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The effect of core strength on long distance running performance

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ABSTRACT

Training the core has become a topic of interest to athletes, health professionals, coaches and researchers. Core training may be an important supplementation to exercise programs. **PURPOSE:** The purpose of this study was to determine the effect of an eight week core exercise program on core function and half marathon run time in long distance runners. **METHODS:** Twenty-four well-trained distance runners were recruited from local running clubs to participate in this training study. Participants ran an average of 20 miles per week and were randomly assigned to the treatment group, receiving core exercises or the control group. McGill's four core tests, the Lafayette Stabilizer Platform and a Pressure Biofeedback Unit were used to measure core function. A simulated half marathon race was conducted to evaluate run time. All tests were performed before and after the eight week intervention. **RESULTS:** Results showed no significant interaction between core strength and running performance ($p<0.05$). A 1.76% ± 3.79% reduction in time for the treatment group versus a 0.79% ± 1.66% increase in time for the control group was observed, however, there was no significant main effect of the eight week training program on run time. A significant interaction was observed for the Lafayette Stabilizer Platform ($p<0.05$), Pressure Biofeedback Unit ($p<0.017$) and right ($p<0.025$), and left ($p<0.025$) side plank, however, simple effects revealed no significant effect of group on any of these core function variables. All other variables showed no significant interactions. **CONCLUSIONS:** The data indicate that eight weeks of core specific training does not result in improved half marathon run time. Core exercises increased strength and stability of the core musculature, however, this increase does not necessarily indicate a subsequent improvement in performance.

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The Problem and Its Scope

Introduction

Running has grown in popularity in recent years; evidenced by the increased number of running events, running clubs and prevalence in the media. Long distance running, half and full marathon races, have especially seen an increase in participation. Once a runner tastes a bit of success they often become interested in improving performance. Running stresses the entire body, activating various muscles to propel the body forward. It has been shown that the core muscles are activated while running (Fredericson & Moore, 2005**)**. These muscles, including abdominals, back, and gluteals, are important for providing stability to the spine so that damage is not accrued and the optimum production, transfer and control of force and motion is obtained (Kibler, Press & Sciascia, 2006). Core musculature strength and endurance has been shown to provide reduced risk of lower extremity injury or low back pain in athletes (Leetun, Ireland, Willson, Ballantyne, & Davis, 2004). Implementing a core strengthening program appears to be most beneficial when working on an unstable surface (Cosio-Lima, Reynolds, Winter, Paolone, & Jones, 2003). While there has been research to support improving core strength and endurance to reduce the risk of injury, there has been very little research on the effects of core strength on running performance, especially in highly trained athletes.

In order to determine the effect of core strengthening on performance, a comparison between the effectiveness of core exercises on strength and performance is needed. Understanding how core muscle function influences running performance would allow for better exercise prescriptions for long distance runners looking to improve their running speed. Previous research on the topic has shown mixed results, with some studies showing no significant differences in performance for pre and post-test measures after implementing a core strengthening routine (Nesser & Lee, 2009), while other studies demonstrate that increased core strength enhances performance (Sato & Mokha, 2009). More research is needed to better understand the effect of core strength on running performance.

Purpose of the Study

The purpose of this study was to determine if the addition of core strength exercises into a running program will influence running performance to a greater extent than running alone. Specifically, attempting to answer the question: "does a progressive core strengthening program positively influence performance in a half marathon?"

Hypothesis

In this study, the following null hypotheses were tested: there will be no significant difference in half marathon running performance when comparing subjects training in programs with or without the addition of core strengthening exercises. Also, there will be no significant difference in core function measures when comparing subjects performing or not performing the core strengthening exercises.

Significance of the Study

The role of core strength in improving running performance is not well researched especially with regards to healthy trained athletes. Specifically, there has been little research published examining the role of core strengthening in improving running performance of long distance runners. Conclusions gathered from this study will help eliminate some of the uncertainty behind the effects of the use of core exercises and running performance. A better understanding of core strength and long distance running performance would be valuable in designing exercise prescriptions for long distance runners, modifying individual training programs, and developing strategies for improving racing time.

Limitations of the Study

1. The age range, 18-65, of the participants in the present study may limit the application of the results to other age ranges.

2. Subjects were recreational long distance runners currently running at least 20 miles per week. The ability of the distance runners in the present study may limit the application of the results to more highly capable or less capable runners.

3. Subjects entered the study with varying levels of core strength and this may have influenced the effectiveness of the core strengthening program as well as the generalizabilty to other groups with more or less core strength.

4. Variations in body size, including height and weight, may impact the results. For example, someone who is shorter may have slower running times than someone who is taller due to proportionally different stride length.

5. Subject compliance to the intervention was verbally confirmed and may not reflect the actual compliance.

6. Current health status of each subject may have changed from pre to post test, impacting running performance.

7. Previous or current injuries may have influenced core strength and/or running speed of each subject.

8. The current training program of each participant may be more or less intense than the program provided to them in the study, leading to variable results.

Definition of Terms

Core- Includes muscles of the abdominal wall, low back, hips, gluteals and pelvic floor (Kibler, Press et al. 2006). Contains musculature that surrounds the lumbopelvic region and includes anteriorly the abdominals: transverse abdominis, rectus abdominis, internal/external obliques, posteriorly: paraspinals and gluteals, erector spinae, latissimus and quadratus lumborum, inferiorly: pelvic floor and hip girdle, laterally/medially: hip abductors, adductors and rotators and superiorly: diaphragm.(Hibbs, Thompson, French, Wrigley, & Spears, 2008; McGill, Grenier, Kavcic, & Cholewicki, 2003; Nadler, Malanga, Feinberg, Prybicien, Stitik, & DePrince, 2001).

Core endurance- The ability of the core musculature to hold a single position for an extended period of time (Liemohn, Baumgartner, & Gagnon, 2005).

Core stability- The ability to control the position and motion of the trunk over the pelvis and leg to allow optimum production, transfer and control of force and motion (Kibler, Press et al. 2006).

Core strength- The ability of the core musculature to exert force and power (Leetun, Ireland et al. 2004).

Half marathon- Running 13.1 miles at a maximal effort self- selected speed.

Running- A cycle comprising a stance phase where one foot is in contact with the ground and the other leg is swinging, followed by a float phase where both legs are off the ground and is continuous in nature.

Stable surface- A surface that does not include an instability component, such as the floor or an exercise bench (Cosio-Lima, Reynolds et al. 2003).

Unstable surface- A surface involving an instability component such as the Swiss exercise ball (Cosio-Lima, Reynolds et al. 2003).

BOSU- Both sides up stability trainer. Used as a progression tool for core exercises.

McGill's Core function tests- The four tests include the extensor test (Biering-Sorenson back extensor test), flexor test (abdominal fatigue) and side bridge tests (McGill, Childs, Liebenson, 1999).

Lafayette Stability Platform core test- A measure of core stability requiring a 4-point position on hands and knees on a stability platform with contralateral knee and arm extension. Subject score is the number of seconds that balance is maintained in each 30 second test. The metronome is set at 40 beats/minute and subjects alternately raise their arms in the sagittal plane at the shoulder joint 10 times in each 30 second test (Liemohn et al., 2005; Liehmohn, Baumgartner, Fordham, Srivatsan, 2010).

Stability Pressure Biofeedback Unit- inflatable pad of a Stabilizer Pressure Biofeedback Unit (PBU) is placed in the natural lordotic curve, while the subject lies supine and the unit is inflated to 40mmHg. The test consists of 5 levels with each level increasing in difficulty **(**Stanton, Reaburn, & Humphries, 2004).

Chapter II

Review of the Literature

Introduction

The purpose of this study was to analyze training programs for long distance runners, specifically, examining the effect of supplementing core exercises into a training program for half marathon distance runners. Despite the lack of evidence based research, many athletes are implementing core exercises into their regular training routines. A better understanding of core strength is needed to determine the effects of core strength on running performance, especially in healthy athletes.

For this review, information will be divided into seven major sections. Throughout these sections, definitions of the core, anatomy and performance will be discussed. First, descriptions of core stability, core strength and core endurance will be explained. Next, anatomy of the core muscles used in running will be highlighted and defined. An overview of the various ways to measure core stability will be examined and will describe the anatomy involved in core training. Core muscle activity during running will also be presented. Studies comparing the various types of core training exercises and specifically those deemed appropriate to provide a runner with the most improvement will be discussed. To provide an overview of the effects of core strength and running speed, core training and performance will be examined. Lastly, core strength and its relationship to running injuries will emphasize the importance of core training and the musculature involved while running.

Review of the Pertinent Literature

Core stability, strength, and endurance. Core stability refers to stability of the spine. There is no universally accepted definition of core stability. A general definition is the ability to control the position and motion of the trunk over the pelvis and leg to allow optimum production, transfer and control of force and motion to the terminal segment in integrated kinetic chain activities (Kibler et al. 2006). Core stability is the product of motor control and muscular capacity of the lumbo-pelvic hip complex (Leetun et al. 2004). It is based on three subsystems, the passive spinal column, active spinal muscles and a neural control unit. The passive subsystem consists of the osseous and articular structures and the spinal ligaments. The active subsystem consists of the force generating capacity of the muscles and the neural control subsystem controls the muscles to produce spinal support (Panjabi, 1992). Core stability requires coordination in addition to core strength and endurance (Liemohn et al. 2005). Abdominal muscular endurance and strength and torso balance are important for trunk stability, appropriate posture and body movements during sports (Cosio-Lima et al. 2003). Core stability is an umbrella term used to explain core strength and core endurance. However, strength and endurance should be discussed separately as they contribute to stability of the core differently.

Core strength is often interchanged with core stability. However, core strength is a component of core stability; the two terms are not synonymous. Core strength is the muscular control required around the lumbar spine to maintain functional stability (Akuthota & Nadler, 2004). Developing core muscle strength may help keep ground reaction forces within an optimal range which increases stability of an individual (Sato & Mokha, 2009). There are numerous ways to measure strength of the core musculature and while some tests emphasize strength and/or endurance (Liemohn, et al., 2005), there is no standard measure.

It has been suggested that core strength and power might be important for improvements to the core in sports related performance measures. Leetun, Ireland, Willson, Ballantyne, and Davis (2004) compared core stability measures between genders and between athletes who reported an injury during their sport season. One hundred and forty intercollegiate male and female athletes participated. They were tested for strength in anterior, posterior and lateral muscles that contribute to core stability. The results of the strength tests suggested that individuals who remain uninjured over the course of the sports season had significantly greater core strength measures than those who reported an injury. When comparing males and females, males generally demonstrated greater core stability measures. These results also suggested that improving strength of the hip, external rotators and abductors may diminish the tendency for femoral internal rotation and adduction frequently observed in athletes with patellofemoral pain. Furthermore, the authors suggested that hip and trunk weakness reduces the ability to stabilize the hip and trunk making one more vulnerable to the large external forces experienced during athletics. Hip external rotation strength weakness most closely predicted injury status over the season. Maintaining strength in the paraspinals and gluteus muscles provides an athlete with greater opportunity for reducing risk of injury over the course of a season demonstrating their importance to the strength in the core musculature (Leetun et al., 2004).

