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CORE STRENGTH TESTING:
DEVELOPING NORMATIVE DATA FOR THREE CLINICAL TESTS

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30 April 2014

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ABSTRACT

BACKGROUND AND PURPOSE: The importance of core stability in activities of daily living, athletic performance, and in preventing low back pain (LBP) and extremity injuries is becoming increasingly accepted and better understood in modern literature. However, normative values for current core endurance tests have yet to be validated for clinic use. The purpose of this research project was to determine core endurance strength normative values for three core endurance tests in healthy men and women between the ages of 18 and 55 years old.

METHODS: One-hundred-sixteen subjects (76 female and 40 male) with a mean age of 28.8 years participated in this study over a two-year period. Subjects completed a general health and exercise history questionnaire. Each subject was randomly assigned a test order and was tested by one of nine student researchers. The core endurance tests performed were the 60 degree flexion test (Fl), trunk extensor endurance test (Ext), right side plank (RSP), and left side plank (LSP). Analysis included a one-way ANOVA and multiple regression to determine differences between groups and to understand what variables influenced test outcomes.

RESULTS: Normative mean values in seconds for each test are: Fl 160(102); Ext 101(51); RSP 54(25); LSP 55(28). One-way ANOVA revealed the following significant differences: gender M/F (RSP p=.00, LSP p=.00), exercise Y/N (RSP p=.03, LSP p=.01, Fl p=.000), active runners Y/N (RSP p=.001, LSP p=.005, Fl p=.001), strength training Y/N (RSP p=.001, LSP p=.000), core exercise Y/N (LSP p=.01), competitive athletes Y/N (RSP p=.01, LSP p=.02, Fl p=.04). Total time of all four tests noted significant differences for exercise Y/N (p=.005) and run Y/N (p=.003), but revealed no significant difference between gender. Multiple regression models revealed that exercise and core time were significant predictors of LSP. Exercise time was a significant predictor of Fl test, and age and waist circumference were significant predictors for Ext test. The overall model for RSP displayed a trend toward significance.

CONCLUSION: Our results suggest that normative values can be established for the Fl and Ext tests regardless of gender, however RSP and LSP tests were significant for differences between genders. The results also suggest that increased activity level improved core endurance.

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The undersigned certify that they have read, and recommended approval of the research project entitled…

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DEVELOPING NORMATIVE DATA FOR THREE CLINICAL TESTS

Submitted by
Alexis Anderson, SPT
Jessica Hoffman, SPT
Brent Johnson, SPT
Anna Simonson, SPT
Laurel Urquhart, SPT

in partial fulfillment of the requirements for the Doctor of Physical Therapy Program

Primary Advisor__________________ Date 4/29/14

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CHAPTER I: Introduction

The importance of core stability in activities of daily living, athletic performance, and in preventing low back pain (LBP) and extremity injuries is becoming increasingly accepted and better understood in modern literature. However, the definition of 'the core' as stated by researchers is not yet explicit nor have consistent normative core endurance values been generated for the healthy adult population. While an abundance of reliable and valid tests and measures have been generated in other areas of physical therapy including fall risk tools for the geriatric population and functional independence measures for cohorts with neurologic disorders, current core endurance tests for clinic use have yet to demonstrate optimal psychometric properties, and so normative values have yet to be solidified. When it comes to the measurement of core endurance, tests currently being utilized in the clinic include one-leg balance tests, one-leg squats, three-plane core strength tests, trunk-curl tests, the Kendall test, the Sorenson test, side bridges, and both static and dynamic abdominal muscle endurance tests, to name a few.[1,2,3,4,5,6] The plethora of tests being administered in physical therapy clinics today reveals the lack of evidence pointing toward a "gold standard" or a valid and reliable core endurance assessment that is universally used among physical therapists and other clinicians.

The core is defined as the basis of proximal stability for distal mobility, and it allows for the transfer of energy from large to small muscles during everyday movements.[1] Multiple authors outline the core differently, and this variability may be one reason that there is much left to understand about the core. While Zazulak et al state that the core comprises the active trunk musculature and the passive structures of the

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thoracolumbar spine and pelvis, Kibler et al declare that the core consists of the spine, abdominal structures, hips, pelvis, as well as the proximal lower extremities.[1,7] However, inconsistencies in the definition of the core do not detract from the unanimous acceptance of the importance of our central muscles in creating efficient movements. In an article published in 2010, Key describes additional functions of the core that include a breathing mechanism related to the generation of intra-abdominal pressure, postural control mechanisms including co-activation between axial flexor and extensor muscle systems, and posturo-movement control of the proximal limb girdles.[8] As one can see, the functions of the core are vast, and its role in everyday function is vital. Table 1 outlines the core musculature as defined by Kibler et al including functions and attachments.[1]

MUSCLE	FUNCTION	PROXIMAL ATTACHMENT	DISTAL ATTACHMENT
Transverse abdominis	Abdominal compression and support, trunk stabilization	Ribs 7-12	Abdominal aponeurosis, pubic bone, thoracolumbar fascia
Internal obliques	Trunk flexion, trunk rotation and lateral flexion same side	Ribs 10-12, rectus sheath	Iliac crest, thoracolumbar fascia
External obliques	Trunk flexion, trunk rotation and lateral flexion opposite side	Lower 8 ribs	Abdominal aponeurosis, iliac crest
Rectus abdominis	Trunk flexion, prevents anterior pelvic tilt	Ribs 5-7, xiphoid process	Pubic symphysis
Multifidi	Segmental rotation, segmental spinal stabilization	Spinous processes	Sacrum, transverse processes 1-2 levels below
Rotatores	Segmental rotation,	Spinous processes	Transverse processes 1-2

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	segmental spinal stabilization		levels below
Erector spinae	Back and neck extension; alone, lateral trunk flexion	Tendon from iliac crest, sacrum, SI ligaments, spinous processes	Ribs, cervical and thoracic vertebrae, mastoid process
Quadratus lumborum	Pelvic elevation, lateral flexion	Transverse processes L1-L4, 12th rib	Iliac crest
Trapezius	Scapular elevation, retraction, depression	Occiput, ligaments of cervical spine, T1-T12	Lateral third of clavicle, acromion process, spine of scapula
Hip rotators	Hip external rotation	Anterior sacrum, pelvis	Greater trochanter
Glutei	Hip extension, external rotation, abduction, internal rotation	Ilium, iliac crest, sacrum, sacrotuberous ligament	Iliotibial band, gluteal tubercle, greater trochanter
Iliacus	Hip flexion	Iliac fossa, iliac crest, SI ligaments	Tendon of psoas major, lesser trochanter
Psoas major	Hip flexion	Transverse process, L1-L5 vertebral bodies	Lesser trochanter
Hamstrings	Hip extension, knee flexion	Ischial tuberosity, linea aspera	Head of fibula, medial tibia
Quadriceps	Knee extension	AIIS, femur, linea aspera	Patella, tibial tubercle
Diaphragm	Respiration	Inner surface of ribs 6-12, costal margins, xiphoid process	L1-L3 vertebrae, central tendon
Pelvic floor Levator ani Coccygeus	Pelvic visceral support, coccyx flexion, increases intra-abdominal pressure	Body of pubis, tendinous arch of obturator fascia, ischial spine Perineal body, coccyx, anococcygeal ligament, wall of prostate or vagina, rectum, and anal canal	Ischial spine Inferior end of sacrum and coccyx

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Obturator internus	Hip abduction and internal rotation, hip stabilization	Ischiopubic ramus, obturator membrane	Medial greater trochanter
Latissimus dorsi	Shoulder adduction, extension, internal rotation	Spine T7 to sacrum, iliac crest, lower ribs	Bicipital groove
Pectoralis major	Shoulder adduction, horizontal adduction, internal rotation	Medial half of clavicle, sternum, ribs 1-6 cartilage	Bicipital groove

TABLE 1. Core Musculature.

As defined by Kibler et al, 'core stability' is "the ability to control the position and motion of the trunk over the pelvis to allow optimum production, transfer and control of force and motion to the terminal segment in integrated kinetic chain activities."[1] It is a combination of passive and active structures and a neural control unit that allows us to perform activities of daily living.[1] According to McGill et al, without muscular support, the osteo-ligamentous spine can hold only 90 Newtons (approximately 20 pounds) of compressive forces in vitro.[5] This demonstrates the essentiality of the core musculature in acting as a buttress for the spinal column. Thus, without our core musculature holding us together, 20 pounds placed upon our heads would cause our spines to collapse upon themselves. However, just as the elastic properties of guy-wires allow television towers to sway in the wind and distribute external forces throughout the entire structure, core musculature needs to provide optimal tension at each spinal segment so as to maintain stability while preventing total rigidity.[5] This ideal balance of stability and mobility should be our focus when training the core.

Not only do most of the prime movers and stabilizers of the distal extremities

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attach to the core, using it as a solid base for propulsion, but core muscle activation creates anticipatory postural adjustments that position the body to resist the perturbations created by forces of kicking, throwing, running and activities of daily living.[1,7] While there is normally a proximal to distal pattern of muscle activation in creating interactive moments,[7] electromyographic (EMG) studies aiming to pinpoint muscle recruitment patterns in both healthy and unhealthy individuals throughout various activities reveal that recruitment patterns are task-specific and that there is not one critical element of motor control that maintains stability.[9] McGill et al state that, "The relative contributions of each muscle continually changes throughout a task, such that discussion of the 'most important stabilizing muscle' is restricted to a transient instant in time."[5]

Borghuis et al suggest that only minimal voluntary isometric contractions of trunk musculature are necessary to stabilize the spine, implying that muscular *endurance* along with *sensory-motor control* are of greater importance than strength when considering core stability.[9] Similarly, Key states that *co-activation* and *coordination* of the core, rather than strength, create an ideal core.[8] An optimal core will allow distal muscles to become more efficient because forces are transferred to their intended target rather than wasted on the displacement of an otherwise weak and easily perturbed core. A core lacking muscular endurance consequently possesses poor motor control and therefore has decreased the function of its stabilizing structures. This can lead to slow kinematic response to sudden trunk loading and can result in injury.

While much is left to understand about the core, current research continues to unveil its importance in day-to-day activities and in preventing injury. Because of this, it

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is vital to develop normative values for current core endurance tests in order to better understand patterns of weakness and instability and so that we can better predict future injuries.

