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CORE STRENGTH TESTING: DEVELOPING NORMATIVE DATA FOR THREE
CLINICAL TESTS

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ABSTRACT

Background/Purpose: Research suggests that core endurance is related to function and injury. Core endurance tests are commonly used in the clinic and yet limited data about normative values exist. This study aims to establish normative values and assess the effect of specific variables on these values in adults 18-55 years old for three clinical core endurance tests.

Subjects/Methods: Fifty-five subjects, 20 male and 35 female with a mean age of 29 participated in this study. Subjects were required to complete a general health and exercise history questionnaire. Each subject was then randomly assigned a test order and tested by one of four student researchers. The core endurance tests performed were right side plank (RSP), left side plank (LSP), 60 degree flexion test (FI) and trunk extensor (Ext) endurance test.

Analyses/Results: Analyses included one-way ANOVA and multiple regression to determine where differences existed between groups and to understand what variables influenced test outcomes. Significant results existed for the following variables: gender M/F (RSP $p=.002$, LSP $p=.003$), exercise Y/N (Ext $p=.02$, FI $p=.003$), active runners Y/N (RSP $p=.03$ FI $p=.0002$), strength training Y/N (RSP $p=.03$, LSP $p=.02$), core exercise Y/N (LSP $p=.02$), previous and/or current competitive athletes Y/N (Ext $p=.045$, RSP $p=.01$, FI $p=.01$) and lower extremity injury Y/N (Ext $p=.03$). Multiple regression revealed exercise time was the most significant predictor of RSP ($p=.01$) and core exercise time and overall exercise time were highest predictors of LSP ($p=.001$).

Conclusion: Our results suggest that gender and exercise play a significant role in core endurance. Data suggests regular general exercise and strength training may have a stronger correlation with increased overall core endurance than participating in exercises specific to the core musculature.

Implications: Normative values about these core endurance tests can be used in clinical practice to assess core endurance in the general population.

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

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CHAPTER I

INTRODUCTION

Core strength and endurance have been linked to function and to injury of the back and extremities in the literature.^{1,2,3,4} Delays in core muscle activation, decreased muscle recruitment, neuromuscular imbalance, impaired proprioception, and delayed reflex responses have all been shown to have an impact on risk for injury.¹ Fatigue of these muscles may also be a factor contributing to injuries, especially in the athletic population.⁵

The core is described as a muscular box and the center of the kinetic chain, consisting of 29 pairs of muscles of the abdominals and lower back.^{6,7} The core produces increased stability with contraction of superficial and deep muscles, made up of both slow and fast twitch muscles.⁸ Three interacting systems make up what is referred to as the core: the active system which includes the muscles; passive system made up of ligaments, fascia, and bones; and the neuromuscular system, the nervous system component that provides the sensory and proprioceptive input.⁷

Core endurance tests exist but are not commonly used in the clinic, as limited data exists for interpreting the results of these tests. Clinical tests of core endurance have proven valid and reliable in multiple investigations; however, no generalizable normative data for these tests has been published.^{9,10,11} Without this normative data, clinical testing of core strength is meaningless as there is no way of knowing what a “normal” result would be. It is impossible to know how a

person's core endurance compares to the general population without established norms and thus, difficult to determine the risk a patient may have in developing an injury due to core weakness.^{9,10,11}

There is an abundance of research on the core musculature including activation patterns studied through EMG,^{12,13,14,15,16,17,18} the involvement of the core in injury processes,^{1,2,3,4} as well as various ways to test muscle strength^{9,10,11} and endurance in a clinical setting⁹ and the best exercises to maximize activation of these muscles.^{14,15,16,17,18} The importance of the core musculature in all body movements has been established and the increased risk of injury in those with poor core control or activation patterns well documented.^{3,4,5,19}

Core strength tests included in this investigation are the right and left side plank test, the 60 degree flexion test, and the Biering-Sorensen Extensor Endurance Test. Due to the multi-directional nature of the core musculature, it is important to utilize several tests in multiple planes to get a clear picture of core function. The tests selected for this study provide a three dimensional look at the core. Having normative values for these simple clinical tests will be beneficial in determining risk for injury without invasive and time-consuming EMG testing. The purpose of this study is to establish normative values in adults 18-55 years of age for three different clinical tests of core endurance. Differences in gender, age, history of injuries, and exercise habits will also be explored.

CHAPTER II

REVIEW OF LITERATURE

Core Definition

The core has been described in the literature as being the center of the kinetic chain and culpable in many common injuries seen in physical therapy clinics.⁶ It includes the abdominal musculature- rectus abdominis, internal and external obliques, and transversus abdominis; the paraspinal muscles- erector spinae, multifidus, rotatores, and semispinalis; back musculature- quadratus lumborum and latissimus dorsi; the diaphragm, pelvic floor, and sometimes the gluteals- maximus, medius, and minimus. For the purpose of this study, we will define the core as including the 29 pairs of muscles that compose the abdominals and lower back. Spine stability can be broken into three interacting systems which include the active system, the passive system, and neuromuscular system.⁷ The active subsystem of the core can be divided into global superficial muscles, such as quadratus lumborum and rectus abdominis, and deep stabilizing muscles, which include transversus abdominis and multifidus. The ligaments, bone, and fascia are considered the passive subsystem of the core. The neuromuscular system is made up of sensory and proprioceptive input from this area of the body. Sensory input is important to alert the central nervous system to changes in the environment and allow the body to refine movement. The musculature of the core stabilizes the spine in order to allow the spine to except loading forces. Without these core muscles,

the spine would be unable to withstand as little as 90N of compressive force which is less than total upper body weight.²⁰ Coordination of the deep and superficial muscles of the core allow for the greatest amount of spinal stabilization. See Table 1.

Muscle	System	Function	Muscle Fiber Type	Attachments
Rectus Abdominis	Global/ Superficial	Trunk Flexion	Fast Twitch	Proximal: Ribs 5-7, xiphoid process Distal: Pubic symphysis
Internal Obliques	Deep Stabilizer	Trunk Flexion, Rotation and Lateral Flexion	Slow Twitch	Proximal: Ribs 10-12, rectus sheath Distal: Iliac crest, Thoracolumbar fascia
External Obliques	Global/ Superficial	Trunk Flexion, Rotation and Lateral Flexion	Fast Twitch	Proximal: Lower 8 ribs Distal: Abdominal aponeurosis, iliac crest
Transversus Abdominis	Deep Stabilizer	Compresses Abdomen	Slow Twitch	Proximal: Ribs 7-12 Distal: Abdominal aponeurosis, pubic bone, thoracolumbar fascia
Multifidus	Deep Stabilizer	Stabilize Spine	Slow Twitch	Proximal: Spinous processes 1-2 levels above Distal: Sacrum, transverse processes
Rotatores	Deep Stabilizer	Stabilize Spine	Slow Twitch	Proximal: Spinous processes 1-2 levels above Distal: Transverse processes
Semispinalis	Deep	Stabilize Spine	Slow	Proximal: Spinous

	Stabilizer		Twitch	processes multiple levels above Distal: Transverse processes
Quadratus Lumborum	Global/ Superficial	Side Flexion/ Rotation	Fast Twitch	Proximal: Transverse processes L1-L4, 12th rib Distal: Iliac crest
Latissimus Dorsi	Global/ Superficial	Shoulder Adduction, Extension and Internal Rotation	Fast Twitch	Proximal: Spine T7 to Sacrum, Iliac crest, Lower ribs Distal: Floor of bicipital groove
Pelvic Floor -Levator ani -Coccygeus	Deep Stabilizer	Forms pelvic diaphragm that support pelvic viscera, increases intra-abdominal pressure and flexes coccyx	Slow Twitch	Proximal: Body of pubis, tendinous arch of obturator fascia, ischial spine Distal: Perineal body, coccyx, anococcygeal ligament, wall of prostate or vagina, rectum and anal canal Proximal: Ischial spine Distal: Inferior end of sacrum and coccyx
Diaphragm		Respiration		Proximal: Inner surface of ribs 6-12, costal margins, xiphoid process, Distal: L1-L3 vertebrae, central tendon

Table 1: Core muscles, system, function, fiber type, and attachments.

Core Function

Electromyography (EMG) has been used to study activation patterns of the core musculature to learn more about the function of these muscles during activity.^{12,13,14,15,16,17,18} Two types of EMG may be used; surface or intramuscular. Surface EMG is less invasive and uses electrodes placed over the skin. Intramuscular EMG may be more precise but requires insertion into the muscle itself to pick up electrical activity. Surface EMG has been shown to be less accurate due to the fact that it is not inserted directly into a specific muscle, has increased signal noise and is limited to superficial muscles.¹² Also, other muscles may be activated along with the muscle being targeted, which is termed cross talk.