Although core strength and power may be more important for improving performance (vertical jump, speed, agility), core endurance appears to be more important for injury prevention and rehabilitation. Liemohn, Baumgartner, and Gagnon (2005) suggest that because only a minimal level of muscle contraction is required to stabilize the spine, muscle endurance may be more important than core strength. It may be appropriate that endurance be trained before strength while focusing on establishing the correct motor control to train both the fast and slow motor units in a muscle to optimize core stability and core strength. Enhancing core stability through exercise might be more effective with an approach consistent with endurance, not strength, that ensures a neutral spine posture when under load or more specifically avoids end range positions and ongoing abdominal contraction and bracing. Other components of core stability, such as muscle capacity, are represented by the athlete's ability to generate and maintain force (endurance) in the lumbo-pelvic-hip complex (Cholewicki, Simons, & Radebold, 2000).

Anatomy of core muscles used in running. Running requires activation of many different muscles to propel the body in a forward linear motion. A runner utilizes the entire lower body (the ankles, knees, and hips) and specifically works the hip flexors, the quadriceps, the hamstrings, gluteals and the gastrocnemius and soleus muscles. Running requires lumbo-pelvic support, which comes from key stabilizing mechanisms of the core to help pull the knee forward. The gluteus maximus is important for stabilizing the pelvis during trunk rotation or when the center of gravity is shifted, while the hamstrings play a more significant role during activities such as running (Montgomery, Pink and Perry, 1994). Core activity is involved with almost all upper and lower extremity activities such as running, kicking and throwing. The core includes muscles of the abdominal wall, lumbar musculature and the associated hip and pelvic musculature. Additionally, both the stabilizing muscles and prime mover muscles attach to the core. Similar to the fact that there is no universal definition for the core, there is no definitive list of muscles that make up the core. The core is commonly viewed as a box or a double walled cylinder. The abdominals make up the front, paraspinals and gluteals in the back, the diaphragm is the roof and the pelvic floor and hip girdle musculature are the bottom (Fredericson & Moore, 2005). Most torso muscles are important, depending on the activity an individual is engaged in. The torso muscles include muscles that are attached directly to vertebra; the uni-segmental multisided and the multi-segmented quadratus lumborum, longissimus and iliocostalis together with the abdominal wall (McGill et al. 2003).

The abdominal muscles make up the anterior portion of the core. Abdominal muscles engaged during core activation include the transverse abdominis, rectus abdominis, external oblique and internal oblique. These are all essential muscles to monitor when analyzing core stability and core strength. The transverse abdominis is selectively activated (for muscle reeducation) by dynamically "hollowing" in the abdominal wall, whereas an isometric abdominal brace co-activates transverse abdominis together with the external and internal obliques to ensure stability in virtually all modes of possible instability (Kibler et al., 2006). Contribution of the abdominal muscles to stability is related to their ability to produce flexion, lateral flexion and rotation movements and control external forces that cause extension, flexion and rotation of the spine. The abdominal muscles are considered stabilizing muscles, muscles that are modulated continually by the central nervous system and provide feedback about joint position. The stabilizing muscles generally result in isometric contractions that support the core, limit movement in a joint and control balance. These muscles keep certain parts of the body steady so that the primary working muscles can do their job properly.

Stabilizing muscles are also responsible for maintaining posture and distributing and absorbing force in the body whereas mobilizing muscles contribute to rapid movement force and power because of their multi-joint positioning and large movement (Hibbs et al. 2008).

The posterior portion of the core is made up of the paraspinals and gluteals, erector spinae, latissimus dorsi and quadratus lumborum. The gluteus maximus plays a major role in stabilizing the pelvis during trunk rotation or when the center of gravity is grossly shifted, while the hamstrings play a more significant role during activities such as running. Poor endurance and delayed firing of the hip extensor (gluteus maximus) and abductor (gluteus medius) muscles have previously been noted in individuals with chronic low back pain and lower extremity instability**.** Hip abductors and adductors along with the internal and external rotators also play an important role in lower extremity alignment. They assist in the maintenance of a level pelvis and in the prevention of movement into hip adduction and internal rotation during single limb support (Schache, Bennell, Blanch and Wrigley, 1999).

The diaphragm is considered the superior aspect of the core. Simultaneous contraction of the diaphragm, the pelvic floor muscles and the abdominal muscles is required to increase intra-abdominal pressure providing a more rigid cylinder for trunk support, decreasing the load on the muscles of the spine and allowing increased trunk stability. The diaphragm contributes to intra-abdominal pressure before the initiation of limb movements, thereby assisting spine/trunk stability. The activation occurs independent of the respiratory actions (Kibler et al. 2006).

The pelvic floor and hip girdle make up the inferior aspect of the core. Stability of the lumbo-pelvic region is crucial to provide a foundation for movement of the upper and lower extremities to support loads and to protect the spinal cord and nerve roots (Willardson, 2007). The pelvis is critical for the transfer of energy from the larger torso to the small extremities, which may be more involved in sporting movements than everyday tasks (Hibbs et al. 2008). The hip extensors and abductors play a major role in all ambulatory activities, stabilizing the trunk and hip and helping transfer force from the lower extremities to the pelvis (Nadler et al. 2001)

The requirements for stability can change instantaneously based on postural adjustments or external loads accepted by the body, resulting in core musculature activation. Researchers focusing on sports performance define the core as including all of the anatomy between the sternum and the knees with a focus on the abdominal region, low back and hips (Hibbs et al. 2008). Due to unexpected requirements on the core muscles to provide strength and stability to someone running on uneven terrain it is important to understand the muscles involved in keeping the person steady. This understanding of core musculature can help with exercise prescription of appropriate core exercises that will engage all muscles in the correct sequence and balance for runners interested in modifying their training routine and increasing core strength

Measuring core function. There are numerous ways to measure the strength of the core musculature. Leetun et al. 2004, used a Biodex dynamometer to test the strength of core muscles specifically the hip extensors and abductors and anterior and posterior muscles. A dynamometer is a device used for measuring force or power. It is commonly used for back, grip, arm and leg strength in athletes to evaluate physical status, performance and task demands (Pintar, Learman, & Rogers, 2009). Tse et al. 2005, and Nesser & Lee 2009, have also used tests suggested by McGill as a measure of core muscle capacity, including side bridge, extensor test (back extensor test) and flexor test (abdominal fatigue test). Some studies also use electromyography (EMG) as a technique to evaluate and record the activation signal of muscles. EMG provides insight for muscle recruitment patterns while performing certain tasks and is typically used to evaluate low back pain (Behm, Leonard, Young, Bonsey, & MacKinnon, 2005). Another measure for core strength is the "Sahrmann test" in which a pad is put under the low back and subjects perform five levels of tests with each level increasing in difficulty. Changes in the position of the spine are recorded by measuring pressure changes in the pad under the subjects back (Stanton, Reaburn, & Humphries, 2004).

McGill et al., (1999) identified a number of tests as valid and reliable in assessing endurance of the core musculature. The four tests include the extensor test (back extensor test), flexor test (abdominal fatigue) and side bridge tests which have reliability coefficients between 0.97 and 0.99. The back extensor tests used is the Biering-Sorensen test which has also been shown to be consistently reliable as a measure of low back extensor endurance. During this test the upper body is extended out over a table with the lower legs secured and the subject attempts to maintain a 180 degree angle between the upper and lower body. The arms are folded across the chest with the hands held on opposite shoulders. The test is terminated when the subject’s upper body falls below the horizontal position and time is recorded. The abdominal fatigue test is performed by having the subject sit on a bench with a back support that is at a 60 degree angle. Both the knees and hips are flexed at 90 degrees and the feet are fixed securely to the bench with a strap and towel. The arms are folded across the chest with the hands placed on opposite shoulders. Subjects lean against a 4 inch thick rubber pad that is wedged between their back and the 60 degree back rest. Subjects are instructed to maintain their body position once the supporting wedge is removed to initiate the test. The test is ended when the upper body can no longer maintain a 60 degree angle. The side bridge test starts with the subject lying on either side with the legs extended. The top foot is placed in front of the lower foot for added support. Subjects are instructed to support themselves on only the elbow, forearm and feet. The hips are raised off the floor and a straight body position is maintained in the frontal plane. The non-supporting arm is held across the chest with the hand placed on the opposite shoulder. The test is terminated when the hips begin to sag and body position cannot be maintained or when the lower leg starts to rest on the floor. During each test, subjects should be reminded that these are maximum effort tests and they should maintain each position for as long as possible**.** Normal values for each of these tests are in seconds as follows: side bridge, 83-86 seconds, abdominal fatigue test, 34 seconds, and back extension, 173 seconds (McGill at al. 1999). The McGill tests have been utilized by many research teams in combination with other tests to evaluate subject's core strength and endurance (Tse et al. 2005; Leetun et al. 2004).

Leetun et al. (2004) compared core stability measures between genders and athletes who reported lower extremity injury during their season versus those who did not. Strength of the anterior, posterior and lateral muscles that contribute to core stability was tested using four testing stations. Hip abduction isometric strength testing was performed with subjects positioned in side-lying on a table. A pillow was placed between the legs to abduct the hip to approximately 10 degrees as measured with respect to a line connecting the anterior superior iliac spines. In order to stabilize the subject's trunk a strap was placed just proximal to the iliac crest and secured firmly. The center of the force pad of a Nicholas hand-held dynamometer was then placed directly over a mark 5 cm proximal to the lateral knee joint line. The dynamometer was secured between the leg and the underside of the table. The subject was instructed to push the leg upward with maximal effort for 5 seconds and the force value was recorded. One practice trial and 3 experimental trials were completed on both sides.

Hip external rotation isometric strength testing was performed with subjects seated on a padded chair with the hips and knees flexed to 90 degrees. To limit the contribution of hip adductors to force production in rotation, a strap was used to stabilize the thigh of the involved leg and a towel roll was placed between the knees. Force values were recorded for 3 experimental trials for each leg. Muscle capacity of the posterior core was measured using the modified Biering-Sorensen test. The subject was in a prone position with the pelvis at the edge of a treatment table. Straps were used to secure the pelvis and legs to the table. The torso was supported with the subject's hands on a bench in front of the table until they were instructed to cross their arms and assume a horizontal position. The total time the subject was able to maintain the horizontal position until they touched down on the bench in front of them with their hands was recorded with a stopwatch.

Lateral core muscle capacity, particularly the quadratus lumborum, was measured using the side bridge test described by Stuart McGill. Subjects were positioned in right side lying position with their top foot in front of their bottom foot and their hips in zero degrees of flexion. Subjects were asked to lift their hips off the table using only their feet and elbow for support. The opposite arm was held across the chest with the hand placed on the shoulder. The total time the subject was able to lift their bottom hip from the table was recorded. The test was only performed on the right hand side due to documentation that there was no significant difference in right and left side bridge endurance times.