The purpose of this study was to establish normative values and to assess the effect of specific variables on these values in adults 18-55 years of age for three clinical tests of core endurance. The core endurance tests chosen for this investigation consisted of the left side plank (LSP), the right side plank (RSP), the 60 degree flexion test, and the trunk extensor endurance test. By utilizing three tests that measure the endurance of various areas of the core it is easier to obtain a larger understanding of overall core endurance. The researchers hypothesized that gender would have an effect on hold times, exercisers would have longer hold times than non-exercisers, exercisers who targeted core musculature would have longer hold times than those who did not, and subjects who had a history of LBP or an extremity injury would have decreased hold times.

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CHAPTER II: Literature Review

The Core and Injury Prevention

Core stability is a vital aspect of the human body as it not only provides strength and balance, but it aids in creating anticipatory postural adjustments, or pre-programmed activation of core muscles, that allow the body to handle perturbations during activities such as kicking, throwing, and running.[1] This demonstrates the importance of the core in decreasing incidences of injury. The purpose of anticipatory postural adjustments within the body are to allow proximal stability with distal movement. Injuries can occur when core stability does not keep the proximal body stable while an individual carries out distal movements or perturbations. Hip musculature, often classified as part of the core, can significantly alter the position of the hip and trunk if not strengthened properly, which has been shown to increase incidences of injuries in the knee.[1] Kibler and colleagues reported that alterations in hip and trunk positions can result in increased hip adduction, hip flexion, and knee valgus, which increases the load placed on knee ligaments, specifically the anterior cruciate ligament.[1] Core instability has also been shown to affect overhead athletes, including tennis players, by increasing loads at the shoulder.[1] We can therefore conclude that core stability is a vital component in the function and performance of athletes.

Leetun et al hypothesized that athletes who did not experience an injury during their sports season would test better on core strength measures compared to athletes who did experience an injury.[10] The purpose of this prospective study was to examine the differences in core stability between male and female athletes and to compare the core

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stability of athletes who experienced an injury with those who did not. This study consisted of male and female athletes from varsity intercollegiate basketball and cross-country teams (f=80, m=60). Exclusion criteria included any athlete who reported pain in their lower extremities, low back, and/or abdominal region at the time of testing. During the process of testing there was one dropout due to illness. Each athlete was tested within two weeks of the beginning of their season and was followed throughout one full season of their sport. Each study participant signed a consent form and completed a health history form where they were instructed to detail previous injuries or surgeries that they may have had. Foot dominance and weight were also recorded. To measure abdominal stability, each athlete completed four tests bilaterally including the isometric hip abduction test, the isometric hip external rotation test, the side bridge test, and the modified Biering-Sorenson test. The modified Biering-Sorenson test was carried out by positioning the athlete in a prone position where they were secured with straps over their pelvis and legs. The athlete was then instructed to cross their arms over their chest and to maintain a horizontal position until fatigue. The results collected over the two years were analyzed using an analysis of variance. Out of the 139 participating athletes, 29% (n=41) experienced back or a lower extremity injuries during one collegiate season. Of the athletes injured, 35% were female while 22% were male.[10] Overall, male athletes performed better than females on the core stability tests. Along with variation between genders, athletes who experienced an injury during their collegiate sport season performed worse on the core stability tests compared to the athletes who did not experience an injury. Female athletes performed at a lower level in the hip external

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rotation test compared to male athletes, and athletes who experienced an injury during their season demonstrated significant weakness with the hip abduction and external rotation tests compared to the athletes who were not injured.[10] One limitation of this study was that the measurement of hip strength was defined in terms of torque rather than in units of force. Because of this, if injured athletes were taller than uninjured athletes, on average, the difference in hip torque measurements may have been less significant than the force measurements that were depicted in this study. [10] A second limitation was that intra-tester reliability was not measured between the two examiners.[10]

A prospective observational study by Cholewicki et al aimed to determine whether delayed muscle reflex response to sudden trunk loading is a result of or a risk factor for sustaining a low back injury (LBI).[11] A total of 292 college athletes with an average age of 19.4 years (148 females and 144 males) from 22 different sports teams at Yale University were used for the final analysis in this study.[11] Measurements were collected at baseline and again during a 2- to 3-year follow-up period. Muscle reflex response was measured by placing subjects in a specially built apparatus that restrains pelvic motion while permitting isometric contraction in trunk flexion, extension, and lateral bending. A resisted force was suddenly released in each of these planes at random time intervals, and EMG signals were recorded from 12 major trunk muscles both before and after the release. Of the 292 athletes in the final analysis, 31 (11%) sustained an LBI throughout the 2- to 3-year follow-up period.[11] Authors found that a delay in trunk muscle reflex responses during flexion and lateral bending load releases predicted 74% of LBI outcomes correctly, suggesting that core muscle response can play a large role in

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preventing LBI.[11] These delayed latencies also appear to be a preexisting risk factor and not the effect of an LBI because no significant change in muscle reflex latencies were found post-LBI in athletes who reported no previous history of LBI.

A similar study by Zazulak et al examined the relationship between the neuromuscular control of the trunk and lower extremity injuries.[7] The purpose of this study was to determine core stability neuromuscular factors that may predispose athletes to knee injury. For this study, core stability refers to the body's ability to control the trunk in response to internal or external forces. A total of 277 athletes volunteered and were followed for a total of three years. Each athlete completed a 45-item questionnaire, which included demographic information and history of injury. None of the athletes that were included in this study had a history of knee injury. Zazulak et al defined injury as "any injury that resulted in a visit to a sports physician", and a knee injury was defined as "a ligament, meniscal, or patellofemoral injury to the knee joint."[7] Each athlete was placed in a sudden force release apparatus in order to assess trunk response to sudden unloading in flexion, extension, and lateral bending. Each direction was tested at 150 milliseconds and maximum displacement. Results found that athletes who experienced a knee injury had a statistically significant higher displacement rate than those athletes who did not experience an injury.[7] This tells us that muscles were slower to react in an attempt to decrease potentially unhealthy forces that were exerted upon the body. Twenty-five knee injuries occurred during the three-year period; female athletes experienced 11 injuries while male athletes experienced 14 injuries. The authors suggest that deficits in trunk control may aid in identifying athletes who are at an increased risk

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of injury, specifically ligamentous knee injuries.[7]

Van Dieën et al carried out a comparative study focusing on the patterns and variations of trunk muscle recruitment in people with LBP.[12] Past studies have looked at the relationship between muscle activation and LBP. Authors suggest that changes in trunk muscle activation may be a result of weak spinal stabilizers. This can lead to excessive strain on certain muscles that may lead to LBP.[5] A total of 32 participants, including 16 healthy control subjects and 16 patients with chronic low back pain (CLBP), were included in this study. Van Dieën et al defined CLBP as "a persisting or periodic pain with duration longer than 6 months."[12] Exclusion criteria included patients with neurologic deficits, structural deformities, genetic spinal disorders, or a history of spinal surgery. Inclusion criteria included patients who had experienced CLBP for a duration lasting anywhere between six months and 35 years. Study participants completed the Roland Disability Questionnaire and were then asked to perform trunk movements in the sagittal, frontal, and transverse planes at the same time that 12 EMG signals were collected. Patients were positioned in an apparatus in a semi-seated position that prevents hip motion. They were also instructed to move slowly throughout each motion, and measurements were taken at approximately -20° to 20° from neutral spine in each direction.[12] For example, the participants would start in -20° of extension in the sagittal plane, move into neutral spine, and then continue until they reached 20° of flexion. Participants completed motions in the transverse and frontal planes utilizing the same method. For males, 16 kilograms were added to a weight vest, and for females, 8 kilograms were added. Statistical analysis included analysis of variance for the motion

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trials and ramp contractions as well as a ratio between the control group and the subjects experiencing CLBP. Analysis within subjects included load, plane, and the direction of movement. Analysis was also performed to compare differences in gender and health status. Results demonstrated that patients with CLBP have different muscle recruitment patterns than healthy individuals who are not experiencing CLBP.[12] Participants experiencing CLBP showed a larger ratio between antagonist and agonist muscle activation during movement as well as higher lumbar erector spinae muscle activation compared to thoracic erector spinae muscle activation. It is thought that a change in recruitment of trunk muscles may be due to compensatory mechanisms that allow the spine to be stabilized when they are weak or when injured muscles can no longer perform their function.[12]

Core Gender Differences

When establishing normative values for core strength and endurance it is important to consider differences between genders. While most studies have found that men have greater abdominal strength and endurance than women, others have found no difference. In a study conducted by Evans et al in 2007, no significant difference was found between males and females during the Trunk Flexor Endurance test at 60°, the Biering-Sorenson test, or the Ito test.[13] Krause, on the other hand, found conflicting results with the Kendall Double Leg Lowering test, where males demonstrated significantly better scores than females. Further research needs to be performed in order to determine whether or not these differences between males and females truly exist.

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Apart from potential differences in abdominal strength when comparing male and female athletes, one study found that females utilize different muscles than males when performing a double leg landing test from a 60 centimeter box.[14] Forty-two athletes were selected for this study which included 20 males (average age = 23) and 22 females (average age = 20). Athletes qualified if they engaged in physical activity at least 30 minutes per day three times per week. Measurements that included activation amplitudes were collected from each athlete's rectus femoris (RF), external oblique (EO), internal oblique (IO) and transverse abdominis (TA) muscles throughout the pre-activation phase (150 milliseconds prior to landing) and at contact phase (150 milliseconds after landing). Activation amplitudes was measured with surface EMG using a Myopace 2000 System.[14] The results revealed that males had a tendency to utilize their TA and internal oblique muscles more frequently than their external oblique and rectus abdominis.[14] Males also had greater amplitudes of force generated from their TA and IO when compared to females. Females tended to use all abdominal muscles equally.[14]

Core Endurance in Athletes

In a review article by Kibler et al in 2006,[1] the authors emphasize the importance of core strength during athletic activities not only to help decrease forces on the back, but also to create large rotational movements with small muscles and to provide the body with central stability in order for distal segments to be mobile. Ideally, athletes should have a strong core to avoid injury. In an article by Leetun et al, previously mentioned, the researchers found that athletes who were injured generally demonstrated poor core

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stability and weak hip abductors and external rotators.[10] Injured athletes also generally performed worse on the straight leg lowering test, but no statistical difference was found.[10] In 2007, Zazulak et al found that poor core proprioceptive control in collegiate athletes, as measured by increased flexion, extension, and lateral flexion displacement, was a strong predictor for the occurrence of knee injury.[7]

