on the endurance tests, which were highly correlated with each other, than the stability tests simply because they possessed more trunk muscle endurance than lumbar postural stability. Because subjects were asked to hold both of these tests until they fatigued, there may have been a lack of effort in performing the tasks as well. On the other hand, subjects may have performed poorer on the endurance tests due to fatigue from completing the other tasks first, or simply because they lack trunk muscle endurance. Since the unstable sitting tasks were associated with each other, it indicates that many individuals did not possess both lumbar postural stability and trunk muscle endurance. Although no relationship exists between the unstable sitting task and both the human arrow and side plank task, these tests may still be important clinically for measuring spinal stability (Tse et al., 2005). Research in other areas of the body has shown no relationship between muscular endurance and balance as well (Hung-Maan Lee, 2009). Hung-Maan Lee et al (Hung-Maan Lee, 2009) looked at patients with unilateral ACL deficiency without surgical intervention and compared quadriceps and hamstring strength, proprioception, and standing balance in both the injured and uninjured knee. In the injured knee, hamstring and quadriceps strength were not significantly correlated with standing balance. We know that muscle strength is important for the stability of any joint, but in this case it did not contribute to standing postural stability, similar to our results for the endurance tasks and the unstable sitting task.

Athletes are susceptible to a number of injuries that may affect their playing time, but LBP has been one of the most prevalent conditions in the athletic population that hugely decreases playing time (Trainor & Wiesel, 2002). Clinicians have many ways of trying to quantify trunk NMC to help prevent LBP, but very few studies have been able to determine an accurate screening tool for poor trunk NMC. The present study shows promise for validating a clinical screening tool to assess trunk NMC and identify those individuals susceptible to LBP.

The seated ball task involves very little equipment and is a fairly simple error scoring system that could be added to a standard screening protocol. The BESS and LESS are similar tools that have been accepted by clinicians for identification and definition of cognitive function and lower extremity biomechanics that may promote injury. Implementing the seated ball task may be a beneficial addition to the athletic trainer's testing that may help prevent injuries in susceptible individuals. While the human arrow and side plank were not found to be accurate screening tools for trunk NMC according to the definitions in the present study, they may hold a place in the screening process. The side plank has been shown to activate the muscles of the trunk important in stabilizing the spine (S. M. McGill et al., 1999; Tse et al., 2005), which may indicate that the task has a place in the treatment of poor trunk NMC as well.

We recognize that the present study has several limitations. First, the subject population consisted of recreationally active people, not necessarily athletes or inactive people. Our subject pool may not represent the athletic population or the inactive population. Athletic trainers generally have the best opportunity to implement prevention programs with the individuals they work with, which is generally the athletic population. The results of the study may be generalized to the recreationally active population, but no conclusions can be drawn in regard to the athletic or inactive populations. The unstable sitting task and the seated ball task involved a standard size hemisphere and physioball. Therefore, anthropometric differences between subjects were not accounted for during these tasks. A correlation was run between height and weight and all measures of trunk NMC, and revealed a significant correlation between height and sway area ($r_{(22)}$=0.553, P=0.005). No significance was found between weight and this task ($r_{(22)}$=0.358, P=0.086). Height was not significantly correlated with the seated ball task, the human arrow or the side plank task ($r_{(28)}$=0.354, P=0.055, $r_{(28)}$=0.027, P=0.889, $r_{(28)}$=0.080, P=0.674). Weight was also not significantly correlated with the seated ball task, the human arrow or the side plank task ($r_{(28)}$=0.055, P=0.773, $r_{(28)}$=-0.007, P=0.972, $r_{(28)}$=0.073, P=0.700). Taller individuals may have experienced a more difficult time performing the unstable sitting task than did other individuals because of their increased trunk moment.

Future research warrants further investigation between clinical measures of trunk NMC and laboratory measures of trunk NMC. Muscle activation patterns between clinical tests and laboratory tests involving EMG information may help to give us further knowledge about the relationship between these measures. Only three clinical measures of trunk NMC were looked at in this study, and many more exist that are commonly used in the clinic. Investigation of additional clinical measures may reveal a stronger relationship than the tests included in the present study.

Further research may develop a battery of tests used to assess trunk strength in the clinic including measures of lumbar postural stability as well as trunk muscle endurance. Both kinds of activities have been found to activate the spinal stabilizing musculature (Radebold et al., 2001; Tse et al., 2005) important in reducing one's risk of suffering from LBP, which suggests that both trunk stability and endurance are important in the prevention of LBP. More testing needs to be done involving the seated ball task in order to establish a feasible and reliable protocol. We had individuals complete 60 second trials, which may be excessive as other studies have had subjects complete as little as seven second trials. The present study did not include individuals with significant LBP, and future studies are warranted to determine the sensitivity of the task. A cut-off value should also be established to determine the number of errors that may indicate poor trunk NMC versus adequate trunk NMC. Studies that compare the role of lumbar postural stability versus trunk muscle endurance and how each type of exercise contributes to spinal stability may also be warranted.

This study investigated the relationship between three clinical measures of trunk NMC commonly used in the athletic training clinic and a laboratory measure of trunk NMC that represented the gold standard. Based on the results of this study it can be concluded that:

1. Sway area from the unstable sitting device shows a significant correlation with the seated ball task in recreationally active individuals, with a moderate, positive relationship.

2. Sway area from the unstable sitting device shows no significant correlation with the human arrow task in recreationally active individuals.

3. Sway area from the unstable sitting device shows no significant correlation with the side plank task in recreationally active individuals.

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