Anterior core muscle testing was performed using the straight leg lowering test. The subject lay supine on a table with their hips flexed to 90 degrees and knees fully extended. Subjects were asked to steadily lower their legs back to the table over a 10 second period while maintaining contact with the examiners hand at the L4-L5 interspace. A board was placed behind the subject during testing with marks indicating 10 degree increments of hip flexion. The angle at which the low back raised from the examiners hand was recorded. Lower angles of hip flexion indicated better performance on the test. The authors questioned the sensitivity of the straight leg lowering test and used a different test for subjects in the second year of this study. A flexor endurance test as described by Stuart McGill was used to measure strength of the anterior core muscles. This test was performed seated on a table with the back supported on a 60 degree wedge (measured from horizontal). The subjects hands were crossed across the chest and their toes were placed under a stabilization strap. Subjects were asked to maintain the position as the supporting wedge was pulled 10 cm away from the body. The time the subject was able to maintain the 60 degree angle was recorded. The test ended when the angle of the athlete’s upper body fell below the 60 degree threshold. This test was found to be a more sensitive indicator of anterior core muscle capacity than the straight leg lowering test based on a larger range of evenly distributed values.

The results showed that the core stability measures included in this study generally demonstrated moderate but significant correlation. Side bridge scores were significantly correlated with performance on all other postural muscle tests. Side bridge scores were 84.3 ± 32.5 s for men and 58.9 ± 26.0 s for women. Back extension demonstrated a very low correlation with hip abduction and external rotation isometric strength measurements and scores for this test were 130.4 ± 40.0 s and 123.4 ± 48.4 s, respectively for men and women. Uninjured subjects had a back extension score of 128.3 ± 43.6 s and a side bridge score of 121.6 ± 48.9 s. Side bridge scores for injured participants were 72.0 ± 32.4 s and 64.7 ± 28.8s for the back extension test. The data suggests that males on average outperform their female counterparts during static core strength tests such as side bridge and back extension. There is also evidence that testing performance is higher in non-injured individuals compared to individuals who have an injury (Leetun et al, 2004).

Stanton et al. (2004) investigated the effect of short-term Swiss ball training on core stability and running economy. Eighteen male subjects were assessed before and after a training program for stature, body mass, core stability, EMG activity of the abdominal and back muscles, treadmill VO_{2max}, running economy and running posture. Core stability was evaluated using the Sahrmann core stability test. The inflatable pad of a Stabilizer Pressure Biofeedback Unit (PBU) is placed in the natural lordotic curve, while the subject lies supine and the unit is inflated to 40 mmHg. The test consists of five levels with each level increasing in difficulty. Level 1 requires the participant to activate the abdominal musculature bracing the trunk in an isometric fashion without movement being produced. Once this is achieved the subject slowly raises one leg to 100 degrees of hip flexion, with comfortable knee flexion. The opposite leg is brought up to the same position in the same manner with a change in pressure on the PBU no more than 10 mmHg. A pressure reading greater or less than 10 mmHg indicates lumbo-pelvic stability was lost at this level. This level 1 position was used as the start position for subsequent levels of the test protocol. Level 2 from the start position the subject slowly lowers one leg such that the heel contacts the ground. The leg is then slid out to full knee extension and then returned to the start position. Level 3 from the start position requires the subject to slowly lower one leg reaching the heel 12 cm from the ground. The leg is then slid out to fully extend the knee and returned to start. Level 4 from the start position the subject slowly lowers both legs so the heals contact the ground. The legs are slid out to extend the knees and returned to the start position. Level 5 from the start position the subject slowly lowers both legs, heels reaching 12 cm from the ground, the knees are extended and brought back to the starting position. In order to attain each new level of the Sahrmann test, the lumbar spine position had to be maintained as indicated by a change of no more than 10 mmHg in pressure on the PBU.

Subjects also performed a Swiss ball prone stabilization test that required them to adopt a push up position with the elbows locked and the toes placed on the vertical apex of a Swiss ball. EMG and video analysis was collected to determine time to failure by observing the change in hip flexion angle as well as muscle activity during core testing. The participant was required to hold this position as stable as possible until failure to maintain the position was observed during subsequent video analysis. The treatment group underwent 6 weeks of Swiss ball training. Exercises were performed twice per week for approximately 25 minutes. Exercises included lunges, supine lateral roll, alternating superman, forward roll on knees, supine leg bridge and supine Russian twist, descriptions of these exercises were exclude from the article.

The results showed that 6 weeks of Swiss ball training significantly improved performance on the Sahrmann test and Swiss ball prone stabilization test. The control group showed no significant performance difference on either the Sarhmann test or prone stabilization test. Participants in the control group were on average able to attain a level of 0.5 in the Sarhmann test and reached 20 s before failure in the prone stabilization stability test. Individuals in the experimental group did show significant improvement on both core function tests. After 6 weeks, the Sarhmann level went from an average 0.5 to 1.5 and the time to failure during prone stabilization went from 25 s to 40 s suggesting that the core strengthening exercise program was effective in improving core strength on these two specific tests. No significant results were found in VO_{2max}, running economy or running posture (Stanton et al. 2004).

Sato and Mokha (2009) utilized the Star Excursion Balance Test (SEBT) to measure core strength and lower extremity stability in long distance runners. Tape was placed in 8 directions bisecting each other at 45 degree angles on the floor, only 3 of 8 directions were used in the study to reduce the chances of fatigue during the test. Before the SEBT, subject leg length was measured to calculate a ratio of the total score of the SEBT and leg length. The test was performed barefoot to eliminate extra balance and stability from shoes. Each subject placed his/her left foot on the center of a 0-180 degree line and reached out their toes as far as possible to the direction of 0, 90, and 180 degree lines while maintaining balance. The test was performed on both right and left sides. Subjects lightly touched the maximum reaching point while in a static position for at least

3 seconds to ensure their ability to maintain stability. Two trials in each condition were performed by all subjects. The length between the toes of the reaching foot and the starting position of the stable foot were measured with a tape measure. The SEBT evaluates the stability of the hip. A Trendelenburg sign may be apparent, indicating weak hip abductor muscles. Lumbo-pelvic control and balance are also assessed and any functional differences between the planes are noted and incorporated into the training. After the 6 weeks of core strength training performance on the SEBT significantly improved. SEBT scores increased for both groups during the 6 weeks, however, there was greater improvements seen in the experimental group. Reaching length improved by +10.25 cm in the control group and +21.92 cm in the core strength training group, however these results were considered to be not significant. The improvements seen in the control group may be due to test-retest effect which may explain why the interaction effects were not significant. The core strength training group performance on the SEBT post- test was much greater than the control group suggesting improvement in dynamic stability (Sato & Mohka, 2009).

Liemohn et al. (2010) investigated the reliability of the Lafayette Instrument Co. stability platform for measurement of core stability. The core stability activity that was tested was the quadruped arm raise because it is an exercise commonly used in low back rehabilitation. Subjects are in a 4-point position, on hands and knees, on the stability platform and contralateral knee and arm extension is required. Subject score was the number of seconds that balance was maintained in each 30 second test. The metronome was set at 40 beats/minute and subjects alternately raise their arms in the sagittal plane at the shoulder joint 10 times in each 30 second test. The 10 trials were performed on four different days to determine reliability and consistency of the testing procedures. The mean trial scores on the first day were markedly lower than on other days of testing along with the first trial of the test for days 2 through 4, which may be explained by a practice effect. For this reason, participants' scores for a day was the mean score of trials 2-6. Interclass reliability coefficients for the mean of the scores for trials 2-6 within a day were 0.97 for day 1, 0.89 for day 2, 0.95 for day 3 and 0.92 for day 4. Day one had the highest reliability, however, it represented the lowest means and the largest standard deviations. Therefore internal consistency reliability was calculated for testing days 2, 3 and 4 and the results showed consistent trial means and reliability coefficients amongst the days. Administering 10 trials of the balance test on days 1 and 2 and 6 trials on day 3 is sufficient to obtain a test score with good consistency and reliability. The test score would be the mean of trials 2 through 6 on day 3 of testing with trial 1 representing a practice/warm-up trial (Liemohn et al. 2005; Liemohn et al. 2010).

Core function can be measured in many different ways. Research has shown that some tests may be more reliable for testing strength, stability and endurance of the core muscles. Due to the disagreement of which muscles make up the core, it can be difficult to measure core strength. More research is needed to determine which test provides the most accurate reflection of core function.

Core muscle activation in running. Running involves a series of unilateral hip flexion and extension movements that can place considerable destabilizing torques on the trunk. To run efficiently and smoothly, the trunk muscles must stabilize the upper body from the moments and reaction forces of the lower limbs. Efficient runners attempt to exert their propulsive forces such that their body is moved in a linear manner. Less activation of the core musculature would not efficiently absorb the disruptive torques of the unilateral reactive running movements. The trunk and body would tend to rotate in reaction to the limb induced moments. Limb forces would then be exerted at angles that would divert the runner from the intended path, i.e. a straight line (Behm, Cappa, & Power, 2009).

Investigations of trunk control during locomotion have described an association between foot strike and low level (0-10% maximum voluntary contraction) phasic activity of superficial paraspinal and abdominal muscles. With respect to the superficial abdominal muscles (rectus abdominis, external oblique and internal oblique) most authors have found no activity or no clear relationship to lumbo-pelvic motion during walking but high activity associated with foot strike in running (Callaghan, Patla, & McGill, 1999; Mann, Moran, & Dougherty, 1986). In contrast to the superficial muscles, the deep abdominal muscle, the transversus abdominis (TrA), is tonically active during walking and running at speeds up to 3 $m \cdot s^{-1}$. Tonic activity of the TrA during locomotion is consistent with the contribution of this muscle to segmental control of the spine and pelvis and support of the abdominal viscera (Hodges, Holm, Ekstrom, Cresswell, Hanson & Thorstenson, 2003). It has also been argued that the TrA has a limited moment arm to generate torque at the pelvis and spine and would contribute little to control of lumbo-pelvic motion (McGill, 1996). The discrepancy in views regarding the TrA activity and it relationship lumbo-pelvic motion during running is unclear and more research is needed.