The core is described as a muscular box that is composed of both fast-twitch and slow-twitch muscle fibers.⁸ The bottom of the box is the pelvic floor, the top is the diaphragm, the front are the abdominals and the back is the paraspinals and gluteals. Deep stabilizing muscles include the transversus abdominis, multifidi, internal oblique, deep transversoparaspinalis and pelvic floor muscles which are primarily made up of slow-twitch fibers. These muscles respond to changes in posture, external loading, and spinal intersegmental movement due to the short length of the muscles. Fast-twitch fibers are located in the global superficial muscles such as erector spinae, quadratus lumborum, rectus abdominis and external oblique. Each of these muscles is long in length and able to generate large movements and torque based on the large lever arm. Co-contraction of the internal oblique and transverse abdominis increases

intra-abdominal pressure and increases stiffness in the spinal segments. It only takes 5-10% of maximal abdominal and multifidi contraction to stiffen the spine. The diaphragm, which acts as the superior border of the core contracts and causes a further increase in intra-abdominal pressure adding to spinal stability.⁸

Abdominal muscle activation patterns have been studied by Stokes et al. using a biomechanical model of the spine and its musculature.¹² A computer generated model of the spine was used since instability of the spine cannot be studied in living subjects. The goal of this study was to determine the stability of the spine given different abdominal activation patterns and stress on the spine. One hundred and eleven pairs of muscles were incorporated into the model including the psoas, internal and external oblique, transverse abdominis and rectus abdominis. This biomechanical model allowed the spine to be loaded with flexion, extension, lateral side bending or axial rotation. The load started at 20 Nm and increased by 20 Nm each trial with a maximum of 60 Nm. A Newton meter (Nm) is a unit of torque resulting from the force of one Newton applied perpendicularly to a one meter long moment arm. Similarly, the intra-abdominal pressure was increased in increments of 5 from 5 kPa to 10 kPa. A kilopascal (kPa) is equal to 1,000 pascals which is a measurement of force per area which is one Newton per meter squared. Abdominal muscle activation patterns were investigated by controlling the amount of maximal activation of the transverse abdominis, internal and external oblique, and rectus abdominis. Each muscular group, transverse abdominis, internal and external obliques, or rectus abdominis

was activated 10% and 20% with all four effort directions of the spine. The transverse abdominis and obliques were found to need only 10% activation to increase spinal stability, whereas the rectus abdominis actually weakened the spine. Forced muscle effort with lateral bending and extension resulted in increased spinal stability, but decreased stability with flexion and axial rotation. Main results of this study found that spinal stability was 1.8 times greater at 10 kPa intra-abdominal pressure than 5 kPa. Therefore, higher intra-abdominal pressure results in increased spinal stability. Limitations to this study are as follows: the model was only able to reproduce three pure movements of the spine whereas in reality, the spine is able to move in infinite number of ways and the model is static and unable to replicate the variations in core musculature sequencing.¹²

Transversus abdominis has been found to participate in anticipatory postural control, intersegmental stabilization of the spine and unloading of the spine. Bjerkefors et al. explored this statement by testing to see if commonly used core stabilization exercises were in fact activating the transversus abdominis.¹³ Nine healthy women participated in this study with a mean age of 27 ± 6 years. EMG activity was recorded using intramuscular electrodes, which were inserted into the transversus abdominis bilaterally, as well as the rectus abdominis bilaterally. Patients performed five exercises routinely used in a core program with and without instruction to hollow during the exercise. "Hollowing" was achieved with these instructions, "Breath in and out. Gently and slowly draw

in your lower abdomen below your navel without moving your upper stomach, back or pelvis.” The exercises included: bridging, bridging with right leg lift, crook lying with right leg lift, four point kneeling with straight right leg lifted horizontally and four point kneeling with right leg and left arm lift. Significant results included interaction between instruction and left transversus abdominis ($p=0.042$); between instruction to hollow and transversus abdominis activity versus rectus abdominis activity; and between muscle, side and exercise ($p=0.007$).¹³ The transverse abdominis was found to have three times greater activation with simple instructions to hollow compared to the rectus abdominis which did not increase. This study concluded that healthy patients are easily able to activate the transversus abdominis muscle during core exercises with proper instruction.¹³ Limitations to this study include the small sample size, gender dominance and health of the subjects. Due to these factors, these findings may not be able to be applied to the general population.¹³

Surface EMG was used to investigate the activation of rectus abdominis, external oblique, multifidus and longissimus thoracis during rehabilitation exercises in a study by Ekstrom et al.¹⁴ The purpose of this study was to determine what muscles activate during each exercise in order to form a targeted rehabilitation program. The electrodes were applied unilaterally on the right or left, with no preference for the side of electrode placement. Thirty healthy subjects, nineteen males and eleven females with a mean age of 27 ± 8 years participated in this study. Each subject performed nine exercises in a random

order, including: active hip abduction, bridge, unilateral bridge, side bridge, prone plank, quadruped arm and lower extremity lift, lateral step up, standing lunge and dynamic edge. Subjects performed the standing lunge and lateral step test slow and controlled through the full range of motion with a five second hold at maximal knee flexion. The dynamic edge exercise aimed to replicate a skiing motion and thirty second rest periods were allowed during trials. Each trunk exercise was repeated three times and held for 5 seconds.¹⁴ Significant results showed that gluteus medius has the greatest activation during side bridge ($p=.005$) and gluteus maximus with quadruped with arm and leg lift ($p=.008$).¹⁴ The external oblique and rectus abdominis are most active during prone bridging and side-bridging ($p=.001$). The side bridge, lateral step up, lunge, and quadruped with arm and leg lift have been found to be the strongest exercises for increasing overall core strength. These exercises have EMG amplitude greater than 45% maximum voluntary isometric contraction and 45-50% of one repetition maximum correlates with an increase in strength.¹⁴ This finding will allow core rehabilitation programs to focus on different exercises to increase core endurance and strength. Limitations of the study include potential cross-talk of the surface electrodes, especially the gluteus medius and gluteus maximus electrodes; that data was collected only during the static phase of the exercises; that the subjects may not have reached maximum voluntary isometric contraction; or that the testing positions were not optimal, and lastly that the study subjects were healthy and results may not be applicable to a patient population.¹⁴

Another study targeted patients' status post microdiscectomy and stabilization exercises were revealed to decrease pain, increase function, strength, and flexibility compared to a control group. A study by Hides et al. included in the Barr review determined that patients with an episode of acute low back pain that were taught multifidi and transverse abdominis co-contraction techniques had less recurrent episodes compared to a control group that did not receive training.¹⁵

In a prospective comparative study, Vezina et al. used surface EMG to explore the relative activation amplitudes of the right upper and lower rectus abdominal, external oblique, erector spinae and multifidi during movement and stability phases of trunk exercises including pelvic tilting, abdominal hollowing, and trunk stability test (TST) level I exercises.¹⁶ Twenty-four healthy male subjects recruited at a military base were included in the study and had a mean age 30+/-8.1 years without known neuromuscular, orthopedic, or cardiovascular conditions. Further exclusion criteria consisted of a history of low back pain, spinal deformities or previous spinal surgeries. Subjects were instructed on performance of the three exercises and provided written instructions to use while practicing the exercises. The pelvic tilt exercise consisted of a posterior pelvic tilt performed in supine held for 4 seconds during testing. The abdominal hollowing exercise was performed in supine with the subjects instructed to "bring their navel up and in towards the spine" for a 4 second hold. The TST exercise was performed in supine with hips and knees bent, stabilizing the spine as in the

abdominal hollowing exercise, before the subject raised each leg to 90 degree hip flexion then lowering each leg back to the plinth. Testing sessions occurred 1 to 2 weeks after exercise instruction. Statistical analysis was performed using a repeated measures ANOVA. Results showed statistically significant differences in activation of the muscles during the exercises. The external oblique activated at a significantly higher level ($p < .0016$) than the other 4 muscles during all 3 exercises for both the stability and movement phases, with an activation level 2 to 3 times higher than the rectus abdominis. There was no statistically significant difference between the upper and lower rectus abdominis ($p > .0008$) and the multifidi and erector spinae had equivalent activation on all exercises except the TST.¹⁶

Lee et al. investigated the role muscle co-contractions have on trunk stiffness by comparing minimal and maximal voluntary co-contraction in 17 healthy subjects, without a history of previous back pain.¹⁷ Surface EMG data was collected from electrodes on the right and left rectus abdominal, lumbar paraspinals, internal obliques and external obliques. The subjects were tested while maintaining constant trunk extension exertions at 15% and 30% percent maximum voluntary exertion as a horizontal load was applied at the T10 level of the trunk. The subjects had a mean height of 175.5 +/- 12 cm, and a mean mass of 74.3 +/- 14.2 kg. Preliminary results indicated no statistically significant difference between the left and right muscles within each muscle group, so the recorded scores were an average of both sides of each muscle group

examined.¹⁷ An ANOVA was used for statistical analysis of the effect of co-contraction condition and preload on trunk stiffness and muscle activation. The maximum co-contraction conditions produced a 12.5% greater co-contraction of the rectus abdominis than the minimal co-contraction conditions ($p < 0.005$), while the external oblique had a 19.4% ($p < 0.02$) greater co-contraction and the internal oblique had a 7.5% ($p < 0.04$) greater co-contraction under the same conditions.¹⁷ The paraspinals showed significant increased EMG activity during the maximal co-contraction conditions ($p = 0.248$). The study showed trunk stiffness increased by 37.8% from minimal to maximal co-contractions of the trunk musculature ($p < 0.004$), and 18.4% with preload effort ($p < 0.002$). Results support the biomechanical model's suggestion that co-contraction increases trunk stiffness.¹⁷

Monfort-Panego et al. conducted a literature synthesis of electromyographic studies in abdominal exercises, including 87 relevant articles primarily focusing on the intensity of muscle contractions and the loads on the spine in different movements and postures.¹⁸ The examined studies lacked overall consistency, preventing a rigorous meta-analysis. In studies on healthy subjects, common technical issues included an insufficient number of subjects, inadequate descriptions of physical activity levels, insufficient explanation of EMG recording techniques and incomplete techniques for EMG signal processing.¹⁸ A number of studies either did not perform or did not describe techniques for normalizing the surface EMG signals to maximum voluntary

contraction (MVC) amplitudes per the recommended normalization method for comparison data. An additional concern in the methodology of the studies was the inconsistency of terminology used, with article authors using different names for the same exercises.¹⁸