In a comparative study by Brophy et al in 2009, researchers measured core strength, hip strength, hip flexibility, and lower extremity dynamic alignment of 54 male and 44 female division 1 soccer players with average ages of 20.06 and 19.77 respectively.[15] Hip flexion range of motion (ROM) was measured while participants were in the Thomas test position, and hip internal and external ROM was measured in sitting with the knees flexed to 90° and in supine with the knees and hips flexed to 90°. Hip extension was measured with the participant in a prone position. A goniometer was used for all ROM measurements. Lower abdominal stability control during lower extremity movements was measured using a pressure biofeedback stabilizer. A bladder attached to a pressure pump was filled and placed under the participant's spine at the S2 level while the patient was in a hook-lying position. When the participant contracted their abdominal muscles the pressure would change and this measurement would be recorded. Participants were instructed to maintain a TA contraction while performing lower extremity movements, and, similarly, they were then asked to contract their rectus abdominis muscles while performing a full sit-up. A trial was considered successful or not weak if the patient had a change less than 10 mmHg from the starting pressure. Results showed that both male and female soccer players demonstrated limited hip

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rotation and poor abdominal core control, with males having better lower abdominal control than females.[15] Female soccer players were also found to have a significant discrepancy in hip abductor strength, which was not present in males. Conclusions of this study revealed that increased deficits in hip and core strength and ROM in females as compared to males might play a role in the differences between male and female rate of ACL injury.[15]

Another study aimed to determine whether or not core endurance correlated to athletic ability.[17] Athletes were asked to perform several tests often correlated with athletic ability including the vertical jump, 40-yard dash, T-test, and medicine ball throw. Researchers then compared these test results to each athletes' core endurance as measured by the Kendall leg lowering test. Between athletes of both genders, the only correlation that suggested abdominal strength as having a relationship to athletic ability was the medicine ball throw in female athletes. No other test of athletic ability was found to have a significant correlation to the Kendall leg lowering test. This suggests that athletic ability is not necessarily correlated with good abdominal strength.[17] These findings do not retract from the importance of core endurance in preventing injury. The question then arises--which exercises are best at increasing core strength and endurance?

Testing and Evaluation of Core Strength

There are many ways to examine and test the musculature of the core. In reviewing the literature, testing core *endurance* has been found to be more functional than testing core *strength*. There are many ways to test the endurance of the core;

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however, this study focused on those tests that can be utilized in the clinic, which is more useful and practical. Although there are many tests that are currently used in clinical practice, there is no standard way to measure core strength and endurance. Many of the current tests lack established normative values for age groups and differences between gender and are therefore not useful when comparing an individual score against population norms. Further research is needed to establish normative values for tests of core muscular endurance.

The Kendall test, also known as the double leg lowering test (DLLT), can be used in the clinic to assess abdominal strength. The DLLT assesses the ability of core muscles to stabilize the pelvis in a posterior-tilted position against an external load imparted by the lower extremities as they are lowered from a vertical starting position.[3] According to Krause, this aspect has an important clinical application because core stability and lumbar stabilization programs rely on the abdominal muscles to function effectively in a stabilizing role. One-hundred healthy volunteers (50 males and 50 females) between the ages of 18 and 29 years old participated in this repeated measures study. The reason they focused on this age group was because this is the typical age range for the onset of LBP. Participants performed the DLLT as defined by Kendall et al which describes the utilization of the abdominal muscles to maintain the pelvis in a posterior-tilted position while lowering the extended legs from a vertical position.[18] Subjects wore shorts and removed their shoes to avoid additional external loads. To perform the test, the subject was supine on a wooden table covered with a 1-centimeter–thick pad, and their arms were folded across their chest. Two trials were performed with a 1-minute rest between

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trials. A gender difference was found in abdominal muscle performance as measured by the DLLT. While the males were able to lower their legs on average of 15.4° from a horizontal reference, females were able to lower their legs on average of 37.0°.[3] The DLLT had an excellent intra-tester reliability of 0.98; however, the test lacks functionality in position and movement.[3] This data provides useful clinical guidelines for assessing abdominal strength in subjects between the ages of 18 and 29 years old but does not assess muscular endurance, which is needed for core stabilization.[3]

In 2010, Mbada et al performed a study to establish gender and age normative data on static and dynamic abdominal muscle endurance.[6] The participants consisted of 503 apparently healthy Nigerian volunteers between the ages of 16 and 70 years of age. Exclusion criteria included history of symptomatic LBP, visceral pain within one year of the time of the study, spinal deformity, neurologic disease, participation in high intensity regular exercise or elite sports at a competitive level, any prior systematic exercise program of the lumbar or hip extensor muscles, history of cardiovascular disease representing contraindications for exercise, being pregnant, or any disability limiting the ability to exercise. The physical performance tests used in this study included the static and dynamic partial curl up test of the Canadian Standardized Test of Fitness. The static abdominal muscles endurance (SAME) test required the participant to hold an abdominal curl in a crook lying position on a mat with their knees bent at 90°. To begin the test, participants were asked to place their hands face down at their sides. Two strips of tape were then placed parallel to each other and perpendicular to the length of the mat: the first was placed at the tips of the fingers, and the second was placed 3.5 inches more

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caudally. Participants were instructed to slide their fingers down the length of the mat until they reached the second line of tape. This position was held to fatigue, and time was recorded with a stopwatch. The dynamic abdominal muscles endurance (DAME) test required the same setup as the SAME test, but required participants to repeatedly curl up to the second line of tape and back to the original position to the beat of a metronome, which was set to 40 beats per minute. This required a slow, controlled, and continuous cadence of 20 curl-ups per minute. This study established normative values according to age and gender for both the static and dynamic abdominal muscle endurance tests, which can be found in Tables 2 and 3 respectively.

Age	**≤20 years**	**21-30 years**	**31-40 years**	**41-50 years**	**51-60 years**	**>60 years**
Males	38.7 (±18.2)	43.7 (±31.6)	42.6 (±27.8)	37.8 (±17.1)	24.0 (±0)	18.7 (±9.01)
Females	33.5 (±18.1)	37.2 (22.8)	35.2 (±14.4)	50.9 (±11.8)	19.6 (±5.07)	-

TABLE 2. SAME mean hold times for males and females by age group as measured in seconds.

Age	**≤20 years**	**21-30 years**	**31-40 years**	**41-50 years**	**51-60 years**	**>60 years**
Males	18.3 (±8.11)	21.8 (±11.3)	22.5 (±10.5)	20.1 (±11.5)	16.0 (±0)	12.3 (±4.01)
Females	14.7 (±7.90)	15.5 (7.77)	17.0 (±9.33)	22.7 (±7.42)	13.4 (±3.04)	-

TABLE 3. DAME mean hold times for males and females by age group as measured in repetitions.

The authors suggest that these normative values could be used in rehabilitation to estimate the level of endurance impairment in a patient at intake and could also serve as an outcome measure for improvement.[6] However, a limitation of this study is that abdominal endurance was tested in only one plane, which primarily tests the rectus abdominis muscle and not the other abdominal musculature that makes up the core.

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A systematic review by Demoulin et al in 2006 evaluated the Sorensen test for isometric endurance of the trunk extensors.[4] Articles studied in this review were found on Medline. For the Sorensen test, the patient was prone on the examination table with the upper edge of their iliac crests aligned with the edge of the table. The lower body was fixed to the table by three straps located around the pelvis, knees, and ankles. The arms were folded across the chest and the patient was asked to isometrically maintain their upper body in a horizontal position. The time until the patient could no longer maintain this position was recorded, or 240 seconds, whichever occurred first. The Sorensen test was originally designed as a tool to predict LBP within the next year in males.[4] However, the debate continues as to its ability to predict LBP. This test has good discriminative validity, reproducibility, and it is safe. However, females tend to perform better on this test, and the reason remains unexplained. Also, this test has no predictive validity in females, but a hold time of less than 176 seconds in males predicted LBP during the next year.[4]

Knudson and Johnston advocate for trunk curl-ups or abdominal crunches as the best and safest abdominal muscle strengthening and testing tool as it minimizes the activity of the iliopsoas and hip flexors while protecting the lower back.[2] These researchers presented the two-minute bench trunk curl (BTC) as a standardized test because it limited the action of the hip flexors, decreased lumbar lordosis, and is performed without requiring stabilization of the feet. The purpose of this study was to examine the validity and reliability of the BTC in measuring abdominal muscular endurance of college-aged persons. Participants included 20 subjects (10 males and 10

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females) aged 19 to 32 years old. The starting position of the BTC placed the subjects in supine with their knees and hips flexed to 90° and with their thighs and buttocks against the side of a bench that was 0.46 meters high. The participant crossed their arms and grasped the elbow of their opposite arm and then curled up their trunk so that their forearms touched the front of their thighs. They then uncurled so that their shoulder blades touched the floor. The number of repetitions completed in two minutes was utilized as the score. The BTC test was highly reliable for males (R=0.88) and females (R=0.94) when compared to the criterion assessed using a Cybex trunk flexion/extension isokinetic dynamometer. Although this test demonstrates high reliability, it is unclear whether it is a good measure for abdominal muscular strength and endurance or whether it is correlated with incidence of LBP. This test also lacks normative data; however, it achieves easy standardization during testing and would be practical to administer to a large number of people.[2]

McGill et al utilized the side bridge test to assess core endurance, as it stresses the quadratus lumborum, the muscle best suited to be the major stabilizer of the lumbar spine while minimizing the load on the lumbar spine.[5] The purpose of this study was to collect isometric endurance times from a healthy population utilizing the side bridge and isometric flexion and extension exercises in order to establish normative data for healthy subjects. Seventy-five healthy subjects were selected from a university community (31 males and 44 females) with a mean age of 23 years. Subjects performed the Biering-Sorensen test (as described previously), the flexion endurance test, and the side bridge test, and they were asked to hold each position until fatigue with a minimum of five

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minutes of rest between each test to allow for sufficient recovery.[5] The flexion endurance test required subjects to sit on the test bench and place their upper body against a support with an angle of 60° from the test bed. Both the knees and hips were flexed to 90°. The arms were folded across the chest, hands were placed on opposite shoulders, and toes were tucked under toe straps. Subjects maintained this position while researchers removed the supporting wedge back 10 centimeters from the subject's back to begin the test. Time until the upper body fell below 60° was recorded. The side bridge test required subjects to lie on an exercise mat that was 2.5 centimeters thick. The subjects were asked to lay on their side with their legs extended and with their top foot in front of the other foot for support. Subjects supported themselves by lifting their hips off the mat to maintain a straight line over their full body length while supporting themselves on one elbow and their feet. The uninvolved arm was held across the chest with the hand placed on the opposite shoulder. The test ended and time was recorded when the hips returned to the exercise mat. Mean endurance times for the exercises and ratios of endurance times were established. The ratios of endurance times were normalized to the extensor-hold exercise because subjects were able to hold their position the longest during this exercise. For males, the mean endurance times were as follows: 146 seconds for the extensor test, 144 seconds for the flexor test, 94 seconds for right side bridge, and 97 seconds for the left side bridge. For females, the mean endurance times were as follows: 189 seconds for the extensor test, 149 seconds for the flexor test, 72 seconds for the right side bridge, and 77 seconds for the left side bridge. The test-retest reliability of this study was 0.99 for extensor exercise, 0.93 for flexor exercise, 0.96 for the right side

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bridge, and 0.99 for the left sided bridge. According to the authors, the side bridge is a good test because it is cheap, safe, and reliable.[5] Our study has aimed to model the methods and procedures described by McGill et al with our goal being to expand upon the target population including increasing the number and age range of the participants.