In 2005, Saunders, Schache, Rath and Hodges investigated the changes in 3D lumbo-pelvic kinematics and trunk muscle EMG across a range of walking and running speeds. Seven subjects, all right side dominant, participated in the study. The EMG recordings were made from trunk muscles on the right side including the transverse abdominis, external oblique, internal oblique, erector spinae and rectus abdominis. Gait cycle parameters (e.g. foot strike and toe off) and 3D motion of the lumbar spine and pelvis were identified using a motion analysis system. Data was collected while subjects walked and ran on a treadmill. The results showed that during walking and slow running small amplitude lumbo-pelvic motion occurs in each plane and is associated with low levels of trunk muscle activity. A single peak of lumbar motion relative to the pelvis was identified in the frontal plane during walking and running. Two peaks of lumbo-pelvic motion occurred in the sagittal plane and a single peak in the transverse plane during running. Amplitude of the lumbo-pelvic peaks in all three planes was higher during running compared to peaks during walking. With increased running speed there was no change in timing of peak EMG for any muscle. The TrA was tonically active with walking and running at speeds less than 3 $m \cdot s^{-1}$. In running at 5 $m \cdot s^{-1}$ the first internal oblique peak occurred prior to the first peak of the TrA, external oblique and the deep and superficial multifidus. Most periods of peak EMG coincided with foot strike during walking but occurred later in the stance phase while running. This coincided loosely with stance phase reversal and kinematic transitions in the frontal and sagittal planes. Peak external oblique EMG occurred at the transition from right to left rotation during running when the muscle is maximally lengthened and from left to right during walking. With progression to faster running speeds, increased lumbo-pelvic motion is associated with augmented abdominal and superficial muscle activity. In general, periods of peak trunk muscle activity during running were associated with eccentric phases suggesting trunk muscles play a critical role in decelerating lumbo-pelvic motion during running (Saunders et al. 2005).

Montgomery et al., (1994) described the firing pattern of 11 hip and knee muscles during running. Thirty recreational and low-level competitive runners who were running at least 15 miles per week participated in the data collection. Sixteen subjects had 8 muscles tested: rectus femoris, vastus medialis, vastus intermedius, vastus lateralis, iliacus, semimembranosus, biceps femoris short head and biceps femoris long head. Fourteen subjects had 3 muscles tested: adductor magnus, tensor fascia latae and lower gluteus maximus. Recording of the signal was measured using the Basmajian single needle technique. Each runner completed at least 5 passes at every pace of running: jogging (8.45±0.90 min/mile), training (6.48 ± 0.70 min/mile) and race (5.44 ± 0.72 min/mile). A 16-mm high speed camera capturing 100 frames per second was positioned for a sagittal plane view and recorded the subject's performance. The four phases recorded were stance phase (beginning with right heel strike and ending with right toe off), early swing phase (beginning with right toe off and ending with left heel strike), mid-swing phase (beginning with left heel strike and ending with left toe off) and late swing phase (beginning with left toe off and ending with right heel strike).

The results showed differences in muscle activity during the four phases of running. During the stance phase, the three heads of the vasti and the rectus femoris all contracted to stabilize the knee during the loading response. Without this contraction, the knee undoubtedly would have buckled as it accepted the body weight. The three heads of the vasti had greater activation than the rectus femoris, suggesting they play a more vital role in knee stabilization. The adductor magnus, lower gluteus maximus and tensor fascia latae were also active during the loading response when there was forward momentum; they functioned to stabilize the hip medially, laterally and posteriorly. Thus as the lower extremity accepted the body's weight and the momentum was moving forward, muscles from both the hip and knee were active for stabilization.

Data from the early swing phase showed the short head of the biceps femoris muscle increased activity as it initiated knee flexion. The semimembranosus and long head of the bicep femoris were silent. The vastus intermedius showed increased activity as it contracted eccentrically, controlling knee flexion. As pace increased the vastus intermedius was the only vastus muscle that was active during the early and middle swing phase. The rectus femoris, iliacus, tensor fascia latae and adductor magnus all demonstrated activity in controlling the hip extension and in preparing to initiate hip flexion. During the middle swing phase the iliacus and rectus femoris showed peak activity as the hip flexed. The tensor fascia latae and adductor magnus muscles demonstrated activity as they assisted hip flexion from an extended position and stabilized the pelvis. The semimembranosus and long head of the biceps femoris contracted eccentrically controlling the hip flexion. The lower gluteus maximus assisted the hamstrings only during the race pace. The three vasti were activated in extending the knee during the late swing phase. The semimembranosus, long head of the biceps femoris, and lower gluteus maximus were active for hip extension with assistance from the adductor mangus muscle, which could extend the hip from the flexed position. The tensor fascia latae was active in controlling the hip extension. With an increase in pace the muscles in the core as well as the lower extremity, not only increase their eccentric activity but also must withstand more rapid and severe lengthening of the muscles. Due to this increased activation it is recommended that strength training for recreational runners should concentrate on eccentric strengthening of the hip and knee flexors and extensors (Montgomery et al. 1994).

Behm et al. (2009) suggested that running is an effective and safe method for activating dorsal and ventral trunk musculature, and additional trunk specific callisthenic exercises such as sit ups and back extension may not be necessary. The objective of the study was to ascertain the extent of dorsal and ventral trunk muscle electromyographic (EMG) activation during two intensities of running and to compare the extent of activation to typical trunk specific exercises (i.e., curl-up and back extension) in run trained and non-run-trained individuals. Seventeen subjects participated in three experimental sessions. Seven subjects were highly trained tri-athletes and 10 were highly active non-run trained. EMG of the ventral and dorsal trunk musculature included external oblique, lower abdominals, lumbosacral erector spinae and upper lumbar erector spinae. Muscle activity was recorded while subjects ran on a treadmill at 60% of their maximal heart rate reserve (HRR) for 30 min, 80% HRR for 30 min, while performing 30 curl-ups and 180 second isometric back extension posture.

The most important findings of this study were that tri-athletes had greater trunk activation (external oblique, lower abdominal and lumbo-sacral erector spinae) than non-run trained subjects. Also, moderate and high intensity running provided greater activation of back stabilizer muscles than prolonged back extension. The curl ups provided higher activation of the external oblique than running and the lower abdominal activity was equal with running and repetitive curl-ups. The greater activation of the external oblique, lower abdominals and lumbosacral erector spinae by the tri-athletes may have contributed to their enhanced running performance which could be attributed partially to a greater absorption by the trunk muscles of disrupting torques generated by the lower limbs. These results suggest that an instability inducing exercise such as running, which involved unilateral hip flexion and extension movements, provides an activation stimulus to trunk stabilizing muscles that is greater than or similar to that of callisthenic exercises but is not as effective as a prime move of the trunk. Furthermore, highly trained runners such as tri-athletes demonstrated greater trunk activation than non-run training participants suggesting that prolonged run training may specifically train the trunk stabilizers, contributing to their greater running performance. These findings suggest that additional callisthenic exercises may not be necessary with moderate or high intensity run training which may help counter time constraints as a barrier to exercise. However, greater activation and training of the external oblique as a prime mover may be augmented with trunk callisthenic exercises such as the curl-up. Running may be considered a safe, effective and efficient multifunctional training activity for cardiovascular and trunk muscle endurance benefits (Behm et al. 2009).

While running, muscles of the core and lower extremity are activated at different times during the leg cycle. As a runner increases his/her speed muscle activation increases, suggesting more eccentric muscle activity (Montgomery et al. 1994). Research suggests that core musculature is important for absorbing the torque and force from the lower limbs (Behm et al. 2009). Supplementing a core training program could possibly increase a runner’s core strength and stability which could further aide in reaction force absorption as well as improve performance.

Core training exercise programs. Research has shown that there are various ways to train the muscles of the core. Determining which exercises improve core strength most effectively requires further research. Core related exercises such as Swiss ball training, balance training, weight training and yoga have become popular physical activities even among general populations in recent years (Sato & Mokha, 2009). Due to the many methods available to train the core, it is important to incorporate a variety of exercises to be sure to activate all appropriate core musculature. It is suggested that exercises prescribed for strengthening or increasing the endurance of the core stabilizers for activity of daily living, sports performance or rehabilitation should involve an instability component (Tse et al. 2005). The floor curl-up and back extensions are often used to evaluate and develop abdominal musculature endurance and strength (Cosio-Lima et al. 2003). The optimal technique to maximize activation but minimize the spine load appears to be the side bridge. Lateral musculature exercises are performed, namely the side bridge for quadratus lumborum and muscles of the abdominal wall for optimal stability. The main emphasis of core strengthening is focused on muscular stabilization of the abdominal, paraspinals and gluteal muscles to provide better stability and control for sporting activity (Nadler et al. 2002).

The purpose of incorporating core strength training is to increase strength for better movement control, especially to optimize running kinetics in the lower extremities (Sato & Mokha, 2009). Middle distance runners have a unique and specific training program that demands strength, power and endurance. These runners place significant demands for balance and precise functioning on the structures all the way from the core to the feet. Specific exercises for the runner should progress from mobility to stability and reflexive motor patterning, to acquiring the skills of fundamental movement patterns and finally progressive strengthening (Fredericson & Moore, 2005)

It has been suggested that Swiss ball exercises are an effective tool for training core stability. Research has demonstrated higher core muscle activity when resistance exercises were performed on a Swiss ball versus a stable surface. Behm, Leonard, Young, Bonsey, and MacKinnon (2005) evaluated the effect of unstable and unilateral resistance exercises on trunk muscle activation. Subjects performed 6 core exercises on either a stable bench or an unstable surface (Swiss ball) as well as bilateral and unilateral chest and shoulder press. The exercises included bridge, pelvic tilt, alternate arm and leg extension, parallel hold, side bride, superman, chest press and shoulder press.

In the bridge exercise, subjects lied supine on the floor with knees bent at 90 degrees. Legs were placed on the bench or ball and the hips were raised until the torso was 45 degrees to the floor. The pelvic tilt required subjects to sit with their feet flat on the floor and contract the hip flexors and extensors to rotate their hips in a posterior and anterior direction. The alternate arm and leg extension included a 4-point stance on the hands and knees, the contralateral arm and leg were extended until both were parallel to the floor. When the Swiss ball was used, subjects lied on the ball with their abdomens and performed the exercise. In the parallel hold subjects lie prone with their feet either on the floor or the ball and pushed up until their arms were straightened. Side bridge involved subjects lying on their side with their legs straight and elevated on a platform. Subjects elevated their hips until their torso was 45 degrees to the floor; this exercise was performed on both left and right sides. To perform the superman exercise, subjects lie prone with shoulders, arms, hips and legs extended. Feet were shoulder width apart and flat against a wall for support. The chest press required subjects to lie supine on the support with their feet on the floor and knees bent at 90 degrees. Bilateral contractions started with upper arms parallel to the floor and elbows bent at 90 degrees, weight was pushed until the arms were fully extended. Chest press was also performed unilaterally and the non-weight supporting arm was kept resting at the waist. Shoulder press was performed seated with the upper arms parallel to the floor and elbows at 90 degrees. Subjects fully extended weights both bilaterally and unilaterally. Each trunk exercise was performed twice and held for 3 seconds with a 2 minute rest between each exercise.