Per Monfort-Panego et al., EMG studies on exercises involving spine and hip flexion show high compressive forces on the lumbar spine (3000 N or greater). Some of these studies described irregular activation patterns of the trunk musculature during spine and hip flexion exercises, including activation of the rectus abdominis falling sharply during the initial phase of the exercise when the lumbar spine was lifted off the floor. Additional recent studies have shown a decrease in abdominal EMG activity occurs with initial pelvic displacement. Recommendations for exercises include a preference towards abdominal exercises without active hip flexion versus exercises with active hip flexion in order to reduce heavy loads on the lumbar spine. Further studies showed the highest abdominal muscle recruitment with the least amount of disc compression in exercises with spinal flexion, making these exercises more highly recommended for safety and effectiveness since they maximize rectus abdominis activity and minimize risk for spinal injury with lower compressive loads. Exercises incorporating trunk rotation versus single plane movements showed a higher activation of anterolateral muscles, such as the external obliques. Exercises with lower extremity support showed lower levels of activation in the rectus abdominis, but with increased activation of the hip

flexors. Arm and hand position impacts the load experienced through the spine, with lower loads when hands are resting along the trunk than when raised above the head. The articles show inconsistencies in the impact of knee and hip position on abdominal activation.¹⁸ The consensus reached by the authors is that abdominal strengthening exercises should incorporate spine flexion and rotation without hip flexion to maximize muscle strengthening while minimizing risk for injury. Exercises can also include arm support or lower body segments used to support correct performance, and inclined planes or additional loads to increase difficulty. Safety recommendations include avoiding active hip flexion, fixing the feet, or placing hands behind the head while applying a pulling force. Knees and hips should also remain in a flexed position during upper extremity exercises to prevent overloading the spine.¹⁸

Injuries and the Core

Subjects with low back pain or lower extremity injury have demonstrated alterations in normal muscle recruitment patterns in studies using EMG. It is unclear if these neuromuscular changes are the cause or the result of injury. Silfies et al. looked at the differences in feed-forward trunk muscle activity between 43 subjects with mechanical low back pain and 39 healthy, asymptomatic control subjects.²¹ Using surface EMG to measure onset time of 10 trunk muscles during self-perturbation tasks relative to anterior deltoid onset, the researchers found that the activation timing patterns and number of muscles functioning in feed-forward were statistically different between groups. The

subjects with mechanical low back pain did not activate the trunk musculature in a feed-forward manner and showed significantly delayed activation as compared to the control group. The control group activated the external obliques, lumbar multifidi and erector spinae muscles in a feed-forward manner.²¹ The subjects with mechanical low back pain were further divided into a stable and unstable group. The unstable group showed some injury or degeneration consistent with segmental hypermobility or instability. The stable subgroup were able to activate trunk extensors in a feed-forward manner, closer to the control group, and were significantly earlier than the unstable subgroup. This demonstrates that even within the low back pain group, there is a difference in muscle activation based on the stability of subjects' spines.²¹

Low back injuries can have debilitating effects on individuals. Impaired activation, decreased flexibility, neuromuscular imbalance and delayed reflex responses have all been implicated in low back injuries.^{1,2,19} History of low back injury has been shown to be the biggest predictor of future low back injury.^{1,2,19} Cholewicki et al. conducted a prospective observational study to determine whether delayed muscle reflex response to sudden trunk loading is a result of or a risk factor for sustaining low back injury.¹ Low back injury was defined as low back pain causing at least three days absence from competition or practice.¹ A total of 299 Yale varsity athletes and four club level athletes volunteered for the study. A total of 292 were used (148 females, 144 males) with a 2 to 3 year follow up to track low back injuries. Trunk muscle reflex

response was measured in response to quick force release in trunk flexion, extension, and lateral bending using a specially built apparatus. The apparatus was different from one used by Zazulak et al. in that the subjects were kneeling instead of sitting and the force was provided from three different directions.^{3,4} Five trials of 30% of the maximal isometric trunk exertion for age matched subjects established in a previous empirical study were used. Muscles' onset and offset times were recorded for rectus abdominis, external oblique, internal oblique, latissimus dorsi and erector spinae. If athletes suffered a low back injury, they were selected for retest. Sixty athletes suffered low back injury during the study duration and a total of 31 during the follow-up period. ANOVA showed significant latencies in deactivation of muscles in the injured population in flexion, lateral bend, and extension. Athletes with no history of low back injury responded to increased load with a greater number of muscles than athletes with low back injury history.¹ Researchers documented the risk of sustaining a low back injury to be 2.8 times higher in athletes with previous low back injury history. Additionally, an athlete's odds of low back injury increased by 3% for each kilogram of increase in body weight. For every millisecond delay in muscle response latency in flexion and lateral flexion, an athlete's odds of low back injury increased 3% and 2%, respectively.¹

Mehta et al. further explored the difference in activation of trunk muscles by comparing surface EMG data from the bilateral internal obliques, rectus abdominis, external obliques, transversus abdominis, and superficial lumbar

multifidus between 30 subjects with chronic nonspecific low back pain and 30 healthy, asymptomatic controls.²² The researchers found that the subjects with nonspecific low back pain had a significant delay in trunk muscle onset and shorter burst and co-contraction durations ($p < .02$). This suggests that individuals with nonspecific low back pain may be inefficient at regulating trunk posture during voluntary extremity movements or that these alterations in timing could represent a compensatory control pattern imposed by the central nervous system to avoid pain.²²

Core stability has been shown to play an important role in preventing musculoskeletal injuries. It is therefore imperative to examine the components of core strength closely with hopes of identifying possible risk factors for injury and eliminating them. Research has shown that core instability and poor motor control are risk factors for debilitating knee and low back injuries.^{1,23} Additionally, fatigue of the 'kinetic chain', specifically the core, has led to increased potential for upper extremity injury.²⁴ Significant findings have also been documented in regards to hip strength and injury. Specifically, females have been shown to have significantly weaker hip external rotators and abductors. Such impairments are often found with those suffering knee injuries.¹

Ershad et al. explored differences in trunk muscle activity between 10 female chronic low back pain subjects and 10 age-matched healthy subjects during holding loads in various trunk positions.⁵ Subjects with chronic low back pain were included if they had lumbar or lumbosacral pain with the primary

complaint being low back pain versus leg pain, a current pain episode present for at least 3 months, and an inability to perform daily living activities secondary to pain. Exclusion criteria included prior spine surgery, structural deformities or radiculopathy. The age-matched healthy subjects were also matched by gender, height and weight. Surface EMG recorded activation patterns of the right rectus abdominis, external oblique, internal oblique, erector spinae, and multifidus. Activation patterns were explored as the subjects performed 6 holding tasks, consisting of holding loads of 0, 6, and 12 kg each in a neutral trunk posture and in 30 degrees trunk flexion. Results showed there was no significant difference between groups in muscle activation when the subjects were in a neutral position. The subjects with chronic low back pain demonstrated significantly higher activation levels of the external obliques during loading of 12 kg in a flexed trunk position and lower activation of the internal obliques during loading of 6 and 12 kg in a neutral trunk position than the control group ($p < 0.05$). There was no significant difference in activation of the erector spinae and multifidus between subject groups.⁵ Intergroup results demonstrated activation of the rectus abdominis, erector spinae, and multifidus increased with increased loads at all load levels, and erector spinae and multifidus activation also significantly increased with trunk flexion ($p < 0.05$). The researchers noted there is higher activation of global muscles and lower activation of local abdominal muscles in patients with chronic low back pain that may represent pain changes to the neuromuscular control systems. The study concluded that the increased

activity of the extensor muscles during trunk flexion is probably due to a need for stability and control in flexion, and suggests that abdominal muscles may play a more significant role in trunk stability than the extensors.⁵

Injuries to the knees have been shown to take significantly longer to recover from than hip, back, thigh (41% longer), or ankle injuries (131% longer).²³ Zazulak et al. documented impaired core neuromuscular control and proprioception as key knee injury predictors in two epidemiological studies.^{3,4} The purpose of the first study was to identify potential factors related to neuromuscular control of the trunk that predispose athletes to knee injuries. A cohort study included 277 Yale varsity athletes (140 female, 137 male). Athletes were only included if they had no previous history of knee injury. Injury to the knee was classified as any ligament, meniscal, or patellofemoral injury diagnosed by the university physician. Subjects were prospectively tested for core proprioception by active and passive proprioceptive repositioning and then monitored for three years.³

Core proprioception was evaluated using a previously validated apparatus designed to produce passive lumbar spine motion in the transverse plane. Subjects were rotated 20 degrees and were then passively and actively rotated back to neutral. Subjects stopped the apparatus when they perceived they were back in the neutral position, thus indicating core proprioception. Degrees of error in repositioning were measured. In three years, 25 of the subjects suffered knee injuries (11 female and 14 males). It was found

that increased error in core proprioception was associated with increased knee injury risk.³ ANOVA showed a significant interaction between sex and knee injuries. These deficits were observed in active proprioceptive testing, but not for passive testing in injured females. Significant error was observed in female subjects with knee injuries compared with uninjured female subjects ($p < .05$), but not male subjects ($p > .05$). A 2.9 fold increase in odds ratio for knee injury occurred, and 3.3 fold increase in odds ratio occurred for ligament/meniscal injury for each degree increase in average error. The researchers hypothesized that women who suffer from ACL injuries may carry neuromuscular deficits which predispose them to injuries.⁴

The second epidemiological study compared displacement after a sudden release of the trunk in injured and non-injured males and females.⁴ The purpose was to identify potential neuromuscular risk factors related to core stability that predispose athletes to knee injuries. This study used the same subjects as the previous study with same inclusion/exclusion criteria and used a quick force release in three directions to assess trunk response to reloading.^{3,4} Displacements were in the flexion, extension, and lateral bending directions. Motion was then measured after force release using an electromagnetic device.³