Kibler et al explained that evaluation of specific muscles in the core is difficult because numerous muscles fire in task-specific patterns to provide core strength.[1] Kibler proposed to test core strength by assessing one-leg standing balance ability, one-leg squat, and a standing three-plane core strength test.[1] For the one-leg standing balance test, the patient is asked to stand on one leg with no other verbal cue. Deviations such a Trendelenburg posture or internally or externally rotating on the weight-bearing limb indicates inability to control posture and suggests proximal core weakness. The one-leg squat would be the next progressive evaluation if the one-leg standing balance test is performed well. The patient assumes the same starting point as the one-leg standing balance test and is asked to perform repetitive partial quarter to half squats with no other verbal cues. Similar deviations in the quality of the movement are assessed as in the one-leg standing balance test. A Trendelenburg posture, which may not be noted on standing balance, may be brought out with a single-leg squat. The patient may use their arms for balance or may go into an exaggerated flexed or rotated posture in order to put the gluteal or short rotator muscles on greater tension to compensate for other muscular weakness. Three-plane core testing is an attempt to quantify core control in the different planes of spine and core motion. Testing is done with the patient standing a given distance (usually 8 centimeters) away from a wall. They are asked to slowly extend backwards keeping

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their feet flat on the floor so that they just barely touch their head against the wall. Initially, this can be done with both legs on the ground and can then be progressed to partial weight-bearing on each side and ultimately to single-leg standing. Sagittal plane core strength testing creates eccentric activation in the abdominals, the quadriceps, and hip flexor muscles while creating concentric activation of the hip and spine extensors. Frontal plane testing is done by having the patient stand with one hip 8 centimeters away from a wall. While standing on the inside leg, they are asked to barely touch their inside shoulder to the wall. This test evaluates eccentric strength of the quadratus lumborum, hip abductors, and some long spinal muscles that are working in the frontal plane. Both sides are tested. Finally, transverse plane motion is tested by having the patient stand 8 centimeters away from a wall with their backs facing the wall. This is progressed similarly to the sagittal plane test—from bilateral weight bearing to single-leg stance while alternately touching one shoulder then the other barely against a wall. Quality of motion and speed can be assessed. With lesser degrees of core strength, there is a greater breakdown in the ability to maintain single-leg stance and the ability to just barely touch the wall. This test will assess transverse plane motions that incorporate abdominal muscles, hip rotators and spine extensors. Kibler believed that emphasis should be put on functional positions, motions, and muscle activation sequences instead of isolating specific joints or muscles. The function or dysfunction of core muscles could be approximated by evaluations that reproduce the three-planar motions that are used by the core to accomplish its functions.[1] The authors suggest that therapy can then be instituted based on the muscles and planes of motion that are found to be deficient. More research

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is needed to better understand the complex muscle activations and to establish normative data.

Evans et al state that all athletes who aim to optimize their performance and to minimize their risk of injury should incorporate multi-directional exercises into their training regimens.[13] This study had two parts. The purpose of part one of this study was to examine intra- and inter-rater reliability of the side bridge and trunk flexor endurance tests at 60° in 24 healthy subjects (16 males, 8 females). Two raters performed all measurements. Prior to data collection, the raters practiced using the test protocols to ensure that standardized procedures were employed. Both raters applied each test in random order on two occasions separated by two weeks. Measurements from the two raters were recorded on separate data collection forms to ensure that they were blinded to each other's results as well as to their own previous results. Inter-rater reliability values were high for all tests with intra-class correlation (ICC) scores ranging from 0.82 to 0.98.[13] Intra-rater reliability values were also high for all tests with ICC scores ranging from 0.81 to 0.95.[13] The purpose of part two of the study was to examine the performance of 79 elite athletes using the Biering-Sorensen, side bridge, and two trunk flexor endurance tests: the trunk flexor endurance test at 60° and the Ito trunk flexor test. Results can be found in Table 4. Performance on the right and left side bridge endurance tests were strongly correlated ($r=0.86$ and $p=0.01$), and the performance on the Biering-Sorensen test was significantly related to the LSB endurance time but with low correlation ($r=0.26$ and $p=0.01$). The relationship between RSB time and Biering-Sorensen time had a similarly low correlation ($r=0.20$ and $p=0.05$). Although the

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relationships between these tests were statistically significant, the results yield little clinical significance. No other significant relationships between the tests were found, and the authors concluded that no single endurance test provides information about trunk muscle endurance in all four planes.[13]

	All Athletes		Male Athletes		Female Athletes	
	n	**Mean (S.D.) (s)**	***n***	**Mean (S.D.) (s)**	***n***	**Mean (S.D.) (s)**
Biering-Sorensen	76	163.6 (50.7)	29	157.4 (42.9)	47	167.4 (55.0)
RSB	75	104.8 (44.1)	29	126.6 (44.9)	46	91.1 (38.0)*
LSB	77	103.0 (41.3)	30	121.2 (44.4)	47	91.4 (35.0)**
Trunk flexor	19	223.0 (134.4)	8	224.4 (128.0)	11	222.0 (145.1)
Ito trunk flexor	19	148.8 (97.7)	8	162.6 (116.5)	11	138.7 (86.1)

TABLE 4.[13] Mean hold times for five isometric trunk endurance tests performed by athletes. Tests where holding times were significantly lower for female athletes than male athletes are indicated by asterisks. RSB = right side bridge, LSB = left side bridge.
* p=0.000.
** p=0.002

Cowley et al explain that because of the complex interplay among the core musculature, fully assessing core stability is difficult by utilizing just one test.[19] Presently, isokinetic testing of trunk extensor and flexor strength is the standard measure of core stability in clinical sports medicine, primarily because it provides reliable data. However, these isokinetic tests require expensive and immovable machines, which is impractical for the clinical setting. As a result, there is a need for field tests that require little or no equipment, are fast to administer, and assess the various aspects of core stability. The purpose of this study was to design and to test the reliability of two new field tests of core stability: the plank to fatigue test (PFT) and the front abdominal power test (FAPT), both of which were designed to measure the endurance and power of the

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core musculature.[19] The preliminary study included eight subjects (five females and three males) and was conducted to test the reliability of trunk flexion strength (TFS), trunk extension strength (TES), trunk flexion work (TFW), trunk extension work (TEW), PFT, and FAPT and to make sure the testing protocol was reliable. The main study included 50 subjects (31 females and 19 males). TFS, TES, TFW, and TEW were assessed using a Cybex trunk extension and flexion dynamometer according to the protocol by Karatas.[19] The PFT was assessed in a prone plank position on the toes and elbows and required the subject to hold the position with a neutral back until fatigue. The FAPT required the subject to lay with their back on a mat, arms at their sides, and knees bent to 90°, where their feet were secured to the ground with an E-Z curl bar. Subjects raised their arms overhead, and a 2-kg medicine ball was placed in their hands. The subject then performed an explosive concentric contraction of the abdominal and hip flexor muscles while using their arms as a lever to project the medicine ball. The distance the ball traveled was measured and the subject was given three trials. All tests had excellent test-retest reliability. The ICC values were as follows: 0.93 for TES, 0.95 for TFS, 0.97 for TEW, 0.98 for TFW, 0.95 for FAPT, and 0.85 for PFT. The FAPT is a reliable test that can predict isokinetic flexion and extension strength, which allows appropriate comparison to normative data. The PFT was found to be unreliable for use when tested on a small sample size in a preliminary study and was therefore not included in the regression analysis.

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CHAPTER III: Methods

This study included 116 voluntary participants (40 males and 76 females) recruited from St. Catherine University and the surrounding community via flyers, e-mail announcements, and verbal announcements. As incentive for participation, each volunteer's name was entered into a drawing to win a gift card. Study approval was obtained from St. Catherine University's Institutional Review Board prior to subject recruitment and testing.

Healthy volunteers between the ages of 18 and 55 were recruited to participate in the study. In order to participate, the volunteer must be able follow directions and to perform the three core tests, which will be described later. Exclusion criteria included any history of back or abdominal surgery due to the musculature being injured by a procedure (excluding laparoscopic procedures), current back pain or injury, being pregnant or having delivered a child within the past year, being currently injured (neck, shoulder or lower extremity), and having a current or previous diagnosis of a neuromuscular condition including, but not limited to, multiple sclerosis, fibromyalgia, or Guillain-Barre.

Participants were asked to fill out a health history and exercise questionnaire (Appendix A). The questionnaire consisted of questions regarding age, sex, height, weight, smoking habits, types of exercise, frequency of exercise, level of athletic competition, and history of illnesses and injuries. In addition, the participant's body mass index (BMI) was calculated and waist circumference measurements were obtained. Prior to testing, the investigators clarified and confirmed all pertinent questions, including

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inclusion and exclusion criteria. Following completion of the intake form and interview, subjects performed a three-minute walk to warm up. The walk was performed at a comfortable, self-selected pace. After the warm up, subjects began testing. Three different core endurance tests were completed by each subject, with the order of the tests randomized for each subject. Each core endurance test was timed using a stopwatch until the participant was unable to control the test position or could hold the position no longer. A five-minute rest period was provided between each core endurance test. Subjects were observed for any adverse reactions and were instructed on the risk of muscle soreness following testing procedures.