The results showed that performing core exercises on a Swiss ball resulted in significantly greater activation of the lower abdominal region compared to stable surfaces. Increasing the degree of instability resulted in greater activation of the trunk stabilizing muscles. From these results it is suggested exercises prescribed for strengthening or increasing the endurance of the core stabilizers for activities of daily living, sports performance or rehabilitation should include a destabilizing component. (Behm et al. 2005)

Another study performed by Cosio-Lima et al. (2003) also suggested performing exercises on the physioball may increase proprioceptive demand and stress the core muscles that are important for balance and stability in sports. The study suggested that performing curl-ups and back extensions on the physioball may be a better method for strengthening core muscles since exercises are performed on an unstable surface. During a 5 week training program core stability and balance were measured in 30 female subjects. Fifteen women performed curl-ups and back extension on a physioball and the control performed the same exercises on the floor. The program consisted of 5 days of training per week with sessions lasting 15 minutes in duration. The first week required all women to perform 3 sets of 15 repetitions of each exercise, alternating back extension and curl-up. The second week consisted of 4 sets of 15 repetitions of each exercise. During the 3rd and 4th week, training included 4 sets of 20 repetitions and week 5, 4 sets of 25 repetitions of each exercise. The results showed significant increases in abdominal and erector spinae muscles' EMG activity and duration of static balance times also increased after implementing core training on an unstable surface. Therefore it is evident that performing abdominal and back exercises on unstable surfaces stresses the musculature and activates the neuroadaptive mechanisms that lead to the early phase gains in stability and proprioceptor activity (Cosio-Lima et al. 2003).

Sato and Mokha (2009) implemented a core strength training program into long distance runners training routine. The control group did not receive any core strength training and were instructed to maintain their training routines. The treatment group received a core strength training program that consisted of 5 core-related exercised performed 4 times per week for 6 weeks. Five exercises included the abdominal crunch on a stability ball to target abdominal muscles, back extension on a stability ball to target back extensor muscles, hip raise on a stability ball to target back and hip extensor muscles, supine opposite 1-arm/1-leg raise to target hip and back extensors and the Russian twist to target abdominal muscles. After six weeks of training the experimental group's performance on core strength tests improved as well as improved 5000 m run time. The control group on average improved running time by 0:17 min:s and the experimental performance improved by 0:47 min:s. Both groups were equally affected by minor limitations such as climate difference between pre and post tests and increasing weekly mileage during the six weeks. The results suggest that 6 weeks of core strength training may improve running times to a greater degree (Sato & Mokha, 2009).

Carter, Beam, McMahan, Barr and Brown (2006) studied the effects of stability ball training on spinal stability. The static back endurance and side bridge tests were used to measure spinal stability during pre and post-testing. The treatment groups performed stability ball training sessions twice per week for 30 minutes. The exercises focused on targeting spinal stability by working abdominal and back muscles with stability balls. Subjects were each given a ball that was in accordance to their height; conducive to achieving ≥90 degree angle of the hip and knee. All subjects completed a total of 20 exercise sessions. The exercise protocol used in this study was based on specific movements not involving changes in spinal positioning; subjects did not flex or extend the spine. During the first week, subjects were taught stabilization techniques such as how to obtain natural spine. The exercise program progressed in difficulty by increasing the repetitions, building from 10-20, increasing the complexity of the exercises, adding opposing limb movements, increasing the duration that static exercises were held, ranging from 10-60 seconds, increasing the speed at which the exercises were performed, increasing the lever arm of the exercise and altering the base of support. The results showed that the experiemental group significantly improved their performance on the static back endurance test (149.3 s ± 72.3 s pre to 194.6 s ±56.7 s post) and side bridge test (45.4 s ± 39.4 s pre to 71.3 s ± 59.7 s post) after the intervention. Control group performance decreased on the static back endurance test which may be explained by the reporting of back pain before particiaption in the study. Stabililty ball traning may be an appropraite intervention to decrease the risk of back pain and improve core stabilty and strength (Carter et al. 2006).

Proper technique is imperative when incorporating a core exercise program and there are various theories on which technique is best. According to Hodges and Richardson (1996), dynamic lumbo-pelvic stabilization is achieved through training of both local and global systems. The local system consists of muscles that have direct attachment to the spine and controls segmental motion; transverse abdominis and multifidi. The global system consists of muscles that do not have direct attachment to the spine and produce larger torque that cause trunk and spine movements; rectus abdominis, internal, external obliques and the thoracic iliocostalis. It is suggested that co-contraction of the transverse abdominis and multifidi as well as simultaneous contraction of the pelvis floor is essential during core training. An individual is educated in the co-contraction through palpation of the lower abdominal wall during a drawing in or hollowing exercise when the lower abdominal is actively pulled posteriorly. At the same time, the subject contracts the pelvic floor and slightly anteriorly rotates the pelvis to activate the multifidi.

The McGill theory is that all stabilizers are important and dynamically change depending on their need to contract during performance of a required task. Bracing of the spine which activates all the abdominal musculature and extensors at once is advocated. This is usually accomplished by first palpating active low back extensors while the torso is slightly flexed. The individual then moves into extension until the extensors shut off, at which time the abdominals are contracted and the extensors reactivate (McGill, 2004).

It is also suggested that diaphragmatic breathing is an essential component of core training. It requires an individual to breathe with the diaphragm rather than the accessory muscles of the upper rib cage. Stability of the spine is increased as the diaphragm contracts and increases intra- abdominal pressure (Akuthota and Nadler, 2004). There is much debate regarding which technique, hollowing or bracing is best. There is a possibility that both are essential to a core program and both should be incorporated into a core program however, more research is needed to determine whether both theories are correct.

Once an athlete has learned to stabilize the lumbo-pelvic region utilizing isometric type exercises, progression of core conditioning and stabilization can take place. McGill (1996) recommends early incorporation of three important exercises into a training program including, curl-ups, side bridge and leg and arm extensions in a hands-knees position. Basic strengthening exercises are initiated on the ground and progress to positions of function from a stable ground to a progressively unstable surface. Eventually external resistance can be added to challenge the athlete even more. Exercises should also be performed in all planes. The sagittal plane is the most commonly trained including exercises such as sit ups and forward lunges. Frontal plane exercises include side walking and lateral bridges. The transverse plane is often neglected but important to incorporate into a program. A transverse plane exercise could include from a standing position, grasping a medicine ball with both hands and moving it diagonally through all planes strengthening the external obliques (Bliss & Teeple, 2005). Instability with trunk strengthening exercises has shown to increase the activation of the lower abdominal muscles. Implementing a higher degree of instability results in greater activation of the trunk stability muscles (Behm et al. 2005). Balance exercises can be considered a type of core stability training in that these exercises activate the core musculature (Yaggie & Campbell, 2006). Postural adjustments require activation of the core musculature to stabilize the lumbar spine. Because sports skills are often performed off balance, greater core stability provides a foundation for greater force production in the upper and lower extremities. Surface stability should be taken into consideration when implementing a core strengthening routine.

Core training and performance. Improving running performance may be running injury free for one runner or setting a personal record for another. For middle and long distance runners whose chosen sport involves balanced and powerful movements of the body, a stable core as well as a strong foundation of muscular balance is essential (Fredericson & Moore, 2005). Whether a runner is interested in improving race time or health, supplementing a core strengthening exercise program into a running routine may provide the runner with increased performance benefits. It has been suggested that it is important to have sufficient strength and stability for the body to function optimally in both everyday and sporting environments and that by having sufficient stability and strength, athletic performance could be enhanced (Hibbs, Thompson, French, Wrigley, & Spears, 2008).

Core strengthening and stability exercises have become popular amongst health care providers, personal trainers, coaches and athletes. This shift may have emanated in 1989 from the neutral spine exercises popularized by the San Francisco Spine Institute. It was suggested that neutral spine maintains good posture, supports and protects the spine and strengthens the deep core muscles promoting efficient movement and injury prevention (Willardson, 2007). With the concept of neutral spine in mind, core training has been widely used in the strength and conditioning, health and fitness, and rehabilitation industries with claims of improving performance and reducing risk of injury (Sato & Mokha, 2009). Studies have shown that increasing core strength reduces risk of injury especially low back and knee injuries, typical in runners but there has been little evidence based research regarding strength of the core and its effect on performance (Nadler et al. 2002; Willardson, 2007; Tse et al. 2005).

Sato and Mokha (2009) demonstrated that a core strength training program for runners had no significant influence on lower extremity stability scores. However, there was a significant influence on 5000-m run times, demonstrating that core strength training significantly improved running times in the experimental group compared to the control group during a 6 week training program. The study included 28 recreational and competitive rear foot strike runners who were screened for core stability where runners who already possessed a high level of stability were eliminated. The study included a core strengthening program that consisted of abdominal crunches, back extension and hip raises on a stability ball, as well as 1-arm/1-leg raises and Russian twists to target the back, abdominals and hip extensor muscles. Exercises were performed for six weeks, increasing the number of sets and repetitions every 2 weeks to challenge strength improvement. The control group was instructed to maintain their regular running routine. Post test results showed that the core strength training group performed better on the 5000-m run compared to pre-test times and control group running times. The pretest showed an average time of 29:29 ± 2:38 m:s and a post-test time of 28:42 ± 2:23 m:s, suggesting a difference of 0:47 m:s for the experimental group and 0:17 m:s in the control group. The control groups pretest times were 26:30 ± 1:59 m:s and 26:13± 1:54 m:s for the post test. While both groups improved the run time only the experimental group was significant. These results suggest that by improving core strength through regular core exercises running performance could be enhanced (Sato & Mokha, 2009).

Yaggie and Campbell (2006) investigated the effect of a four week balance training program on specified functional tasks; the shuttle run and vertical jump. This study utilized the BOSU, both sides up balance trainer, for testing balance. Thirty-six recreationally active subjects participated. Balance testing performed on a BOSU, vertical jump and shuttle run tests were performed before and after the intervention. Subjects incorporated balance training three times per week for 20 minutes with difficulty progressions each week. The balance training on the BOSU consisted of exercises progressing from simple to more complex over the four weeks. The protocol was a commercially developed training program that is provided with the BOSU at the point of sale. Exercises included single limb stance with or without torso rotation, rotary squat with or without jump, single leg jumps, v-sit with rotation and opposite leg and arm extension. Progressions and variations of exercises were presented each week to replace those already mastered. Mastery was defined as remaining on the BOSU for a period that was 2 times longer than the previous session without falling or adding support. Additions and modifications to the exercises included rotating the head laterally, tilting the head upward, keeping the eyes open or closed and using the trunk excursion or lean. Results showed that balance training influences performance on the shuttle run, decreasing run time in the post test compared to the control group who did not perform balance training. Shuttle run time (seconds) decreased for the experimental group from pretest (13.16 ±

1.47 s) to post test (12.45± 1.87 s). The control group did not show a significant difference in shuttle run performance, on average post-test times (12.70± 2.07 s) were slightly higher than the pretest times (12.62 ± 2.01 s). There were no significant improvements in vertical jump performance between the two groups. Vertical jump for the pretest was 41.3 ± 10.21 cm and 47.91 ± 13.31 cm for the experimental and control groups. Vertical jump performance did not significantly change between the pre and post-test (40.4 ± 9.24 cm for the experimental group and 48.98 ± 14.21 cm for the control group). This study lacks support of enhancement of strength and power given the insignificant findings in the vertical jump performance in both groups. However, it can be speculated that balance training improves performance of selected activities. Training may influence proprioceptive input, reaction time and specified muscular strength in existing postural control mechanisms via neuromuscular adaption to the activity. Shuttle run speed increased with balance training which suggests that increasing core strength and stability can lead to increased speed performance which could possibly be inferred to longer run performance times.