It was found that both low and maximal isometric trunk displacements were significantly greater in knee-injured, knee ligament-injured, and ACL-injured athletes ($p = .005$). Displacement after trunk force release, active proprioceptive

repositioning, and history of low back pain were found to be highly predictive of knee injuries. Lateral displacement was the strongest single predictor of knee, ligament, and ACL injury in all athletes. In female athletes, lateral displacement predicted ligament injury with 100% sensitivity and 72% specificity, but did not predict injury in male athletes.³ The findings from the previous two studies by Zazulak et al. seem to demonstrate a greater disparity in female proprioceptive abilities in regards to knee injuries.^{3,4}

Renkawitz et al. found there are significant neuromuscular imbalances in the right and left erector spinae at the levels of L2 and L4 during trunk extension in subjects with low back pain.¹⁹ Researchers conducted a clinical experimental longitudinal study of the lower back. The study consisted of 82 elite amateur tennis players with and without low back pain in Germany. Low back pain subjects included 19 females and 27 males; subjects without low back pain included 12 females and 24 males. Subjects were excluded if they had severe internal, cardiovascular, or neurological diseases.¹⁹

EMG electrodes were placed at bilateral L2 and L4 erector spinae. Isometric trunk extension was measured via self-constructed dynamometer and EMG signals were recorded for three, four second bouts. Subjects performed a sport-specific home exercise program for an average of 7.2 weeks (39.9 +/- 8.0 training units for LBP subjects and 39.3 +/- 6.9 units for players without LBP). The training consisted of a warm up of skipping rope or walking in place. A mobilization component consisting of trunk

and upper extremity rotation and stretching followed. The strength, stabilization and coordination part included supine, prone and side lying abdominal and hip strengthening. Stretching followed focusing on lateral trunk, erector spinae, hamstrings and iliopsoas musculature. The cool down consisted of a lying knee to chest stretch. Re-testing took place after seven weeks.¹⁹

Bonferroni-adjusted analysis showed that 39 of the 46 subjects had neuromuscular imbalances at the beginning of the study ($p < .01$). At retest, 11 of 17 subjects with low back pain showed neuromuscular imbalance ($p < .01$). It was found that the strength of the erector spinae is not significantly related to occurrence of neuromuscular imbalance. Similarly, there was no statistical relationship found between back extensor moment and low back pain. A statistically significant finding was identified in the association of handedness and contralateral decrease in EMG activity ($p < .01$). Nearly all players showed a decrease in EMG activity on their contralateral erector spinae. The researchers hypothesized that due to asymmetric loading through hyperextension and unilateral trunk motions common in racquet sports, neuromuscular imbalances are created. However, whether or not these imbalances are a cause or result of LBP cannot be determined from their study. Additionally, the flexibility of the erector spinae was significantly related to the presence of a neuromuscular imbalance.¹⁹

Low back pain has also been documented in regards to the trunk's response to upper extremity motion. Tarnanen et al. recorded electromyographic

amplitudes of rectus abdominis, obliques, longissimus, and multifidi during upper extremity exercise to determine if upper extremity exercises are able to load the core stabilizing muscles sufficiently to increase muscle strength.²⁵ Researchers evaluated whether isometric exercises for the upper extremities could sufficiently activate core stabilizing muscles to increase muscle strength in a cross-sectional study. Using 20 healthy adult women aged 20 to 45 years, peak isometric strength of back and abdominal muscles was measured by surface EMG. Subjects were excluded if they had any neuromuscular, orthopedic, or cardiorespiratory problems preventing physical exertion. It was found that bilateral isometric shoulder extension and unilateral horizontal shoulder extension elicited the greatest trunk musculature activation.²⁵ Thus, upper extremity movements have a possible implication in core strength and injury.

Hodges et al. conducted an experimental design to evaluate motor control of the transverse abdominis and stabilization of the spine to determine if dysfunction in activation during arm movement was related to back pain.² Thirty-six subjects participated in the study including 15 patients (8 male, 7 female) with a history of lumbar pain and 15 age and sex-matched subjects. Patients were screened for pain of non-musculoskeletal etiology and were required to have low back pain of insidious onset of at least 18 months duration for which they have sought medical care for. Subjects had minimal or no pain at time of testing, mean duration of pain was 8.6 years. Subjects were excluded if they had neurologic symptoms, observable spinal deformity, previous lumbar surgery,

neuromuscular or joint disease, or abdominal or back exercise in previous three months. EMG electrodes were placed on the left transverse abdominis, internal oblique and external oblique. Surface electrodes were placed on right deltoid and readings were taken at 40 and 60 degrees of shoulder flexion and abduction. Subjects were asked to move their arms as fast as possible in response to a visual command.² In healthy subjects the transverse abdominis was invariably the first muscle to activate. When the low back pain group initiated rapid shoulder flexion or abduction, none of the core muscles were activated before the prime mover.² It remains unclear whether core instability is the cause or the result of injury.

Tests of Core Function

Testing of core musculature should consider the multi-directional characteristics of these stabilizing muscles as well as the importance of both strength and endurance in preventing injury. One single test is not sufficient to explore all aspects of core stability; several tests must be employed to gain a better picture of the various functions of this important muscle group.

Evans, Refshauge, and Adams assert that trunk endurance may be more important to function than pure strength.⁹ They tested the reliability of several endurance tests, as well as exploring gender differences by testing 24 subjects (16 males, 8 females) with a mean age of 35.3 +/- 14.4 years with BMI values between 19.2 and 30.7kg/m². The Biering-Sorensen test of trunk extensor endurance, side bridge endurance test, and two different trunk flexor endurance

tests (60° trunk flexor endurance test and the Ito et al. test) were examined. Strong inter-rater and intra-rater reliabilities were found for all tests (ICC \leq .81, .82 respectively). The only gender difference found was that male athletes had longer hold times for the side bridge test than their female counterparts. The side bridge tests for endurance in the quadratus lumborum and other anterolateral trunk muscles. Hold times for the Biering-Sorensen were not found to be significantly different, though other researchers have found longer hold times in female subjects. This test is thought to predict future episodes of low back pain in non-athletic subjects with short hold times.⁹

Liemoehn, Baumgartner, and Gagnon added coordination to the list of important characteristics of core musculature to be tested.²⁶ They used core stability training postures as tests of muscle coordination with subjects on a stability platform to detect loss of balance in 16 subjects (9 males, 7 females). Postures tested were the kneeling arm raise, quadruped arm raise (both with the body parallel and perpendicular to the testing surface), and bridging. Interclass reliability coefficients increased with each day of testing and were very high the final day (.95, .89, .94, and .91 respectively).²⁶

Cowley et al. argue that isometric tests, such as those used by Evans, Refshauge, and Adams, only test muscles at one length and are therefore not comprehensive examinations of the full range of movement.¹⁰ Isokinetic tests are arguably better for this purpose, but they do require expensive equipment that may not be available in the clinical setting. However, isokinetic tests are the

standard core strength examination used in sports medicine because of their strong reliability, ability to predict risk of injury, as well as assess injuries and monitor progress in rehabilitation.¹⁰

Cowley, Fitzgerald, Sottung, and Swensen developed two new core stability tests to try to replicate isokinetic testing without the need for equipment to make it more accessible in the clinical setting.¹⁰ They evaluated the reliability of these tests in a preliminary study including 8 subjects (5 females, 3 males) average age 24.4 +/- 4 years for the women and 23.3 +/- 0.58 years for the men. Average heights and weights were 172.2 +/- 6.6cm, 67.5 +/- 10.2kg for the women and 184.6 +/- 6.4cm, 87.3 +/- 13.7kg for the men. The main study included 50 subjects (31 females, 19 males) average age 19.5 +/- 1.4 years for the women and 19.2 +/- 0.8 years for the men. Average heights and weights were 163.2 +/- 6.8cm, 61.8 +/- 8.8kg for the women and 181.1 +/- 9.3cm, 8.6 +/- 10.6kg for the men. The plank to fatigue test was administered by placing 10% of the subject's body weight on the upper gluteal region once appropriate prone plank positioning was achieved and then measuring the time to fatigue. The front abdominal power test (FAPT) measured the distance a 2kg medicine ball could be projected by subjects using abdominal strength. Starting supine with the knees bent to 90° and the feet on the floor, arms were extended overhead and a 2kg medicine ball was placed in the hands. Using a forceful abdominal contraction, the medicine ball was released as the hands lined up over the knees, keeping the shoulders, elbows, and wrists fixed and only using abdominal

strength to propel the medicine ball. The FAPT was shown to have high reliability (ICC=.95), however the plank to fatigue test lacked reliability with high standard deviations throughout testing.¹⁰ Male subjects had higher scores on the FAPT compared to females which the researchers speculate is due to the difference in lean muscle mass between men and women.¹⁰

Cowley and Swensen previously developed another test of core stability in hope of incorporating endurance, strength, power, and coordination in simple tests that can be administered without a lot of equipment and time.²⁷ This test was examined using 24 female subjects average age 20.9 +/- 1.1 years, height 163.9 +/- 6.8cm, weight 61.8 +/- 8.8kg. They argue that strength is a better predictor than endurance for lower extremity injuries in athletes and this element is lacking in most core stability tests. The front abdominal power test (FAPT) is explored, as in the previously mentioned article, as well as the side abdominal power test (SAPT). Both tests were adapted from plyometric abdominal exercises in which the arms are used as a lever to project a medicine ball with an explosive contraction of the abdominal muscles. The SAPT was conducted with knees bent to 90° and the feet on the floor. The hips were at a 45° angle and a 2kg medicine ball was placed in the hands which were outstretched just above the knees. From this position, the trunk was forcefully rotated 90° and the medicine ball released. Reliability was found to be .95 for the FAPT and .93 for the SAPT.²⁷