Clinical Tests

Core endurance tests included the 60 degree flexion test, the Biering-Sorensen Extensor Endurance Test and the side plank test.[5,13,20] Testing was performed on standard or portable plinths. For each test, the subject was given a verbal explanation of the test, correct and incorrect positions were explained, and a demonstration of the testing position was provided if necessary. The subject was instructed to hold the position for as long as possible without deviating from the test position. Each test was timed using a stopwatch and ended when the subject could no longer hold the test position or deviated from the starting position. The raters provided no encouragement and did not reveal the subject's time until completion of the three clinical tests in order to decrease the variable of the participant's motivation or competitiveness. Each subject was timed by one of nine investigators involved in the collection of data. Data was collected and recorded in

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seconds.

60 Degree Flexion Test (Figure 1). The flexor endurance test was originally described in an article by McGill in 1999.[20] The test required subjects to sit on the test bench and place the upper body against a support with an angle of 60 degrees from the test bed. Both the knees and hips were flexed to 90 degrees. The arms were folded across the chest with the hands placed on the opposite shoulder and toes were placed under the toe strap. Subjects were instructed to maintain the body position while the supporting wedge was pulled back 10 centimeters to begin the test. The test ended when the upper body fell below the 60 degree angle.[20] Test re-test reliability was found to have ICC scores of 0.95-0.98, indicating excellent reliability.[20]

Biering-Sorensen Extension Test (Figure 2). For the trunk extension test, also known as the Biering-Sorensen test, participants were instructed to lie prone off the edge of a plinth with all body parts above their anterior superior iliac spines hanging off of the table.[13] Three straps were used to hold lower extremities onto the table: one at gluteal fold, one just above the knee joints, and one just above the ankles. Participants were allowed to rest their upper extremities on a chair prior to start. They were then instructed to cross their arms in front of their chest and to lift their upper body up until their trunk was horizontal to the ground. Time was started when the subject achieved the starting position. This position was held until fatigue or until their body deviated from horizontal, ending the test. The Biering-Sorensen test has been found to have good reliability with

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ICC scores greater than or equal to 0.77.[13]

Side Plank Test (Figure 3). While lying on their side on a plinth, participants were instructed to prop their body up while weight-bearing only on their elbow and their feet, which were stacked on top of one another. Participants were told that their body needed to stay in a straight line in all planes. Participants were timed on both sides, with the order of left and right self-selected by the participant. Time was started when the participant achieved the correct starting position. Time was stopped when the participant could no longer hold the position, if their body dropped out of alignment in the frontal plane, or if the pelvis rotated in the transverse plane. It has been discussed that the side plank, also known as the side support or side bridge test, optimally challenges the quadratus lumborum and the muscles of the anterolateral trunk wall.[13] In a study by McGill et al, intra-rater reliability was excellent with ICC scores greater than or equal to 0.97 for this test.[20]

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FIGURE 1. Testing position for the 60 degree flexion test.

FIGURE 2. Testing position for the extension endurance test.

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FIGURE 3. Testing position for the side plank test.

The raters received training on how to properly conduct testing that included proper set-up of equipment, when to stop the tests, and the script for instructing participants on proper form and technique. Intra-rater reliability was not assessed, as it was unnecessary because the clinical tests have demonstrated good inter-rater reliability in previous studies.[13,20]

Statistical Analysis

Our hypotheses included the following: (1) gender will have no effect on hold times; (2) exercisers will have longer hold times than non-exercisers; (3) those who incorporate specific core exercises will have longer hold times than those who do not; and (4) subjects with history of LBP, lower extremity, and/or upper extremity injury will

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have shorter hold times than those without a history of injury.

One-way analyses of variance (ANOVAs) were used to analyze each of the three tests as well as total time and were run separately with each of the following independent variables: gender (male/female), exercise (yes/no), run (yes/no), strength training (yes/no), core strength training (yes/no), history of being a competitive athlete (yes/no), history of LBP (yes/no), history of lower extremity injury (yes/no), and history of upper extremity injury (yes/no). Dependent variables included hold time in seconds for the side plank test, the Biering-Sorensen Extensor Endurance Test, and the 60 degree flexion test.

Comparisons were made for each of the 3 core endurance tests as well as for total time. These included: (1) male vs. female (2) exercisers vs. non-exercisers, (3) runners vs. non- runners, (4) strength trainers vs. non-strength trainers, (5) core exercisers vs. non-core exercisers, (6) history of being a competitive athlete vs. non-competitive or non-athlete, (7) history of LBP vs. no history of LBP, (8) history of lower extremity injury vs. no history of lower extremity injury, and (9) history of upper extremity injury vs. no history of upper extremity injury. These comparisons were selected in order to test our hypotheses and to determine which factors influence performance on the three core strength tests.

In order to determine which variables were the best predictors of hold times for each test and total time, a multiple regression analysis was run separately for each of the three tests and for total time. Independent variables included age, BMI, waist circumference, exercise time per week, and core exercise time per week. Multicollinearity was tested and was not found for the variables selected. These variables

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were selected based on results of significance in the one-way ANOVAs and the potential influence each factor has on health and muscle performance.

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CHAPTER IV: Results

Data was collected from 116 participants consisting of 76 females and 40 males. The average age of the participants was 28.8 years old with an age range of 19 to 55 years old. The descriptive statistics are depicted in Table 5, including age, BMI, waist circumference, minutes of weekly exercise, and minutes of weekly core exercise. The average BMI of the participants was 24.8 with a range of 18.6 to 43.5. The average waist circumference among the participants was 32 inches with a range of 22 to 55.5 inches. The average minutes of weekly exercise was 177.9, ranging from 0 to 930 minutes. Participants reported an average of 16.3 minutes of weekly core exercise with a range of 0 to 150 minutes. Statistical analysis was performed to determine the mean, standard deviation and range for hold time for each test individually and for all four tests combined. As depicted in Table 6, the average hold time for the flexion test was 160 seconds, with a range of 15-292 seconds. For the extension test the mean hold time was 101 seconds, with a hold time range of 17 to 592 second hold. The RSP mean hold time was 54 seconds ranging from 9 to 136 seconds. The LSP mean hold time was 55 seconds with a range of 2 to 139 seconds. The mean for the total hold time between all four tests was 370 seconds with a range of 63 to 871 seconds.

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	Mean (SD) N=116	Range	Female Mean (SD) N=76	Male Mean (SD) N=40
Age (years)	28.8 (9.64)	19-55	27.3 (8.7)	31.8 (10.7)
BMI	24.8 (4.14)	18.6-43.5	23.8 (3.6)	26.9 (4.4)
Waist (inches)	32 (4.73)	20-55.5	30.5 (3.8)	35.2 (4.8)
Weekly Exercise (minutes)	177.9 (150)	0-930	170.9 (148)	191.1 (126.5)
Weekly Core Ex (minutes)	16.3 (24.9)	0-150	15.5 (18.7)	17.8 (31.4)

TABLE 5. Descriptive Statistics.

	Mean (SD) (sec)	Range (sec)
Flex	160 (102)	15-292
Ext	101 (51)	17-592
RSP	54 (25)	9-136
LSP	55 (28)	2-139
Total Time	370 (161)	63-871

TABLE 6. Normative Values.

Analysis of Variance

An ANOVA was conducted for each of the four tests and for the total time of all four tests to determine differences between groups of patients. Dichotomous variables of gender, whether a participant engaged in regular exercise, core exercise, strength training, or running, a history of being a competitive athlete, a history of low back pain, a history of lower extremity injury, and a history of lower extremity injury were analyzed.

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Flexion Test

An ANOVA of the flexion test results revealed significant differences in the exercise, running, and competitive athlete categories. As seen in Table 7, a significant difference existed between participants who engaged in exercise and those who did not (p=0). Exercisers had a mean hold time of 167.7 seconds while non-exercisers had a hold time of 46.6 seconds. Runners vs. non-runners had significantly different hold times (p=0); runners had a mean of 179.8 seconds while non-runners had a mean of 125.2 seconds. Participants who were or are a competitive athlete had hold times that were significantly longer (p value=0.043) than participants who did not have a history of being a competitive athlete; these hold times were 167.7 seconds and 125.2 seconds respectively. The variable groups of gender, strength training, core exercise, low back pain, lower extremity injury, and upper extremity injury demonstrated no significant differences all with p values greater than 0.05. Figure 4 is a visual representation of the ANOVA results for the flexion test. An asterisk denotes a significant difference.

	F Ratio	Probability Level	Mean (sec)	Standard Deviation (sec)
Gender (F/M)	0.07	0.79	161.2/157.7	112.8/77.8
Exercise (Y/N) *	14.94	0	167.7/46.6	102/62.8
Run (Y/N) *	11.54	0	179.8/125.2	109.4/75.9
Strength Train (Y/N)	3.09	0.08	117.9/150.3	102.3/112
Core Exercise (Y/N)	1.37	0.25	166.2/153.2	100.9/103.3
Competitive Athlete (Y/N)*	4.17	0.04	167.7/125.2	106.2/70.2
LBP (Y/N)	0.02	0.88	157.8/161	78.1/108.5
LE Injury (Y/N)	3.12	0.08	178/153.7	84.4/106.8
UE Injury (Y/N)	0.22	0.64	136.9/162.9	65.6/105.3

TABLE 7. ANOVA Results for Flexion test.
* p<0.05 significant difference.