Tse et al. (2005) examined the effectiveness of a core training program on improving muscle endurance in rowers and determined if changes in endurance effect aspects of performance**.** Forty-five subjects with an average of one year of rowing experience participated in the study. The treatment group participated in core training classes twice per week for 8 weeks, 14-16 sessions total, each lasting 30-40 minutes. Exercise intensity and duration progressed on a weekly basis. All subjects performed the same general circuit training which included one exercise for each major muscle group for two cycles of 12-15 repetitions per exercise at moderate intensity. Vertical jump, standing broad jump, 10-m shuttle run, 40-m sprint, 2kg medicine ball overhead throw and a 2,000m indoor rowing ergometer test were performed by all subjects. Core endurance and strength was measured using four tests, extensor test (back extensor test), flexor test (abdominal fatigue test) and side bridge test on both sides. Tests were performed before and after intervention. The results showed a significant difference in core endurance, especially in side bridge tests, between the treatment and the control group. The abdominal fatigue test showed no significant differences between the two groups where mean values were 206.9 ± 92.1 seconds (pre), 215.5 ± 62.7 seconds (post) and 164.5 ± 7.2 seconds (pre), 176.2 ± 48.9 seconds (post) respectively for the treatment and control groups. The control group showed significant improvement on the back extensor test compared to the experimental group. Although the control and core groups did display marked differences in pretest back extensor tests (100.5 ± 20.7 s and 136.5 ± 36.2 s respectively) the magnitude of the difference was not significant. No significant differences were found between the experimental and control group for right and left side bridge but a main effect of test ($F[1,30]=25.4$ $p< 0.001$ and $F[1,30]=27.1$ $p<0.005$) along with an interaction ($F[1,30]=27.1$ $p<0.005$ and $F[1,30]=13.6$, $p <0.001$) were found suggesting increased performance and strength of the side bridge in the experimental group only. While core exercises increased core muscle endurance there were no significant pre to post-test changes for any of the physical performance tests or the rowing ergometer test. The authors speculate that this may be due to the length of the intervention program. Also, there may have been small changes in performance that the testing methods did not pick up on. There is a possibility that core endurance does not play a major role influencing performance and that strength and power of the core have a more significant effect on performance (Tse et al. 2005).

Scibek, Gueskiewicz, Prentice, Mays and Davis (2001) tested swimming performance and core strength in high school swimmers. Stanton et al. (2004) reviewed running performance and economy and core strength in high school aged touch football and basketball players. Nesser and Lee (2009) looked at identifying a relationship between core stability and various strength and power variables in division I female soccer players. Treatment groups from these studies completed core training and significant improvements were found in regards to core strength. The female soccer players showed significant correlations were identified between total core strength and 20-yd sprint (r = -0.594), 40-yd sprint (r = -0.604), shuttle run (r = -0.551), counter movement jump (CMJ) (r = 0.591), power clean/body weight (BW) (r = 0.622), 1RM squat (r = -0.470), bench press/BW (r = 0.369), and combined 1RM/BW (r = 0.447. The results of this study suggest that core stability is moderately related to strength and performance (Nesser & Lee, 2009). There was no significant difference between core strength and VO_{2max} or running economy at any running speed, 60, 70, 80, 90% of VO_{2max} (Stanton et al. 2004). However, improvements in swimming, running and soccer performance were not shown. The authors speculate that the lack of improved performance may be due to small subject pools, intensity and duration of the study or particular testing methods. The possibility that core strength and power does not play a significant role in enhancing performance is also suggested and more research is needed in sport specifics arenas to determine a relationship between performance and core strength.

In the sporting sector, improved performance may be characterized by improving technique in order to run faster, throw further or jump higher, although it could also include the reporting of fewer injuries. Despite the strong belief that core strength exercises will improve performance, limited scientific studies have shown a direct relationship between stronger core muscles and better athletic performance (Scibek et al. 2001). Less research has been performed on the benefits of core training for athletes, especially long distance runners and how this training should be carried out to optimize sporting performance. Although many studies have reported limited conclusions on the effect of core training and performance, many elite athletes continue to undertake core stability and core strength exercise programs as part of their training.

Core strength and running injuries. Long distance runners unfortunately are at risk for injury. Overtraining or under training can result in injury that can inhibit a runner from participating in the sport for a few days or a few months. Injuries pertaining to the back, pelvis, hip and thigh account for approximately 25-30% of injuries sustained by runners and 74% of runners will experience an injury over the course of the season (Fredericson & Moore, 2005). There are a variety of joint actions, compressive forces and rotational movements that occur during running, placing great stress on connective tissues throughout the body. Runners are aware of these risks and train to decrease the likelihood of injury by progressively increasing exercise intensity and performing resistance training exercises to reduce the likelihood of lower extremity injuries. Runners and other athletes should include exercises that emphasize core stability during dynamic movements. Core strength training has shown to be an effective tool in the rehabilitation field for recovering from previous musculoskeletal injuries, helping to regain muscular strength and to reduce the risk of future injury (Nadler et al. 2002). However, runners should keep in mind that while there is evidence that increasing core strength can reduce the risk of injury there has been little research looking at core strength and performance.

It has been argued that there is a biomechanical link between poor core stabilization and injuries such as posterior tibial tendonitis, medial shin splints, chondomalacia patellae, plantar fasciitis, hamstring tears and other musculoskeletal injuries especially during functional lower extremity movements (Fredericson & Moore, 2005). Low back pain is not an uncommon problem in an athletic population and its occurrence has been well documented in various sports including football, golf, gymnastics, running and tennis. Common running injuries include the low back and lower extremities. It has been suggested that lower extremity injury and/or low back pain are associated with insufficient strength and endurance of the trunk stabilizing muscles and inappropriate recruitment of the core musculature. Weakness or lack of sufficient coordination in core musculature can lead to less efficient movements, compensatory movement patterns, strain, overuse and injury (Nadler et al. 2002)

Both strength and stability of the core appear to partially predict lower extremity injuries in athletes though the biomechanical link between core strength and stability and lower extremity injury remains unclear. The strengthening of the trunk or core stabilizing muscles is an important consideration for activities for daily living, sports performance and the rehabilitation of low back pain. A strong and stable trunk (core) provides a solid foundation for the torques generated by the limbs (Behm, Leonard, Young, Bonsey, & MacKinnon, 2005).

Nadler et al. (2001) evaluated the relationship between previous lower extremity injuries or low back pain and core muscle strength, specifically the hips extensors and abductors in 210 college athletes. Strength tests of the hip extensor (gluteus maximus) and hip abduction (gluteus medius) were recorded. A dynamometer was incorporated into a specifically designed anchoring station for testing. Tests measured side to side strength differences in the subjects' abductor and extensor muscles. Lower extremity injuries or low back pain were reported in 35% of the subjects, occurring within the last year. Thirty-three and two-thirds percent of males and 38.57% of females reported a lower extremity injury over the last year. T-tests were used to determine whether side to side proximal strength differences varied in those with or without reported lower extremity injury. Significant differences were found for extensor strength in females. Female athletes without injuries, on average, had left extensors that were 10.9% stronger than their right extensor muscles. Injured females only had 1.3% strength differences between right and left sides. The side to side extensor strength did not differ significantly amongst injured and non-injured males; there was only a 2.1% mean difference between the two conditions. The results showed that athletes who had sustained an injury were not unilateral in muscle strength and those who had no previous injuries had normal differences in side to side strength implying normal lateral strength dominance. Significant differences between athletes with and without previous lower extremity injuries were noted with respect to their symmetry in hip extensor strength. This suggests that side to side strength or flexibility imbalance of proximal muscles may be related to injury occurrence and/or reoccurrence (Nadler et al. 2001).

Another study by Nadler et al. (2002) evaluated the impact of a core strengthening program on the incidence of low back pain occurrence and hip strength differences. The study expanded over three years and tested collegiate athletes from teams in each year. Hip strength was measured for hip extensors and hip abductors and low back occurrence were monitored throughout the year. The core strengthening program incorporated into the athletes training program included abdominal, paraspinal and hip extensor training, consisting of sit-ups and pelvic tilts to work the rectus abdominis and obliques. Subjects also performed squats, lunges and leg press to activate hips, quadriceps, hamstrings, paraspinals and gluteal muscles. In the 1999-2000 season, 6% of the athletes required treatment for low back pain compared with 8.5% during the 1998-1999 season. Athletes participating in both seasons had no significant differences in maximum abductor or extensor strength. Athletes in the 2000-2001 season, on average, had significantly stronger right hip muscular compared with the previous year (9.1% compared to 6.9% in 1999-2000). There was a significant difference in the mean value of maximum abductor strength during the 1999-2000 season in female athletes who required treatment for low back pain, as the left side becomes stronger the probability that that low back treatment is not needed increases. There were no significant differences found in male athletes regarding low back treatment over the different seasons. The results showed that athletes with previous lower extremity injury or low back pain had differences in hip strength compared to athletes with no history of injury. Subjects with a history of injuries exhibited poor muscle endurance, altered muscle firing rates, muscular imbalance, inflexibility of the lower extremities and leg length discrepancies. This suggests that there are muscular influences on low back pain. The hip musculature plays a significant role in transferring forces from the lower extremity up toward the spine during upright activities and thus theoretically may influence the development of low back pain. Poor endurance and delayed firing of the hip extensor (gluteus maximus) and abductor (gluteus medius) muscles have been noted in individuals with lower extremity instability or low back pain (Nadler et al. 2002). Increasing core strength, specifically the hip extensor and abductor, can help prevent and reduce the risk of lower extremity injury or low back pain.

Strengthening the core has become increasingly more popular in sports training as a method to condition athletes with the hopes of preventing injuries to the spine and or extremities. The occurrence of low back pain and lower extremity injuries may be decreased by strengthening the back, legs and abdomen to improve muscular stabilization. Core strength and endurance training has shown to decrease the risk of lower body injuries which could lead to increased performance in both training and events for long distance runners.

Summary

There has been very little research showing an effect of core strength on performance, especially in long distance runners. Past research has shown that implementing a core exercise program can increase strength and endurance of the core musculature yet, these same studies show no significant effect on performance (Nesser & Lee, 2009; Scibek et al. 2001). Few studies have shown an effect of core strength on performance, however, when the appropriate exercises are implemented into a training routine, performance was enhanced for specific tasks (Sato & Mokha, 2009). More research is needed in sport specific arenas to determine which exercises are suitable for healthy athletes.