Core Exercise/Strength Program

Surface EMG of rectus abdominis, external oblique, multifidus and longissimus thoracis was done to investigate activity during rehabilitation exercises in a study by Ekstrom et al.¹⁴ The electrodes were applied unilaterally with no preference for right or left. Thirty healthy subjects, nineteen males and eleven females with a mean age of 27 ± 8 years participated in this study. Results revealed that longissimus thoracis and lumbar multifidus are most active during bridging, side-bridging, unilateral bridging, and quadruped opposite arm/lower extremity lift ($p=.199-1.00$). Whereas external oblique and rectus abdominis are most active during prone bridging and side bridging ($p=.001$). This finding will allow core rehabilitation programs to focus on different exercises to increase core endurance and strength.¹⁰

An article by Behm et al. suggested that training the core musculature utilizing exercises performed on unstable surfaces can increase core and limb muscle activation.²⁸ Athletes returning to their sport would benefit from a training program that encompasses all planes of movement and varying surfaces and loads. Spinal stability depends on an increase in intra-abdominal pressure and the combination and intensity of muscle activation.²⁸

Lumbar stabilization programs (LSPs) are designed to correct core musculature deficits that may be causing low back pain. A review of the literature by Barr et al. aimed to look at the efficacy of LSPs and describe an evidence-based clinical approach to prescribe a LSP for low back pain.¹⁵ Abdominal strengthening and lumbar spine strengthening is most

commonly utilized to increase trunk stabilization. Barr reported on a study by O'Sullivan and colleagues that revealed that LSPs decreased pain and improved function by teaching patients exercises of the deep stabilizers.¹⁵ It is stated in the review that before a LSP is assigned, a thorough physical exam should be done on the patient. Posture, range of motion, spinal mobility, flexibility, muscle strength, muscle endurance, and balance should all be assessed to determine if an LSP is appropriate. In the beginning stages of the program, therapists should focus on teaching the patient to activate the transverse abdominis and multifidus while maintaining a neutral spine. At the intermediate stage, upper and lower extremity movements may be introduced, but only if the patient is able to maintain a neutral spine throughout the exercise. Uneven surfaces such as an exercise ball or rocker board can be used at the advanced stage to challenge the musculature. A LSP can be a useful tool to decrease low back pain, but it should be appropriate in prescription. Patients should be educated about why the exercises are important and therapists and patients should have realistic expectations about the effects of the LSP. A study of core muscle activation during conventional abdominal exercises compared to Swiss ball exercises was conducted by Escamilla et al. using surface EMG.²⁹ A convenience sample of 18 healthy subjects (9 male, 9 female) participated in the study. Demographics for females included: age 27.7 +/- 7.7 years, 61.1 +/- 7.8 kg weight, 165.0 +/- 7.0 cm height, and 18.7 +/- 3.5% body fat. For males, demographics were: age 29.9 +/- 6.6 years, 73.3 +/- 7.2 kg weight, 178.1 +/- 4.3 cm height, and 11.6 +/- 3.6% body

fat. Exercises performed included the pike, knee-up, skier, decline push-up, and hip extension right and hip extension left on the Swiss ball compared to the standard abdominal crunch and bent-knee sit-up. Electrodes were placed over the upper rectus abdominis, lower rectus abdominis, external oblique, latissimus dorsi, rectus femoris, and the lumbar paraspinals. Data was collected over five repetitions of each exercise, which were randomized for each subject. Findings indicated that the Swiss ball exercises, particularly the pike and roll-out, had higher core muscle activation than the conventional exercises, but were also the most difficult to perform. The authors suggest that these exercises are good alternatives for more advanced populations looking for greater challenge in their exercise routine. All core muscle exercises tested aid in stabilizing the spine and pelvis due to activation of the transverse abdominis and internal oblique which attach to the thoracolumbar fascia.²⁹

Behm et al. explored how EMG activity in the upper lumbar, lumbosacral erector spinae and lower abdominal muscles was affected by unstable and unilateral exercises.³⁰ The study objectives included comparing the EMG activity of commonly prescribed trunk exercises with stable and unstable bases as well as to compare the extent of trunk stabilizer activation between the prescribed exercises. The 11 subjects (6 men and 5 women) performed exercises including bridging, anterior/posterior pelvic tilt, alternating arm and leg extension, parallel hold, side bridging, superman position, and chest press and shoulder press on a stable bench surface and an unstable Swiss ball surface. The subjects ranged in

age between 20 and 45 years (mean age 24.1 +/- 7.4 years) with previous resistance training experience and no history of low back pain. The subjects attended an orientation session at least 24 hours before testing to familiarize themselves with the exercises. Electrodes were positioned on the right side of the body for all subjects, placed 2 cm lateral to L5-S1 spinous processes for the lumbosacral erector spinae, 6 cm lateral to the L1-L2 spinous processes for the upper lumbar erector spinae muscles, and 1 cm medial to the anterior superior iliac crest (ASIS) and superior to the inguinal ligament for the lower abdominal stabilizers. The trunk exercises were held for 3 seconds each; and all exercises were performed twice within a single session with a 2 minute rest break between each exercise. The data was analyzed using an ANOVA, and the test-retest reliability was classified as excellent. The trunk exercises performed in unstable positions produced a 27.9% greater activation of the lower abdominal muscles than when performed in stable positions. Performing a chest press in an unstable position produced an increase in activation of all trunk muscle groups monitored, between 37.7 and 54.3%.³⁰ Additionally the study found that the superman exercise produced the greatest activation of back stabilizers, the side bridge was optimal for lower abdominal muscle activation, and the unilateral shoulder and chest press produced greater activation of trunk musculature than when performing the exercises bilaterally. The important findings of the study included that lower abdominal muscle activation levels are higher during unstable calisthenic-type exercises when compared to stable exercises. There is also no

substantial evidence of greater core activation when resistance is added to these exercises.³⁰

CHAPTER III

METHODS

Subjects

Fifty-five voluntary subjects, 20 male and 35 female participated in this study with mean age $29 + 9.678$ years. Voluntary subjects were recruited from St. Catherine University and the surrounding community and college campuses through flyers and verbal announcements of the study, with a drawing for a gift card offered as incentive for participation. Study approval was obtained from St. Catherine University's Institutional Review Board prior to subject recruitment and testing. In accordance with St. Catherine University's Institutional Review Board and Human Subjects Protection guidelines, subjects were informed of testing procedures and potential risks associated with participation in this study before giving their written consent.

Healthy males and females between the ages of 18 and 55, who are able to follow instructions and perform three tests for core endurance were included as subjects for this study. Exclusion criteria consisted of the following: history of back or abdominal surgery (laparoscopic surgeries may participate), current back pain or injury, current pregnancy or delivery within the past year, current neck or extremity injury, current or previous diagnosis of a neuromuscular condition including but not limited to diagnoses such as Multiple Sclerosis, fibromyalgia, or Guillain-Barre.

A health history and exercise questionnaire (Appendix A) was completed by each participant in order to determine appropriateness for participation in the study and to collect data of factors that may influence performance on the tests. Included in the questionnaire were questions on age, sex, tobacco use, exercise habits, and past medical history. Additionally we took measurements of subject's waist circumference and calculated subject's body mass index (BMI) based on measured height and weight. We hypothesized subjects with greater waist circumference and/or higher BMIs would have shorter hold times than subjects with waist circumference and BMIs within the normal health range. Additionally, we investigated differences in gender performance, hypothesizing there would be no significant difference in hold times between genders. Tobacco use was hypothesized to have a negative correlation with hold times, as tobacco use may decrease endurance. Across the age range we anticipated we would see hold times decrease as age went up.

Questions related to the past medical history were included to assist us with screening for inclusion and exclusion criteria. Previous literature has suggested a correlation between core strength and injury, thus we chose to exclude subjects with current pain or injury in the back, neck, or upper or lower extremities, in an effort to establish normative values among healthy adults.²¹ Additionally, we excluded conditions that may affect the integrity of the core musculature including pregnancy, history of back or abdominal surgery, or neuromuscular disorders. Subjects with past upper or lower extremity injury

were included, provided there was no current symptoms, as we wanted to investigate any correlation between an injury history and core strength. We hypothesized subjects without a history of upper or lower extremity injury would have longer hold times than subjects with the injury history.

We hypothesized subjects who exercised regularly would perform better on the tests than subject who did not regularly exercise so questions around exercise habits were included in the questionnaire. Questions around exercise habits included total number of minutes of exercise outside of normal daily activities, types of exercise performed, and history athletic competition at the high school, collegiate, club, or professional level. Question of types of exercise performed were used to determine if various forms of exercise had a different impact on performance with core strength, hypothesizing subjects who engaged in specific core strengthening exercise would perform better than subjects that engaged in other popular forms of exercise, such as running, biking or swimming.

Procedures

A controlled laboratory study design was selected to minimize data collection errors and support the study objective of establishing normative data. After providing written consent, demonstrating their understanding of testing and the ability to perform these tests and completing the health history questionnaire, subjects completed a three minute warm up by walking at a self-selected pace up and down a level surfaced hallway. Testing began immediately following the warm up. Three different core endurance tests were completed by each subject,

with the order of the tests randomized. All testing was performed on standard or portable plinths with a five minute rest break between each test to address any fatigue. Core endurance tests included side planks, Biering-Sorensen Extensor Endurance Test and 60 degree flexion test. All tests administered had an inter-rater ICC greater than or equal to .81 and an intra-rater reliability of at least .82.⁹ Subjects were given verbal instruction on test positions and a visual example, if needed. For each test, subjects were asked to hold the position as long as possible and the test was completed when the subject broke from the desired position and displayed incorrect form and technique.