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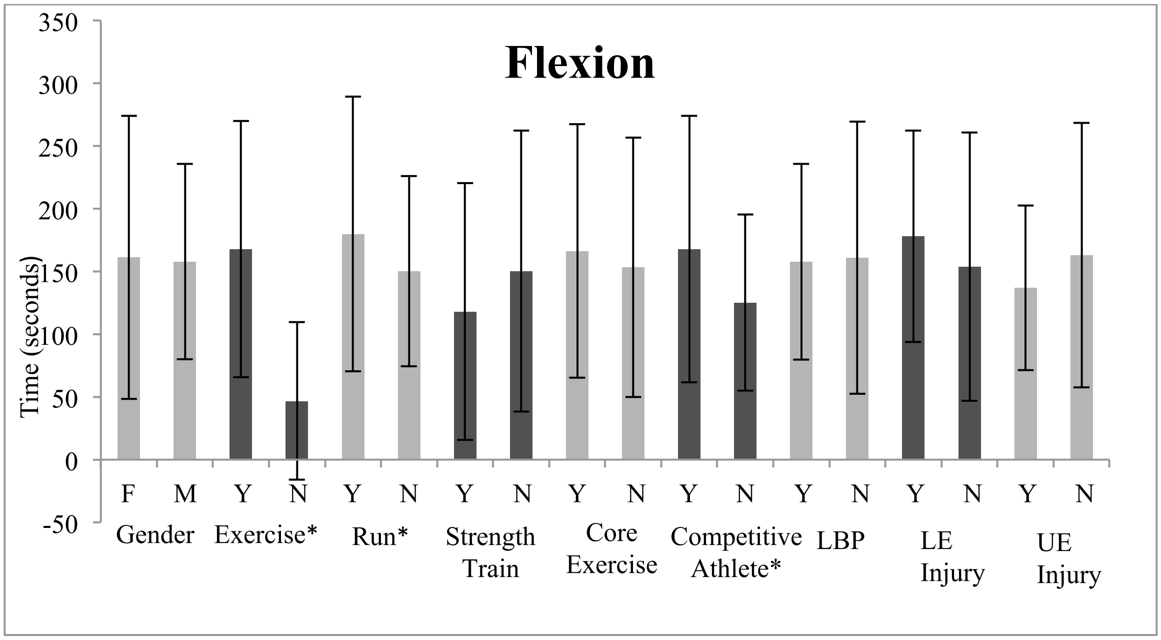

FIGURE 4. ANOVA Results of Flexion Test.
* p<0.05 significant difference.

Right Side Plank Test

Table 8 outlines the variables that were found to be significantly different by group for the RSP test. A significant difference between genders was observed with females averaging 46.8 seconds and males averaging 68.2 seconds. Exercises held the RSP significantly longer than non-exercisers, with means of 55.9 seconds and 38.1 seconds respectively. Runners had a significantly longer hold time, with a mean of 60 seconds while non-runners had a mean of 44 seconds. Participants who engaged in strength training held the position for significantly longer (61.8 seconds) than those who did not strength train (44.9 seconds). Participants that had a history of being a competitive athlete held the RSP longer than those with no history of competition in athletics. Competitive athletes (past/present) had a mean of 56.9 seconds, while those

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who did not had a mean of 41.9 seconds.

Variables without a significant difference between hold times included core exercise, low back injury, lower extremity injury, and upper extremity injury. Participants who performed core exercises regularly had a mean of 57.6 seconds while those who did not had a mean of 50.3 seconds. Subjects with a history of low back pain had a mean of 54.1 seconds; those who did not had a mean of 54.2 seconds. Those who reported a history of a lower extremity injury had a mean of 55.4 seconds while those who did not had a mean of 53.8 seconds. Participants who had a history of an upper extremity injury had a mean of 57.1 seconds while participants who did not had a history of 53.8 seconds. Figure 5 is a visual representation of the ANOVA results for the right side plank test, and significant difference is represented by an asterisk.

	F Ratio	Probability Level	Mean (sec)	Standard Deviation (sec)
Gender (F/M)*	22.08	0	46.8/68.2	21.7/26.2
Exercise (Y/N) *	5.05	0.03	55.9/38.1	25.4/19.1
Run (Y/N) *	11.49	0	60/44	24.5/24
Strength Train* (Y/N)	12.17	0	61.8/44.9	23.5/24.6
Core Exercise (Y/N)	2.43	0.12	57.6/50.3	25.5/24.9
Competitive Athlete* (Y/N)	6.27	0.01	56.9/41.9	25.7/20.4
LBP (Y/N)	0	0.99	54.1/54.2	20.6/26.8
LE Injury (Y/N)	0.09	0.77	55.4/53.8	28.6/24.3
UE Injury (Y/N)	0.19	0.66	57.1/53.8	27.6/25.2

TABLE 8. ANOVA Results for Right Side Plank.
* $p<0.05$ significant difference.

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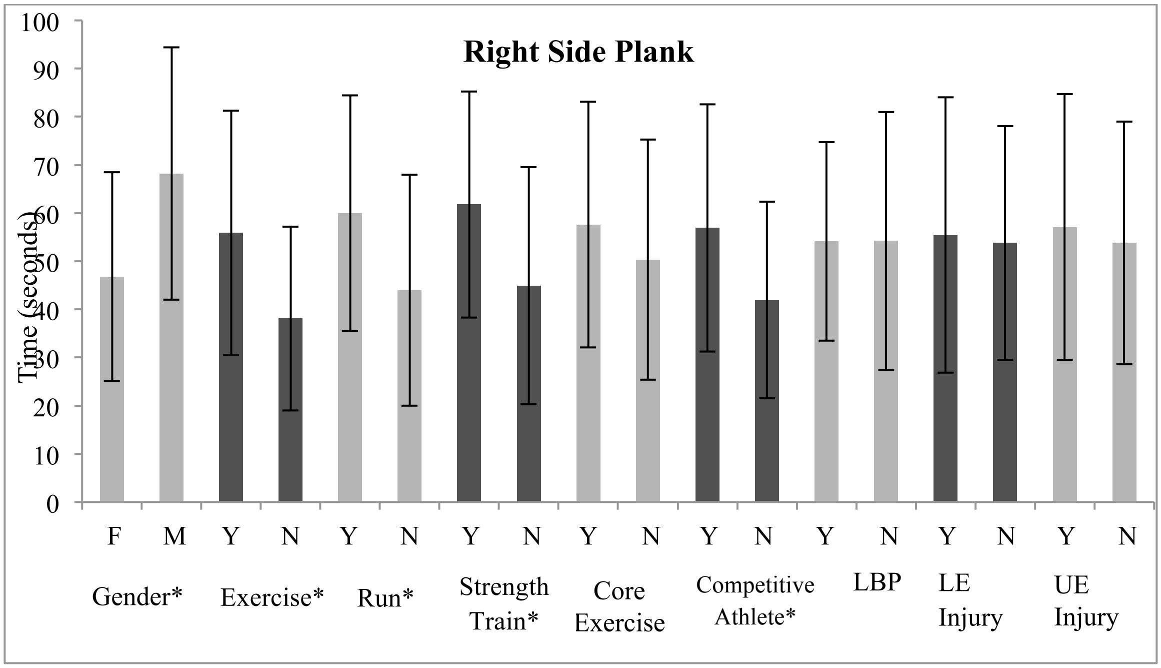

FIGURE 5. ANOVA Results of Right Side Plank.
* $p<0.05$ significant difference.

Left Side Plank Test

Significant differences for hold times on the LSP test, shown in Table 9, were found for gender, exercise, running, strength training, core exercise, and competitive athletes. Males held longer than females on the LSP test. Females had a mean of 47.5 seconds while males had a mean of 69.5 seconds. Exercisers had a mean of 57.3 seconds, which was significantly longer than non-exercisers who had a mean of 33.9 seconds. Runners held the test longer than non-runners. Runners had a mean of 60.5 seconds while non-runners had a mean of 45.5 seconds. People that engaged in strength training had a mean of 63.8 seconds, which was significantly longer compared to those who did not strength train who had a mean of 42.6 seconds. Core exercisers were able to hold for the test longer than people who did not perform core exercises. Core exercisers had a

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mean of 61.2 seconds, and people who did not do core exercises had a mean of 48.3 seconds. People who had a history of being a competitive athlete had a longer hold time with a mean of 58 seconds compared to those who did not, who had a mean of 42 seconds.

The variables with no significant differences between hold times for the LSP test included participants with a history of low back, lower extremity, or upper extremity injuries. Participants with a history of low back pain had a mean of 60.2 seconds while those who did not had a mean of 53.9 seconds. Participants who reported having a lower extremity injury had a mean of 59.1 seconds while the participant group that did not had a mean of 53.7 seconds. Participants that reported an upper extremity injury held for a mean of 28.7 seconds while those who did not report an upper extremity injury had a mean of 27.8 seconds. The ANOVA results for the LSP test are shown in Figure 6, and an asterisk denotes statistically significant data.

	F Ratio	Probability Level	Mean (sec)	Standard Deviation (sec)
Gender (F/M)*	18.7	0	47.5/69.5	25.4/27.4
Exercise (Y/N) *	7.31	0.01	57.3/33.9	28.1/17.4
Run (Y/N) *	8.12	0.01	60.5/45.5	27.4/26.9
Strength Train* (Y/N)	15.1	0	63.8/42.6	28.1/24.2
Core Exercise *(Y/N)	6.31	0.01	61.2/48.3	28.9/25.6
Competitive Athlete* (Y/N)	5.86	0.02	58/42	28/23.7
LBP (Y/N)	1.22	0.27	60.2/53.9	26.2/28.6
LE Injury (Y/N)	0.82	0.37	59.1/53.7	28.7/27.8
UE Injury (Y/N)	0.01	0.94	55.6/55	28.5/28.1

TABLE 9. ANOVA Results for Left Side Plank.
* $p<0.05$ significant difference.

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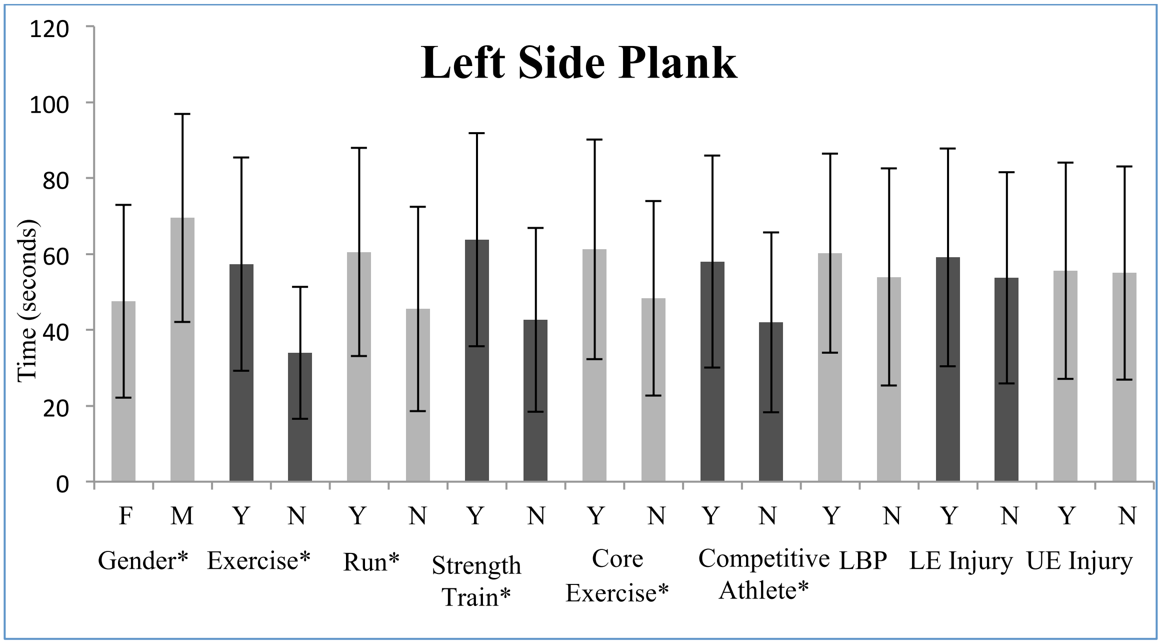

FIGURE 6. ANOVA Results of Left Side Plank.
* p<0.05 significant difference.