Running requires lumbo-pelvic support which comes from key stabilizing mechanisms of the core to help pull the knee forward. The core includes muscles of the abdominal wall, lumbar musculature and the associated hip and pelvic musculature. Both the stabilizing muscles and prime mover muscles attach to the core. The core is commonly viewed as a box consisting of the abdominals in the front, paraspinals and gluteals in the back, the diaphragm as the roof and the pelvic floor and hip girdle musculature are the bottom (Fredericson & Moore, 2005). Runners have shown increased activity of the core musculature and lower extremity during the leg cycle, with greater activation occurring at faster speeds (Montgomery et al. 1994. To run efficiently and smoothly, the trunk muscles must stabilize the upper body from the moments and reaction forces of the lower limbs (Behm et al. 2009).

While the effect of core strength and sport specific performance is unclear there has been a significant correlation shown between increasing core stability, particularly through core endurance training, and prevention and reduction of lower extremity injury (Nadler et al. 2001). When designing a core exercise program, performing exercises on an unstable surface increases core strength and stability (Cosio-Lima et al. 2003). Increasing the degree of instability can further increase stability of the core and should be considered when prescribing exercises to athletes.

No study has compared the effect of core strengthening exercises utilizing an 8 week exercise progression, on performance in healthy long distance runners. Such a study would elucidate the possible differences in running speed before and after core strengthening. Determining a relationship between core strength and performance would provide insight that would be valuable in developing individual training routines for long distance runners interested in improving their running speed.

Chapter III

Methods and Procedures

Introduction

This study was designed to examine the effect of core strengthening exercises on running performance and core strength and endurance by comparing a running program with or without core exercises. Differences in core strength and running performance were assessed after a completion of a half marathon before and following an 8 week intervention. This chapter gives a description of the study sample and the design of the study. Data collection procedures are presented, including instrumentation and a discussion of the measurement techniques and procedures. This chapter concludes with an explanation of the statistical analysis of the data.

Description of Study Sample

Thirty participants were recruited from the Greater Bellingham Runner's Club and Fairhaven Runner's Club. The subjects were both male and female aged 18-65 years. All participants were currently running on average 20 miles a week and had run at least one half marathon in the last year. Runners who reported an injury during the last three months, which kept them from their normal running routine for more than four weeks, were excluded from this study. The subjects were tested during the in-season phase of their racing cycle. No subjects were actively in the process of incorporating core exercises or heavy resistance training into their running routine at the time of testing. All subjects were considered to be in good health and overall fitness. Participants were screened prior to involvement in the study. Subjects with lower extremity or low back injury, illness, core exercise experience or low running mileage (<20 miles per week) were excluded from the study. Upon selection each subject completed a questionnaire regarding their current training routine. To ensure subject compliance, subjects did not have any serious time restraints that would inhibit their progress in training, such as a major work deadline or vacation that would keep them away from a typical routine for more than three consecutive days.

Design of the Study

The research was a pretest-posttest randomized group's design, in which each subject was assigned to one of two groups and tested at the beginning and end of the intervention. Random assignment by a coin flip was used for participant assignment to the two groups, heads associated with control, tails associated with the treatment group. The treatment group, in addition to each individual's regular running routine, underwent 8 weeks of core training. The control group was expected to maintain running an average of approximately 20 miles per week throughout the study. All participants reported weekly mileage and cross training performed each week on an activity log.

Data Collection Procedures

Instrumentation. For this study, the Both Sides Up (BOSU) stability trainer (BOSU® Pro Balance trainer) was used as a progression tool to increase the workload and degree of instability during core exercises. Free weights, dyna discs (DynaDisc® Balance Disc, airex pads (AIREX® Balance Pad), medicine balls, and Swiss balls were also used for exercise progression.

The half marathon course was accurately mapped using a Garmin Forerunner 305 GPS unit (Forerunner® 305, Garmin Ltd., Olathe, KS). A stopwatch was used to monitor race times for the half marathon tests. Anthropometric data including body fat, body density, height and weight were collected using the BodPod (BODPOD ® Gold Standard Body Composition Tracking System, Life Measurements, Inc, Concord, CA) and a stadiometer. The Lafayette Instrumentation Co. stability platform was used to determine subject's core stability. McGill's core function (McGill, Childs and Liebenson, 1999), extensor, flexor and side bridge tests were used as another measurement of core strength. A stabilizer pressure biofeedback unit (Stabilizer ™ Pressure Biofeedback Unit, Chattanooga Group, Hixson, TX) was also used to collect data on individual strength of the core. A stopwatch was used to record all subjects' performance times on the tests.

Measurement techniques and procedures. All subjects were briefed on the testing procedures and participant expectations, and given an overview of the risks and benefits of volunteering. The opportunity to ask questions was provided during all testing and instructional sessions and the experimenter presented sufficient answers to all questions. Body composition, height and weight were all recorded prior to testing core strength and running performance. A stadiometer was used to measure subject height (vertex on top of head to floor). Height was recorded in inches with the shoes off. The BodPod (BODPOD ® Gold Standard Body Composition Tracking System) was calibrated before each testing day, following the written instructions provided by the manufacturer for proper use. Subjects were asked to have minimal food and drink before testing for best results. All jewelry was removed, tight fit clothing, such as a swimming suit, was worn for the test and a spandex hat was worn to keep all hair in to compress any air pockets within the hair. The BodPod test reported body fat, body density and weight.

Individual core strength was measured using McGill's four core function tests and a pressure biofeedback unit. The four tests include the extensor test (back extensor test), flexor test (abdominal fatigue) and side bridge tests. The back extensor tests used is the Biering-Sorensen test where the upper body is extended out over a table with the lower legs secured. The arms were folded across the chest with the hands held on opposite shoulders. The test was initiated after the subject had assumed a prone position with the upper body at 180 degrees and terminated when the subject's torso fell below the horizontal position and time was recorded.

The abdominal fatigue test was performed by having the subject sit on a bench with a back support that was positioned at a 60 degree angle. Both the knees and hips were flexed at 90 degrees and the feet were fixed securely to the bench with a strap and towel. The arms were folded across the chest with the hands placed on opposite shoulders. Subjects leaned against a 4 inch thick rubber pad that was wedged between their back and the 60 degree back rest. Subjects were instructed to maintain their body position once the supporting wedge was removed to initiate the test. The test was ended when the upper body could no longer be maintained at a 60 degree angle.

The side bridge test started with the subject lying on either side with the legs extended. The top foot was placed in front of the lower foot for added support. Subjects were instructed to support themselves on only the elbow, forearm and feet. The hips were raised off the floor and a straight body position was maintained in the frontal plane. The non-supporting arm was held across the chest with the hand placed on the opposite shoulder. The test was terminated when the hips began to sag and body position could no longer be maintained or when the lower leg started to rest on the floor. Performance on each test was recorded with a stopwatch in seconds.

A pressure biofeedback unit was also used to measure core function. The test included an inflatable pad of a Stabilizer Pressure Biofeedback Unit (PBU) placed in the natural lordotic curve, while the subject lies supine with the unit inflated to 40 mmHg. The test consisted of five levels with each level increasing in difficulty. Level 1 required individuals to activate the abdominal musculature bracing the trunk in an isometric fashion without movement being produced. Once this was achieved the subject slowly raised one leg to 100 degrees of hip flexion, with comfortable knee flexion. The opposite leg was elevated to the same position in the same manner with a change in pressure on the PBU of no more than 10 mmHg. In order to attain each new level of the Sahrmann test, the lumbar spine position had to be maintained as indicated by a change of no more than 10 mmHg in pressure on the PBU. A pressure reading greater or less than 10 mmHg above or below this baseline indicated lumbo-pelvic stability was lost at this level and the test is terminated. This level 1 position was used as the start position for subsequent levels of the test protocol. If the pressure reading did not change the subject advanced on to the next level. In Level 2 from the start position the subject slowly lowered one leg such that the heel contacted the ground. The leg was then slid out to full knee extension and then returned to the start position. Level 3 from the start position required the subject to slowly lower one leg reaching the heel 12 cm from the ground. The leg was then slid out to fully extend the knee and returned to start. Level 4 from the start position the subject slowly lowered both legs so the heals contact the ground. The legs were slid out to extend the knees and returned to the start position. Level 5 from the start position the subject slowly lowers both legs, heels reaching 12 cm from the ground, the knees are extended and brought back to the starting position

Subjects also performed a stability test using the Lafayette Co. stability platform. For this test subjects were in a 4-point position, on hands and knees, on the stability platform and contralateral knee, hip and arm extension is required. Subject score was recorded as total amount of time during the 30 second test that balance was maintained. The metronome was set at 40 beats/minute and subjects alternately raise their arms in the sagittal plane at the shoulder joint 10 times in each 30 second test. After completion of the core function tests, subjects were briefed on the running test and given written instructions for race day preparation, directions to the start line, a running course outline and maximal effort expectations.

Participants arrived in the morning no later than 30 minutes prior to the start of the half marathon running test. The 13.1 mile course was mapped out using a Garmin Forerunner 305, and performed twice for accuracy by the experimenter. The course included low traffic roads, some elevation gain and two laps around Lake Samish in Bellingham, Washington. Each subject was given a number to wear on their front side, visible to the experimenter for proper reporting of completion time. Participants were instructed to treat the half marathon as they would a race, and maximal effort was assumed from all subjects. The running test started at the sound of an air horn and two stop watches were used to record completion time, with the average of the two times used for data analysis. Water and first aid was provided every three miles and a bathroom was located at the start, the midpoint and finish of the course. Hammer Nutrition Gel (Hammer Nutrition Products ®) packs were offered at mile 6 along with lemon-lime flavored cytomax (CytoSport®) sports drink. Completion time was documented after the participant had fully crossed the finish line with both feet. Post-race refreshments were provided including chocolate milk, bananas, watermelon and bagels. Following the pre-test run and core strength measurements, participants were randomly assigned to two groups, treatment and control.

Subjects in the treatment group performed core exercises three times per week. Subjects met with the experimenter in groups or individually to receive the exercises for a given week. Tutorial in proper form and execution of the 10 different exercises was provided to ensure the subjects were comfortable performing the exercises on their own. Core exercises for the first week were performed on a stable surface, such as the ground or floor and were meant to allow the participants to gain stability before progressing to an unstable surface. If subjects did not have access to a gym with the appropriate tools for exercise progressions they were provided to individuals by the experimenter. Core exercises included back extensions, bridge, forward/side T's, plank holds, side plank, push-ups, lunges, squats, bird dog and abdominal crunches (see Table 1 for exercise description and progressions). The core exercise program was performed on three non-consecutive days per week, resulting in approximately 30 minute sessions for eight weeks. Progressions included utilizing an unstable surface, to incorporate balance and activate more of the core musculature. As subjects became confident in utilizing the instability implements, exercise advancements were made by changing the surface or resistance was added by the use of dumbbells. If weight was added it did not exceed more than 15 pounds to ensure there was minimal increased risk of injury. A sample progression is provided in Table 2.