For the side plank test subjects were placed in a side plank position with knees in full extension and ipsilateral foot and elbow in contact with the plinth. The elbow was bent at 90 degrees and placed directly beneath the shoulder with trunk in neutral (Figure 1). The test was terminated when subject could no longer hold the position. Movement out of the testing position was considered in all planes, with the test termination occurring when the pelvis rotated out of the coronal plane, or moved out of the sagittal plane by dropping toward the plinth or hiking up. The side plank test was administered on each side, with a five minute rest between the tests. The subjects were allowed to select which side was tested first.

The Biering-Sorensen Extensor Endurance Test has been previously described in the literature and was performed with subjects positioned on the plinth in prone with lower extremities supported by the plinth, bilateral ASIS on

edge of the plinth with trunk and upper body off the edge of the plinth.⁹ Straps placed around the ankles, the knees and the gluteal fold were used to secure the subject's lower body during the test (Figure 2). The test was initiated when subject assumed the correct position with trunk horizontal to the floor and zero degrees of hip flexion, with arms folded across the chest. Subjects were instructed to maintain a neutral spine throughout the test. The test was terminated when the subject could no longer maintain zero degrees hip flexion or the trunk moved out of a horizontal plane.

The 60 degree flexion test was performed with subjects positioned on the plinth against a wedge supporting the back so that the hips were flexed to sixty degrees (Figure 3). Knees flexed to 90 degrees, as measured with goniometry and a cushioned strap was placed over the subject's feet to provide support during the test. The test began when the wedge was removed and was terminated when the subject could no longer maintain the 60 degree angle independently.

Each core endurance test was timed by one investigator using a stopwatch until failure was noted as described above. Five investigators were involved in the data collection. Between each core endurance test, subjects were given a five minute rest and then moved on to the next test. Subjects completed each core endurance test one time. Subjects were observed for any adverse effects and informed of possible muscle soreness following testing. No adverse events occurred during the testing.

Data was collected on the duration of each test, recorded in seconds. The stopwatch was started immediately when the subject assumed the correct testing position, as described above as confirmed by an investigator, and stopped promptly when the position was broken.

Statistical Analysis

One-way ANOVAs were used to analyze each of the three tests and 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 low back pain (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 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 low back pain vs. no low back pain history, (8) history of lower extremity injury vs. no lower extremity injury history, and (9) history of upper extremity injury vs. no upper extremity injury history. These comparisons were selected in order to test our hypotheses and determine what factors may influence performance on the three core strength tests.

In order to determine which variables are the best predictors of hold times for each test, multiple regression analysis was run separately for each of the three tests to determine. Independent variables included were age, BMI, waist circumference, exercise time per week and core exercise time per week. Multicollinearity was tested and was found to not be an issue in the multiple regression tests given the variables selected. These variables were selected based on results of significance in the One-way ANOVAs and the potential influence each factor has on health and muscle performance.

Our hypotheses included: (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; (4) subjects with history of low back pain, lower extremity and upper extremity injury will have shorter hold times than those without a history of injury. We could not analyze the impact of smoking on hold tests, as none of the subjects in this study were smokers.



Figure 1: Side Plank Test



Figure 2: Biering-Sorensen Extensor Endurance Test



Figure 3: 60 Degree Flexion Test.

CHAPTER IV

RESULTS

Statistical analyses involved one-way ANOVA and multiple regression in order to determine if and where differences existed between groups and to recognize what variables influenced test outcomes. Subject demographic means can be found in Table 2. Overall means for each core endurance test are shown in Table 3. These values would be considered core endurance test norms for this specific project. However, this project is limited by sample size and these norms may not be applicable to the general public due to the homogeneity of the subjects age and exercise time per week. One-way ANOVA results are shown in Table 4.

Age	29 years (9.679)
Waist Circumference	31.92 inches (3.79)
Body Mass Index	24.6% (3.55)
Core Exercise Time	16.9 minutes (27.45)
Exercise Time	178 minutes (109)

Table 2. Subject Means

Extensor Endurance Test (Ext)	109 seconds (45.30)
Right Side Plank Test (RSP)	60 seconds (27.68)
Left Side Plank Test (LSP)	62 seconds (29.98)
60 degree Flexion Test (FI)	178 seconds (121)

Table 3. Means of Core Endurance Tests

	Extension F-ratio P value	R Side Plank F-ratio P value	L Side Plank F-ratio P value	Flexion F-ratio P value
Gender	3.69 0.060**	10.42 0.002*	9.62 0.003*	0.98 0.328
Exercise	5.47 0.023*	0.82 0.369	4.86 0.032*	9.84 0.003*
Runners	0.94 0.337	5.26 0.026*	3.84 0.055**	15.89 0.0002*
Strength	1.35 0.250	5.28 0.026*	5.76 0.019*	0.97 0.330
Core Exercise	0.02 0.898	2.26 0.138	6.24 0.016*	1.11 0.296
Competitive Athlete	4.22 0.0245*	6.85 0.012*	3.16 0.081	7.11 0.010*
LBP	0.00 0.988	3.59 0.064**	0.82 0.368	0.07 0.787
LE Injury	5.13 0.028*	0.43 0.515	1.27 0.265	1.00 0.322
UE Injury	0.22 0.638	0.25 0.619	0.15 0.695	0.06 0.809

Table 4. ANOVA Results

*Significant $p < .05$ **Trend Toward Significance $p < .08$

Gender Differences

Figure 4 reveals the significant means for differences in gender. For the extensor endurance test, females average hold time was 118.2 seconds while males average hold time was 94.4 seconds. Females held right side plank 51.7 seconds and males 74.8 seconds. Left side plank test demonstrated a difference of female hold time of 53.7 seconds and males 77.9 seconds.

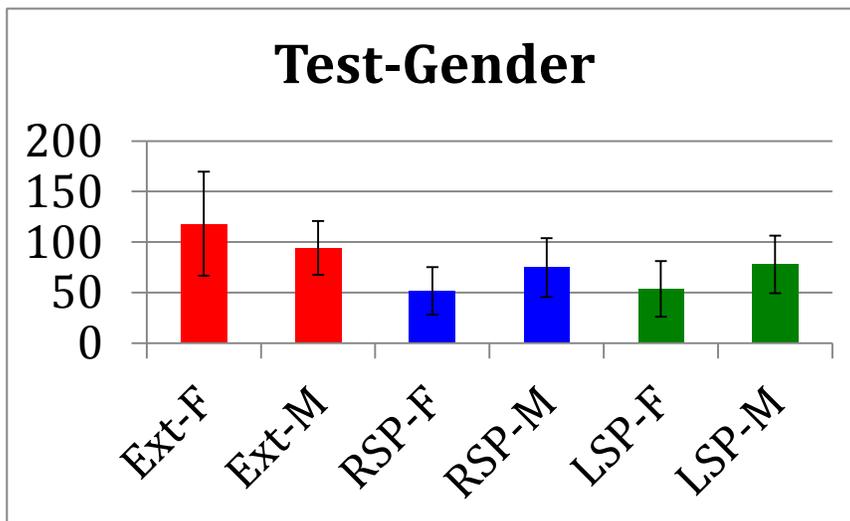


Figure 4. Significant Means for Gender

Exercise Differences

Significant differences in means for participants who exercise vs. non-exercisers is shown in Figure 5. The extensor endurance test revealed that exercisers held 113.4 seconds as opposed to non-exercisers 60.5 seconds. Non-exercisers held left side plank 31.8 seconds while exercisers doubled that to 64.9 seconds. Exercisers demonstrated 186.1 seconds hold with the 60 degree flexion test vs. non-exercisers for 68.25 seconds.

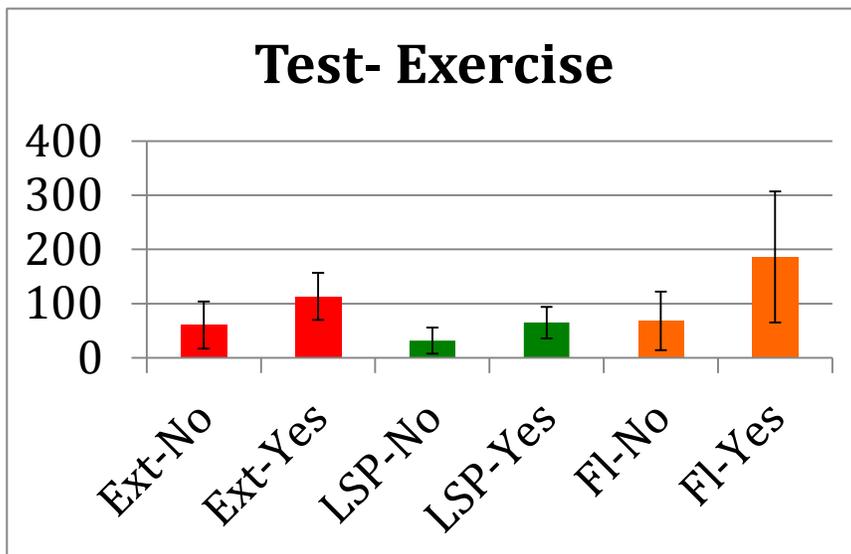


Figure 5. Significant Means for Exercise

Active Runners

For the trunk extensor endurance test, subjects who were runners had a mean hold time of 65.6 seconds, while non-runners held 47.8 seconds. Results may be found in Figure 6. Left side plank trended towards significance with $p=.055$, where runners hold time was 67.7 seconds and non-runners was 50.9 seconds. Runners held the 60 degree flexion test for 208.9 seconds and non-runners for 107.3 seconds.