Extension Test

For the Extension test, no significant differences were found for any variable groups on hold times, as shown in Table 10. Females had a mean of 103.9 seconds while males had a mean of 95.6 seconds. Exercisers had a mean of 102.8 seconds and non-exercisers had a mean of 83.7 seconds. Runners had a mean of 103.1 seconds while non-runners had a mean of 97.3 seconds. Participants who strength train had a mean of 98.4 seconds, and those who did not had a mean of 101.8 seconds. Participants who engaged in core exercises had a mean of 101.9 seconds while those who did not had a mean of 100.1 seconds. Competitive athletes had a mean of 101 seconds while those who did not have a history of being a competitive athlete had a mean of 101.1 seconds. Participants with a history of low back pain had a mean of 115.2 seconds, and those who did not have

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a history of low back pain had a mean of 96.5 seconds. Participants who reported a history of a lower extremity injury had a mean of 108.2 seconds while those who did not report a lower extremity injury had a mean of 98.5 seconds. Participants with a history of an upper extremity injury had a mean of 104.6 seconds; participants with no history of an upper extremity injury had a mean of 100.6 seconds. A visual representation of the ANOVA results for the extension test are shown in Figure 7.

	F Ratio	Probability Level	Mean (sec)	Standard Deviation (sec)
Gender (F/M)	0.7	0.41	103.9/95.6	53.6/45.4
Exercise (Y/N)	1.41	0.24	102.8/83.7	48.7/68.7
Run (Y/N)	0.35	0.55	103.1/97.3	42.7/63.2
Strength Train (Y/N)	0.11	0.74	98.4/101.8	40.5/66.8
Core Exercise (Y/N)	0.04	0.85	101.9/100.1	40.3/60.9
Competitive Athlete (Y/N)	0	0.99	101/101.1	47.7/64.7
LBP (Y/N)	2.9	0.09	115.2/96.5	50.6/50.4
LE Injury (Y/N)	0.8	0.37	108.2/98.5	53.7/50
UE Injury (Y/N)	0.07	0.79	104.6/100.6	56.3/50.4

TABLE 10. ANOVA Results for Extension test.
* $p<0.05$ significant difference.

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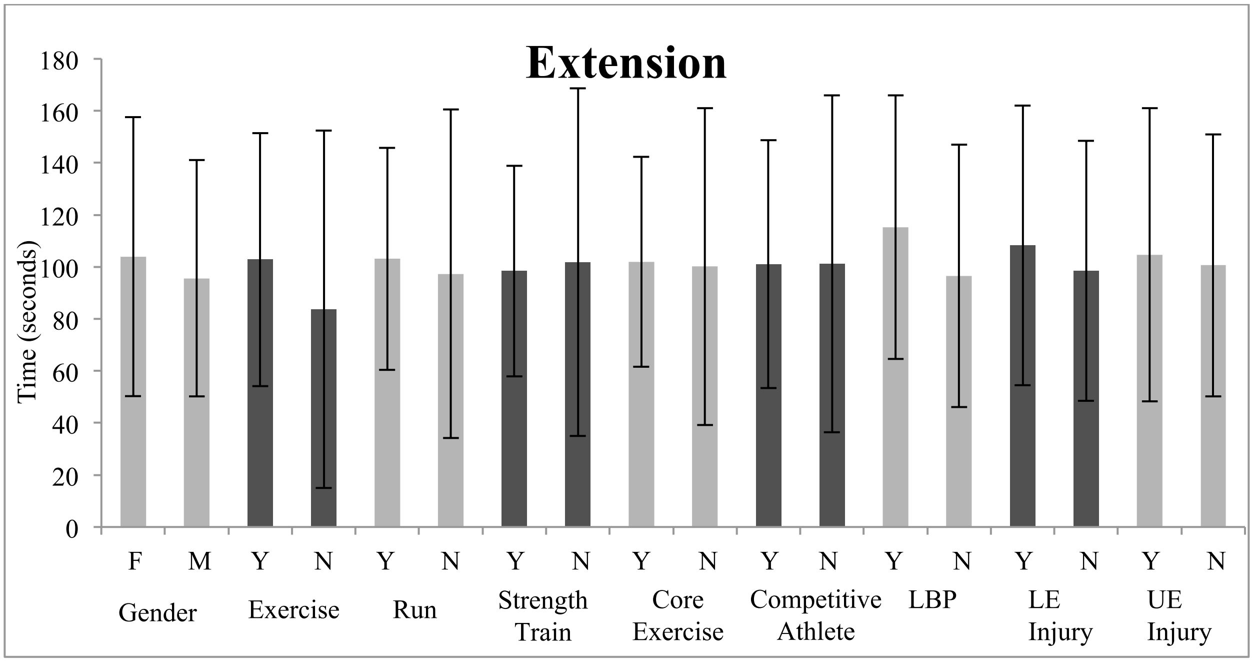

FIGURE 7. ANOVA Results of Extension.
* $p<0.05$ significant difference.

Total Time

Variable groups with significant difference for total hold time of all four tests included exercise, running, and competitive athletes, shown in Table 11. Exercisers had a mean of 383.7 seconds, which was significantly longer than non-exercisers, who had a mean of 242.4 seconds. Runners held longer than non-runners for the total hold time of all four tests. Runners had a mean of 403.6 seconds and non-runners had a mean of 312 seconds. Competitive athletes had a hold time that was trending toward a significantly longer hold time than people without a history of being a competitive athlete. Competitive athletes had a mean of 383.6 seconds while people without a history of being a competitive athlete had a mean of 310.2 seconds.

Variable groups with no significant difference for the total time of all four tests

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were gender, strength training, core exercise, low back pain, lower extremity injury, and upper extremity injury. Females had a mean of 359.4 seconds while males had a mean of 391 seconds. Participants who engaged in strength training had a mean of 395.9 seconds while those who did not had a mean of 339.6 seconds. Core exercisers had a mean of 386.8 seconds; participants who did not perform core exercises had a mean of 351.9 seconds. Participants who reported a history of low back pain had a mean of 386.3 seconds, and those who did not had a mean of 365.2 seconds. Participants that reported a history of a lower extremity injury had a mean of 400.6 seconds; participants that did not report a lower extremity injury had a mean of 359.7 seconds. Participants with a history of an upper extremity injury had a mean of 354.2 seconds, and those who did not had a mean of 372.3 seconds. ANOVA results for the total time of all tests are represented in Figure 8. An asterisk represents statistically significant results, and a double asterisk represents a trend.

	F Ratio	Probability Level	Mean (sec)	Standard Deviation (sec)
Gender (F/M)	1.01	0.32	359.4/391	170.3/141
Exercise (Y/N) *	8.15	0.01	383.7/242.4	157.1/147.5
Run (Y/N) *	9.24	0.00	403.6/312	155/157
Strength Train (Y/N)	2.75	0.10	395.9/339.6	143/199.2
Core Exercise (Y/N)	1.36	0.25	386.8/351.9	143.7/177.9
Competitive Athlete (Y/N)**	3.65	0.06	383.6/310.2	159.4/158.2
LBP (Y/N)	0.36	0.55	386.3/365.2	135.5/168.7
LE Injury (Y/N)	1.44	0.23	400.6/359.7	137.6/167.9
UE Injury (Y/N)	0.15	0.70	354.2/372.3	147.5/163.2

TABLE 11. ANOVA Results for Total Time.
* $p<0.05$ significant difference.
** $p<0.08$ trending significance.

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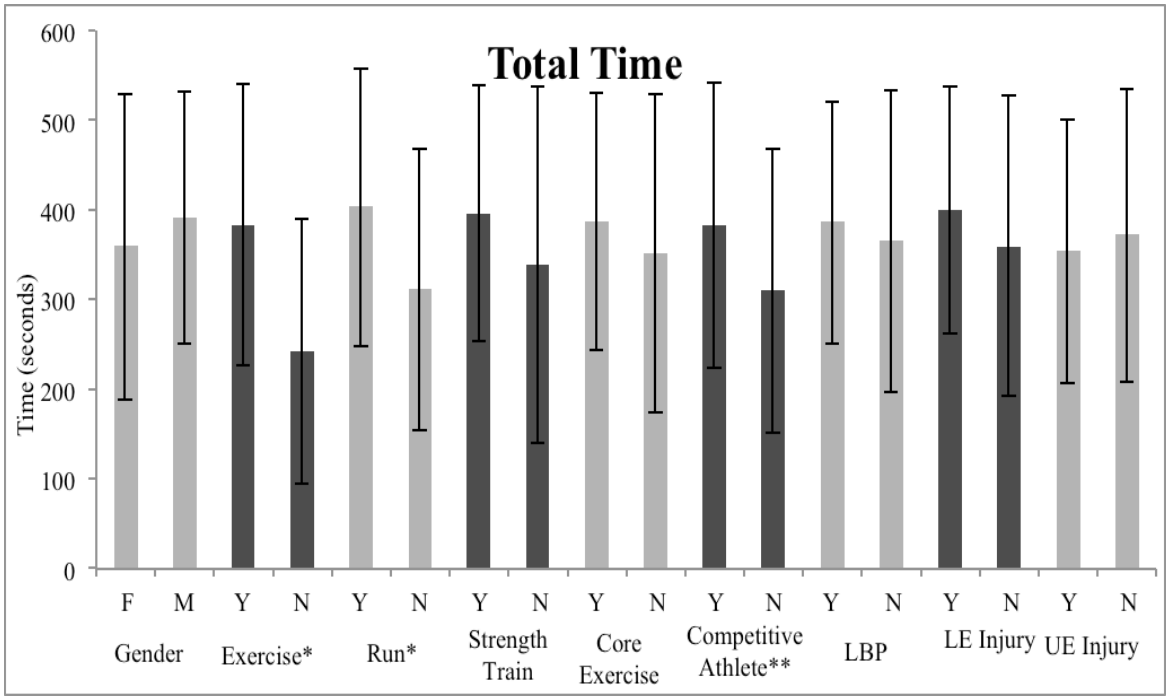

FIGURE 8. ANOVA Results of Total Time.
* p<0.05 significant difference.
** p<0.08 trending significance.