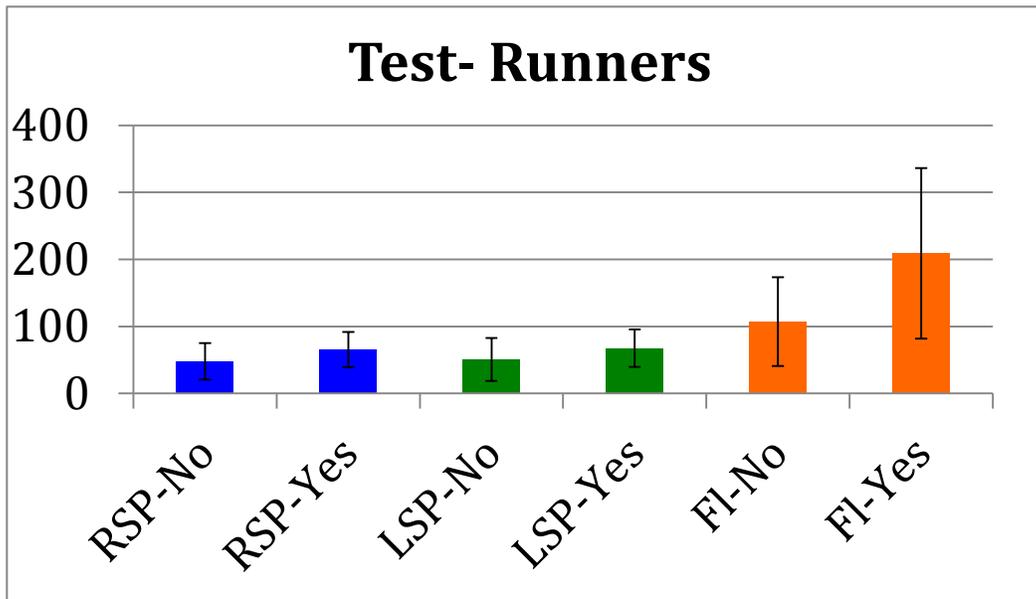


Figure 6. Significant Means Comparing Runners to Non-Runners

Strength Training

Bilateral side plank tests demonstrated significant differences in mean values of those who participated in strength training and those who didn't.

Strength training participants had longer hold times on right side plank (67.4 seconds) vs. non-strength trainers (50.7 seconds) as shown in Figure 7.

Strength trainers held left side plank for an average of 70.7 seconds while non-strength trainers held for 51.9 seconds.

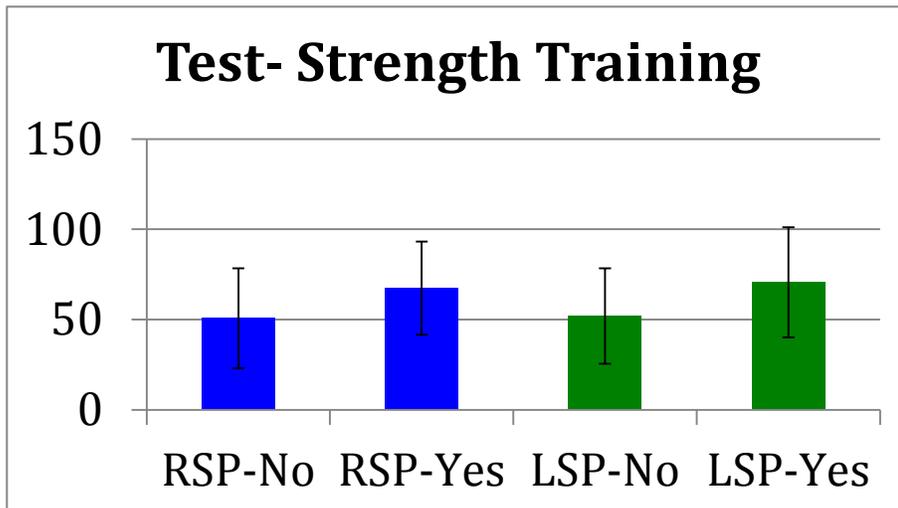


Figure 7. Significant Means for Strength Training

Core exercise participants

A significant difference in hold times of left side plank was demonstrated between subjects who participated in core exercise on a weekly basis compared to those who did not do any core exercise in their exercise routine. Core exercisers held 71.9 seconds vs. 52.7 seconds for non-core exercisers. This data is shown in Figure 8.

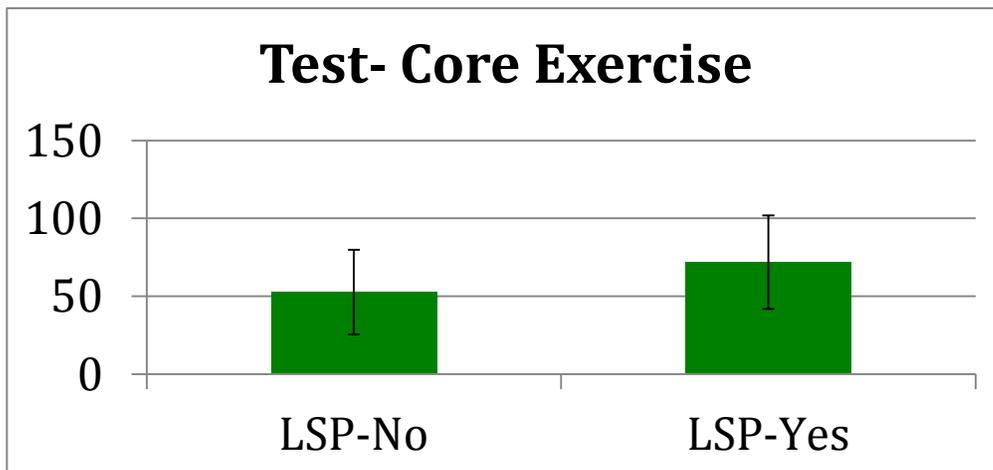


Figure 8. Significant Means for Core Exercise

Competitive Athlete

Subjects were considered a competitive athlete if they played a competitive sport in high school, college, club level or professionally. Significant differences in means were found for extensor endurance test, right side plank and 60 degree flexion test as shown in Figure 9. Competitive athletes held extension position 114.9 seconds compared to 82.0 seconds for non-competitive athletes. Right side plank was held for 64.2 seconds for competitive athletes and 39.1 seconds for non-competitive athletes. Hold times for the 60 degree flexion test were almost doubled for competitive athletes, with an average hold time of 192.4 seconds vs. 101.6 seconds for non-competitive athletes.

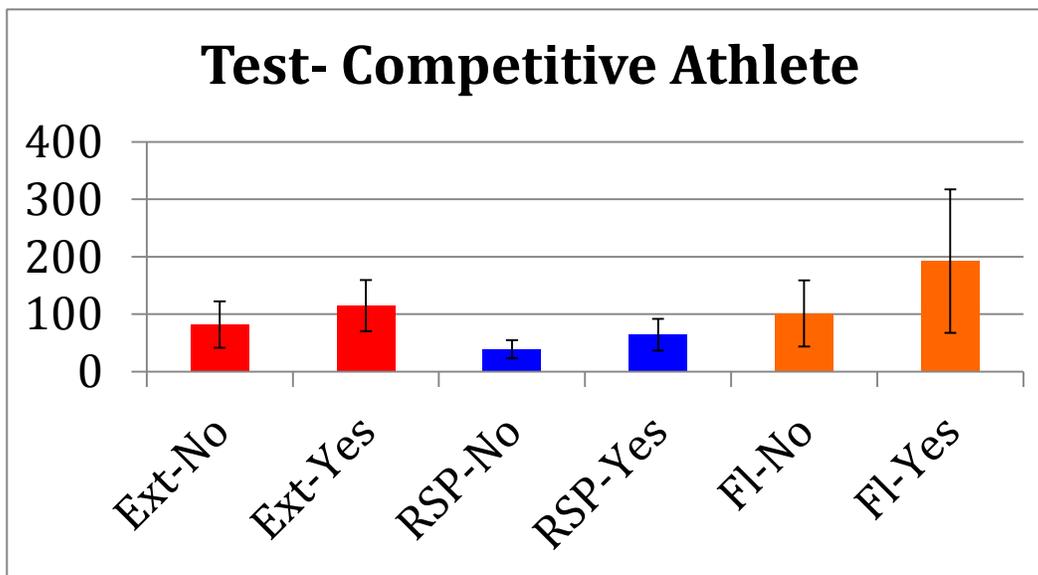


Figure 9. Significant Means for Competitive Athlete vs. Non-competitive Athlete

Low Back Pain

Figure 10 reveals that right side plank test trended toward significance with $p=.064$. Those who did not have low back pain held right side plank 64.7 seconds compared to those with back pain, who held the position for 49.8 seconds.

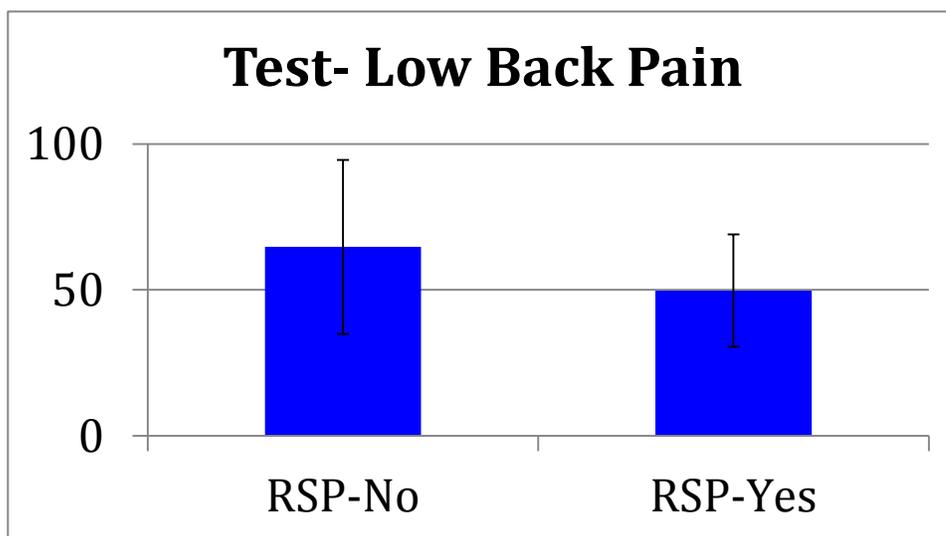


Figure 10. Trend Toward Significant Means for Low Back Pain

Lower Extremity Injury

History of lower extremity injury demonstrated a significant difference in average hold time for the extensor endurance test. Subjects with a history of injury held for 100.2 seconds, while those who have not sustained an injury held 128.7 seconds as demonstrated in Figure 11.



Figure 11. Significant Means for Lower Extremity Injury

Multiple Regression

Multiple regression analysis was run on the four tests to determine what variables predict hold time for each test. Results can be found in Table 5. Variables entered were age, BMI, waist circumference, exercise time per week and core exercise time per week. The multiple regression analysis for the extension test showed a trend towards significance for the overall model, with a p value of .051, with no one variable contributing more than another. Flexion test analysis showed non-significance for the overall model with a p value of 0.117, though one significant predictor variable was present. Exercise had a p value of 0.046 within the multiple regression analysis for the flexion test, but its influence drops once other variables are added. The right side plank test and the left side plank test both showed significance within the overall model with p values of

0.012 and 0.006, respectively. Variables of significant contribution included exercise for the right side plank test with a p-value of 0.017 and both exercise and core strengthening for the left side plank test with p-values of 0.019 and 0.012, respectively. Multicollinearity was not an issue in the multiple regression tests, as we were aware of the potential redundancy of highly correlated variables and therefore only included variables that are independent of each other and appeared to have no relationship with one another.

	Extension	Right Side Plank	Left Side Plank	Flexion
Overall	0.051*	0.012*	0.006*	0.117
Age	0.362	0.460	0.838	0.622
BMI	0.747	0.088	0.975	0.892
Exercise	0.253	0.017*	0.019*	0.046*
Core Exercise	0.439	0.071**	0.012*	0.543

Table 5. Multiple Regression Results (P results)

*Significant at $p < .05$ **Trend toward significance $p < .08$

CHAPTER V

DISCUSSION

The purpose of this study was to establish normative values in adults 18-55 years of age for three different clinical tests of core strength and endurance. We explored the differences in gender, age, past injuries, previous athletic experience, and type and level of exercise for these three tests. Our hypotheses stated that there would be a difference between these variables that would affect hold times for the core tests. In addition, we hoped to establish normative values for these simple clinical tests in order to determine possible risk for injury or compare a person to their normative age and gender match. The three core endurance tests had previously been shown to be valid and reliable in the literature, so that was not the purpose of our study.⁹

Of the specific variables that we looked at, significant findings were revealed for gender, exercise, strength training, running, and core exercise. With regards to gender, men had significantly longer right and left side plank hold times, and women had significantly longer extension hold times. We hypothesize that this difference in side plank could indicate less deep abdominal activity acting to stabilize in women. Research by Evans et al. suggested that differences may be attributed to gender differences in anatomic structure or muscle mass distribution, but didn't appear to be sport specific. The finding of increased bilateral side plank hold times for men over women was also found in past research, specific to athletes.⁹ Additionally, Evans et al. found in athletes

that extension endurance was not significantly different. However, other studies in non-athletic populations have found longer hold times for women, which support our findings. These researchers hypothesized that by participating in sports, men may develop extensor muscle endurance, thus equalizing themselves to female athletes.⁹

Multiple regression analysis suggested that exercise time was the most significant contributor to the prediction of right side plank hold time. For flexion, the overall model was not significant, but there was one significant predictor variable, which was exercise time alone. When isolated, this variable appears to predict well, but when the other variables were added, the overall influence of it dropped and the model was not significant. If we were able to obtain a larger sample size we may have found that this model may have been significant.

A longer duration of exercise was associated with longer hold times for all tests. Participation in regular exercise such as swimming, biking, elliptical, walking, running, and rowing was associated with increased hold times for all tests except for right side plank. This finding supports our hypothesis that those who exercised would have longer hold times. We suspect this is likely due to the need to activate the core musculature during exercise, and those who spend a longer time exercising, likewise spend a longer time conditioning their core musculature. When identifying those who strength train versus those who do not, those who participated in regular strength training had significantly longer bilateral side planks. We think this is due to the dynamic nature of strength

training and need to draw in more lateral core musculature for the varied lifting techniques that occur in multiple planes.

Subjects who reported running on a regular basis demonstrated significantly longer hold times for right side plank and flexion, with a trend for a longer left side plank. We hypothesize that there was an increase in flexion time due to the increased use of hip flexors during running. During testing, qualitative feedback from subjects suggested that there was a large component of hip flexor use during this test. Time spent doing core exercises per week was the most significant predictor of left side plank hold time. Previous studies suggest that training the core musculature can increase core activation.²⁸ Thus, those subjects who reported regular core exercise could have increased core activation that may have led to longer hold times for the left side plank test. Exercise minutes per week was the next significant predictor of left side plank time. These subjects reported many different forms of exercise, so the variety of modes and need to move in different planes of movements may have an effect on core development. Previous LE injury was significant for predicting shorter extension hold time. Zazulak et al. has reported that impaired neuromuscular control of the core leads to an increased knee injury risk.^{3,4} It may be possible that those who had previous lower extremity injuries have decreased core endurance, related to these earlier findings.

Interestingly, previous low back pain did not have any significant findings relative to core endurance test duration. However, there was a trend towards a

shorter right side plank hold time for those who had previous low back pain. Previous research has found impaired function of low back and core musculature in individuals with low back pain or injury.^{1,2,5,19,21,22} However, current low back pain was part of the exclusion criteria for our study because we are collecting normative data. It would be interesting to look at the relationship between those with current low back pain or injury and core endurance; we suspect individuals with current low back pain would have shorter hold times for all of the tests. These results support previous research that core function, endurance and strength is affected by a history of LBP and LE injury; however, a larger sample may further elucidate these findings.^{1,2,3,4,5,19,21,22} In general, hold times decreased with age; however age was not influential in predicting hold times for any test.

Regular exercise and strength training may have a stronger correlation with increased overall core endurance than doing specific core exercises. Interestingly, core and strength training were only specific to side planks. Therefore, combining general exercise with strength training appears to demonstrate greater core endurance overall in all planes than a core exercise program alone.

Limitations

There are several factors that need to be taken into account when interpreting this new data, including limitations. More data across the full age spectrum is needed to establish true norms for these core endurance tests. The

participant population age ranged 21-55, but was skewed towards a younger age with a mean of 29 and a median of 25. In addition, females outnumbered males 35 to 20, giving a slight over-representation in our data. We did not want them to be like a clinical pop but just age and gender matched. There was a fairly equal distribution of groups, with a few exceptions. Exercise did appear to have a large effect on core endurance, which at face value seems to make sense. However, this needs to be interpreted cautiously since there were grossly more exercisers (51) than non-exercisers (4). Subjects with a history of, or who currently are competitive athletes outnumbered those with no history of being a competitive athlete 46 to 9. Lastly, those who had previously suffered any kind of upper extremity injury (46) to no previous injury (9) was also unequally represented. In retrospect, we should have also looked at upper and lower extremity dominance. Several of our tests had significance for one side plank but not the other. Previous research has found significant findings in regards to trunk muscle activation and hand dominance in tennis players.¹⁹ We would have liked to see if there was a relationship between dominance and the significance of those findings. A MANOVA was also run, but there was no further significance to the model versus the ANOVA. Further research will continue to collect data and strengthen current and future findings.

CHAPTER VI

CONCLUSION

The results of this study suggest that gender and exercise play a significant role in core endurance. Females had longer hold times for the extensor endurance test while males held the right and left side plank longer than females. Participants who exercised had significantly longer hold times for the extensor endurance tests, left side plank and 60-degree flexion test. Data suggests that regular general exercise and strength training may have a stronger correlation with increased overall core endurance than participating in exercises specific to the core musculature. This was determined due to the fact that participants who focused on core exercise weekly only showed a significant difference in hold times for left side plank and no other core endurance tests.

Further research is needed to determine true clinical norms. A larger study sample would allow for a better example of a clinical population. Increasing the number of participants in this study could help determine if the multiple regression model is significant and if low back pain and lower extremity injury affect core endurance and strength. Similarly, it would be necessary to have a more diverse study population in age, exercise participation, and past medical history to better represent a wider population.

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APPENDIX A

Subject Intake Form

Name: _____

Subject Number: _____

Gender: Male Female

Age: _____

Height: _____ feet _____ inches

Weight: _____

BMI: _____

Waist Circumference: _____ inches

Body Fat %: _____

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

History of Illness: (please circle all that apply)

Arthritis	Broken Bones	Osteoporosis	Low Back Pain
Neck Pain	Blood Disorders	Circulation/Vascular Problems	Heart Problems
High blood Pressure	Lung Problems	Stroke	Diabetes
Head Injury	Multiple Sclerosis	Parkinson's Disease	Seizures/Epilepsy
Allergies	Thyroid Problems	Cancer	Kidney Problems
Ulcers/Stomach Problems	Skin Diseases	Depression	Pregnancy
Upper Extremity Injury	Lower Extremity Injury	Other	

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

If female:

Are you currently pregnant? Yes No

Have you delivered a child previously? Yes No

If yes, how many? _____