Multivariate Analysis

Multiple regression was conducted to determine the overall prediction model and the most influential predictors for each individual test and total test time. The variables – included in the model were: age, BMI, core exercise duration, exercise duration, and waist circumference. The overall model was significant for each test and total hold time as indicated by the p values in Table 12.

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	Flexion	Right Side Plank	Left Side Plank	Extension	Total Time
Overall Model	p= 0.00	p= 0.01	p= 0.00	p= 0.00	p= 0.00
Age	p=0.36	p=0.69	p=0.17	p=0.03*	p=0.16
BMI	p=0.74	p=0.13	p=0.55	p=0.41	p=0.54
Core Exercise Time	p=0.95	p=0.15	p=0.05*	p=0.94	p=0.64
Exercise Time	p=0.00*	p=0.02*	p=0.02*	p=0.58	p=0.01*
Waist Circumference	p=0.05	p=0.83	p=0.37	p=0.00*	p=0.06

TABLE 12. Multiple Regression of variables.
* p<0.05 significant difference.

Significant Predictors

The significant predictors included exercise duration for flexion test (Flex), exercise duration for RSP, exercise and core exercise duration for LSP, age and waist circumference for extension (Ext), and exercise for total time for all four tests (Total). These results can be found in Table 13. Waist circumference also had a trending significance for total time with a p value of 0.06.

	Flex	RSP	LSP	Ext	Total
Significant Predictor(s)	Exercise p=0.00	Exercise p=0.02	Core p=0.05 Exercise p=0.02	Age p=0.03 Waist p =0.00	Exercise p=0.01 Waist p =0.06**

TABLE 13. Significant Predictors.
** p<0.08 trending significance

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CHAPTER V: Discussion

This study sought to establish normative data for three clinical core endurance tests; flexion, extension and right/left side plank. In order to achieve this, the researchers explored the effect of age, gender, injury, history of injury, athletic experience, and level of exercise involvement. They hypothesized that gender would have an effect on hold times, that exercisers would have longer hold times than non-exercisers, that exercisers who targeted core musculature would have longer hold times than those who did not, and that subjects who had a history of LBP or an extremity injury would have decreased hold times. The hope was to tease out objective values or cutoff scores for clinical prediction, similar to those utilized with the Timed Up and Go to identify patients at increased risk for falls.

The results revealed that each core test was affected by different variables. An individual's ability to hold the flexion position was not significantly influenced by gender, but revealed longer hold times for individuals who participated in general exercise, are runners, and had current or previous experience as a competitive athlete. These results are supported by the findings of Evans et al who found no differences between gender for the flexion or extension tests.[13] In contrast, the findings of McGill demonstrated that women had longer hold times in the extension position while our research revealed no significant difference in extension hold times for gender or any other variable.[20] A review article by Demoulin hypothesized that discrepancies in the literature regarding gender could be attributed to several theories.[4] The first theory was based on a female's tendency to have lower mass on average of their upper body versus

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males. The second was based on the trend in females to have a lower center of gravity as compared to males. Finally, the third theory is based on the increased lordosis found more often in females than males, which Demoulin argued may give them the benefit of a decreased lever arm for the erector spinae during extension.[4] The results of this study show no difference between gender, yet reveal significantly longer hold times for those who were physically active. This may indicate that current or previous physical activity is more influential in yielding longer hold times for the flexion and extension positions than gender. Therefore, one could postulate that engaging the core during physical activity may affect core endurance more than the anatomical differences that commonly distinguish genders. Ultimately, these results are inconsistent with McGill's findings, but are consistent with the ideas of Evans et al.

Results from the side plank tests highlighted the greatest differences between groups in our study. LSP demonstrated longer hold times for males, individuals who had participated in core strengthening, those with previous and/or current experience as a competitive athlete, runners more so than non-runners, general exercisers more so than those who did not regularly exercise, and those who strength-trained versus those who did not participate in a strength training program. Similarly, our RSP results revealed longer hold times for males, those with a history of being a competitive athlete compared to those with no competitive history, runners versus non-runners, general exercisers versus non-exercisers, and those who strength-trained versus those who did not. The findings of Leetun et al found that males performed better on the extension and side plank tests.[10] Similar to the flexion test, these results seem to indicate the value of

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physical activity in increased hold times for the side plank test. The gender difference of males having longer hold times is consistent with the results of Leetun et al. These results could indicate that males benefit from differences between gender, such as greater hip abduction and upper body strength. Additionally, the average anatomical male structure of broader shoulders and narrower hips versus females who tend to carry the majority of their weight in their hip and thigh region may contribute to better hold times for the side plank test. The male structure might allow males to have the majority of their weight closer to their shoulders allowing for a decreased lever arm, whereas females will have the majority of their weight at a longer distance from their shoulders, increasing the burden on the core musculature to act as a stabilizing force in the side plank position.

When we combined the total hold time for all three tests, we also did not find any difference between men and women, but did see longer hold times for regular exercisers and runners. Although not significant, it is worth noting a trend we identified where individuals with experience as competitive athletes also demonstrated greater total hold times of all three tests. These findings are inconsistent with the study by Sharrock et al, which found no correlation between athletic ability and core strength.[17] One could argue that these inconsistencies suggest that if one qualifies as a competitive athlete it is does not mean they are physically fit or athletically capable. In order to further discern the value of these findings, the definition of what qualifies as an athlete should be described as the physical demands from sport to sport can vary dramatically.

The results of this study are able to show normative data, however it is limited for a variety of reasons. These reasons are the limited age range, small sample size, and

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uneven gender distribution. In order to further discern normative data the researchers would have increased the *n* substantially. In addition, the population was uneven in terms of gender distribution and would benefit from a greater proportion of male participants. Another limitation was the average age of our participants. While there was a wide age range of 18-55 years, the mean age of the subjects was 28.8 years, median 25 years, and mode 24 years. This lower mean, median, and mode in age skewed the data toward hold times more indicative of a young healthy population than the clinical population the researchers sought to identify. Finally there was a large proportion of participants who self-identified as regular exercisers compared to those who did not exercise on a regular basis (105/11), and/or had experience as a competitive athlete compared to those with no such experience (95/21). This uneven representation may have altered the results to signify a healthier population than the researchers had desired to test.

The hypotheses prior to data collection predicted that gender would have no effect on core endurance test hold times, which was found to be true for the extension and flexion tests but not for LSP and RSP, where males had greater hold times than females. It was also predicted that exercisers would have longer hold times than non-exercisers, which was found to be accurate for Flexion, LSP, and RSP, but not for extension. In addition, it was hypothesized that exercisers who specifically targeted core musculature in their workouts would have longer hold times than those who did not and our results indicated this was only true for LSP. Finally, the researchers predicted that subjects with a history of LBP, lower extremity injury, or upper extremity injury would have decreased hold times, and the findings revealed no differences. One could surmise that these results

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are potentially due to lack of power representing subjects with LBP, upper and lower extremity injuries, non-exercisers, and non-athletes.

Limitations

Before attempting further research on this subject the researchers would make several suggestions on how to potentially improve the reliability and validity of our findings. First they would attempt to compile a larger *n*. In addition, this sample would be more representative of a clinical population by attempting to obtain a more even age distribution, gender distribution, and by increasing the representation of sedentary subjects in the sample. Finally, they would assess inter-rater reliability of their testers prior to data collection. Even though the inter-rater reliability of these tests is already well documented, documenting specific testers may be beneficial to the consistency of the methods.

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CHAPTER VI: Conclusion

The results of this study suggest that physical activity has the greatest effect on core strength and endurance and that gender has a minimal effect as measured by these clinical tests. Males had greater hold times for right and left side plank than females, but no difference was found for the flexion or extension tests. General exercise revealed greater hold times for all but the extension test, while core-specific exercise only had an effect on LSP. Finally, injury had no effect on hold times in this study. Based on the results, we succeeded in establishing normative data for males and females; however, due to the skewed distribution of age we did not establish normative values for different age groups. The researchers suggest further research must be done taking into account the need for a larger sample size that is more representative of a true clinical population. However, based on the results of increased hold times for exercisers and those with previous and/or current athletic experience one could expect to see improvements in core strength with physical activity.

The researchers propose that physical activity may engage the core to a larger degree than specific core exercises. With movement, the body is challenged to move in all planes of motion forcing it to engage dynamically and throughout the length of activity. One could argue that a 20-minute run could assist with building core endurance more so than a focused 5-minute abdominal session. With running, the core is required to be engaged for a prolonged period of time versus small bursts of 1-2 minute core strengthening exercises. Therefore, general exercise or physical activity in the healthy population may increase core endurance and prevent injury.

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APPENDIX A

Subject Intake Form

Subject ID Number:________________________________

Gender: Male Female

Age:________________

Height: ....feet ....inches

Weight: _____________

BMI: _______________ (calculated from height and weight by investigator)

Waist Circumference: ....inches

Currently smoke tobacco? Yes No

Do you normally exercise beyond your typical daily activities and chores?

Yes (if yes, go to next three questions) No

On average, how many minutes per week do you exercise or do physical activity of a moderate or vigorous intensity?

................min

What types of activities do you do (check all that apply):

Run_____ Bike_____ Swim_____ Elliptical_____ Rowing_____

Classes_____ Strength Training_____ Other________________

Core Exercises_____(if yes, time of session and number of sessions per week______________)

Are you or have you been a competitive athlete? Yes No

If yes, in what sport?__________________________

What level? High School College Club Professional

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History of Illness: (please circle all that apply)

Arthritis	Broken Bones	Circulation/Vascular Problems	Low Back Pain
Neck Pain	Blood Disorders	Pregnancy	Heart Problems
High blood Pressure	Lung Problems	Cancer	Diabetes
Head Injury	Thyroid Problems	Lower Extremity Injury	Seizures/Epilepsy
Allergies	Skin Diseases	Upper Extremity Injury	Kidney Problems
Ulcers/Stomach Problems	Other_______________		

For all items circled above, please include if illness or injury is current or previous, and any treatment received for the condition. ____

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