Table 1. Core Exercise Descriptions

Exercise	**Description**
Plank (prone)	Elbows/hands directly below shoulders, raise up on forearms and toes/knees. Keep head aligned with spine, contract gluteals and pull stomach up and in. Maintain straight line between upper and lower body
Side Plank (left & right)	Elbow/hand directly under shoulder, raise up on forearm and side of feet/knees. Head stays in line with the spine, pull hips up, stomach up and in and contract the gluteals. Maintain straight line between upper and lower body. Switch sides.
Bird dog	Start in prone 4-point position on hands and knees. Extend opposite arm and leg out keeping foot flexed, lower back down to start and switch sides. Keep stomach pulled in tight to maintain stability and proper alignment in spine.
Push-ups	Start with hands directly below the shoulders, feet/knees hip width apart. Arms fully extended, drop to the floor, until nose touches or elbows come to 90 degrees of flexion, push back up into starting position. Stomach pulled up and in throughout range of motion.
Squats	Feet are hip width apart, legs fully extended. Lowering the body down, flex at the knee to 90 degrees, keeping shoulders back and spine straight. Engage stomach muscles throughout the movement, contract gluteals and hamstrings as the legs extend back to start position. Important to keep knees directly behind toes at all times during flexion.
Lunges	One leg is forward and the other positioned behind the body. Contract the stomach muscles and drop the body straight down, being sure not to lean forward, keeping the Center of Mass (point about which the body's mass is evenly distributed) directly between the two legs. Both knees should come to 90 degrees of flexion, contract gluteals, quads and hamstrings to extend back to start position. Switch forward legs.

Forward T's	Shift weight into one leg, flex at the knee and hip in the free leg in front of the body. Raise the arms directly above the head or keep them resting on the hips, engage the back muscles and abdominals, lean forward keeping arms align with head and trunk, extend the flexed leg back behind the body. Return to start position. Repeat on other side.
Bridge	Lying supine on the floor, arms resting at the side of the body, raise hips up keeping shoulders on the floor. Contract the gluteal muscles and hamstrings.
Abdominal Crunches	Various exercises laying supine on the floor with either upper, lower or both portions of the body flexing/extending. Requires abdominal muscle contraction, as well as bracing and hollowing of the trunk.

Table 2. Core Strength Progression

Exercise	**Beginner (Week 1-2)**	**Intermediate (Week 3-5)**	**Advanced (Week 6-8)**
Plank (prone)	**Week 1:** Forearms & knees: until fatigue **Week 2**: Forearms & toes: until fatigue	**Week 3:** Forearms & toes- alternate leg lift: until fatigue **Week 4:** Forearms & toes, walk feet in and out: until fatigue **Week 5:** Hands & toes: until fatigue	**Week 6:** Hands & toes- alternate leg lift: until fatigue **Week 7:** Hands & toes, roll forward and back on toes: until fatigue **Week 8:** Hands BOSU, feet on floor, crunch leg in toward opposite arm, alternate legs: until fatigue
Side Plank	**Week 1**: Forearms & feet: until fatigue **Week 2:** Forearms & feet- lift top leg: until fatigue	**Week 3:** Forearm & feet- roll down: until fatigue **Week 4:** Forearm & feet, raise hips up and down: until fatigue **Week 5:** Hands& feet: until fatigue	**Week 6:** Forearm & feet, resistance band around ankles, lift top leg, keep foot dorsiflexed: until fatigue **Week 7:** Forearm on BOSU, feet on floor: until fatigue **Week 8:** Hands & feet- lift top leg: until fatigue

Bird Dog	**Week 1:** Hands & knees-alternating sides: until fatigue **Week 2:** Hands & knees crunch in leg to bring to opposite elbow: until fatigue	**Week 3:** Hands & knees-extend opposite arm and leg, pull down arm into 90 degree angle and leg up into 90 degree angle: until fatigue **Week 4:** Hands & knees, crunch in same arm & leg to touch knee to elbow: until fatigue **Week 5:** Hands & knees, extend opposite arm & leg, abduct both arms & legs laterally and return to start: until fatigue	**Week 6:** Hands & toes, alternate opposite leg/arm lift until fatigue **Week 7:** Hands & toes, crunch in opposite arm and leg to touch knee to elbow: until fatigue **Week 8:** Hands & toes , place cloth under feet. Bring legs forward, knees to elbow, switch sides: until fatigue
Push-ups	**Week 1:** Hands & knees: until fatigue **Week 2**: Hands & knees/toes: until fatigue	**Week 3:** Hands on step & toes on floor: until fatigue **Week 4:** Hands on dynadisk & toes/knees: until fatigue **Week 5**: Hands & toes, lift one leg up, alternate leg lift with each pushup: until fatigue	**Week 6**: Hands & toes/knee alternate arm raise between each pushup: until fatigue **Week 7:** Hands on BOSU, toes on floor: until fatigue **Week 8:** Hands on BOSU, feet on floor, shift upper body weight side to side: until fatigue
Squats	**Week 1:** Feet hip width apart on floor: until fatigue **Week 2:** Wall sit, knees bent to 90 degree, keep head against wall, hands resting at side: until fatigue	**Week 3:** Static sumo squat, feet outside hips: until fatigue **Week 4:** Single leg squats: until fatigue **Week 5:** Single leg squats on dynadisk: until fatigue	**Week 6:** Squats with resistance band around legs, push out laterally against band: until fatigue **Week 7:** Squats on round side of BOSU, feet hip width apart: until fatigue **Week 8:** Squats on BOSU-flat side: until fatigue
Forward T	**Week 1:** Foot on ground & hands at hips, lean forward & extend back leg, return to start- switch sides: until fatigue, both sides **Week 2:** Foot on ground & arms overhead lean forward & extend back leg, return to start- switch sides until fatigue	**Week 3:** Place resistance band around hands, press hands outward against band. Foot on ground & arms overhead, lean forward & extend leg back, switch sides: until fatigue **Week 4:** Foot on dynadisk, hands on hips: until fatigue **Week 5:** Foot on dynadisk, resistance band around hand pressing outwards:	**Week 6:** Extend one leg back, swing out laterally, and around to front to a 90 degree flexion at hip and knee, keep foot dorsiflexed: until fatigue **Week 7:** Foot on round side of BOSU & hands at hips: until fatigue **Week 8:** Foot on flat side of BOSU & hands on hips: until fatigue

		until fatigue	
Back Extension	**Week 1:** Lie prone on floor, raise opposite arm and leg, switch side: until fatigue **Week 2:** Lie prone on floor, raise trunk and legs up, hold: until fatigue	**Week 3:** Lie prone on floor, scissor arms and legs back and forth: until fatigue **Week 4:** Lie prone on floor, raise arms & legs, lateral pull down with arms: until fatigue **Week 5:** Resistance band around ankles, lie prone on floor, raise arms and legs. Push legs out laterally against band: until fatigue	**Week 6:** Lie prone, alternate leg and trunk lift: until fatigue **Week 7:** Lie prone, lift trunk off the ground, extend arms backward and circle out laterally and forward: until fatigue **Week 8:** Lie prone on BOSU, raise trunk upwards with arms overhead: until fatigue
Bridge	**Week 1:** Lie supine w/knees bent arms at side. Raise the hips upward: until fatigue **Week 2:** Lie supine w/knees bent, arms at side. Place foot on opposite knee, raise hips up and down, switch sides: until fatigue	**Week 3:** Lie supine w/knees bent arms at side. Place a resistance band above the knees-raise hips upward: until fatigue **Week 4:** Lie supine w/feet on chair/ball, arms across chest. raise hips upward: until fatigue **Week 5:** Lie supine with feet on dynadisk, arms across chest. Lift one leg straight up into the air, raise hips up/down: until fatigue	**Week 6:** Lie supine feet on dynadisk, arms across chest. Raise hips upward and alternate leg raises: until fatigue **Week 7:** Lie supine with feet on BODY, arms at side, push heals into BOSU and raise hips upward: until fatigue **Week 8:** Lie supine with back on BOSUand knees bent. Place dishcloth under the feet. Raise hips upward and extend/flex the legs: until fatigue
Lunges	**Week 1:** Walking lunge, step forward, bend knees to 90 degrees of flexion, twist trunk to bring opposite elbow to knee: until fatigue **Week 2:** Static lunge, step leg forward bend knee to 90 degrees, raise up and pull leg up and through to 90 degrees of hip flexion, switch sides: until fatigue	**Week 3:** Start in neutral position on a step. Step one leg back behind the body, bend legs to 90 degrees, extend supporting limb on step and pull back leg through to 90 degrees of hip flexion: until fatigue **Week 4:** Place one leg on bench behind the body and one leg in front. Keeping back leg on the bench bend legs until reaching 90 degrees of flexion and raise back up- switch sides: until fatigue	**Week 6:** Place one leg on bench behind the body and one leg out in front on a dynadisk. Keeping back leg on bench and front leg on the dynadisk, bend legs to 90 degrees of flexion and raise back up- switch sides: until fatigue **Week 7:** Place front leg on round side of BOSU, bend legs to 90 degrees, swtich sides: until fatigue **Week 8:** Side lunge on BOSU, stand with BOSU to one side, place foot on

		Week 5: Place front foot on dynadisk, extend back leg, flex both legs to 90 degrees- repeat on other side: until fatigue	round side, shift weight laterally to 90 degree bend in the knee, switch sides: until fatigue
Abdominal Crunches	**Week 1:** Lie supine with knees bent & toes on the floor, keeping hands on head and elbows abducted to 90 degrees, refraining from horizontally adducting, flex at trunk, lifting shoulders and upper body off of the floor: until fatigue **Week 2:** Lie supine, flex hip and knees to 90 degrees. Keeping upper body stationary on the floor, drop legs to the floor touching the heals to the ground, flex back up to starting position: until fatigue	**Week 3:** Lie supine, with knees and hips flexed to 90 degrees. Keeping hands on head and elbows abducted to 90 degrees, refraining from horizontally adducting, flex at trunk, lifting shoulders and upper body off of the floor- laterally rotate to one side as the opposite leg is extended out. Keep the extended leg as close to the floor as possible. Return to start position with legs on floor and alternate extended leg: 4 x until fatigue **Week 4:** Sit on floor, with knees bent & feet on the floor. Roll the upper body back toward the floor and hold at 60 degree angle, return to start position: until fatigue **Week 5:** Sit on floor with knees bent & feet on the floor. Roll the upper body back toward the floor (60 degrees) and rotate laterally to one side hold, return to start and switch sides: 4 x until fatigue	**Week 6:** Lie supine with knees bent, raise trunk, keep shoulders elevated throughout the exercise. Reach laterally to one side touch hand to ankle, alternate sides: until fatigue **Week 7:** Sit BOSU with hips and knees flexed arms straight out in front. Extend legs out straight and bend back in: until fatigue **Week 8:** Feet on BOSU, place dishcloth under hands in push up position. Extend one hand out forward and bring back to start position, alternate sides: until fatigue

Participants in both groups were given exercise logs to track their weekly running mileage. Subjects were expected to run at least 4 days per week, accumulating on average 20 miles**.** All other forms of exercise were reported so that they could be accounted for in the results. At the end of the 8 week intervention, all subjects completed the same half marathon course that was run before the intervention. Core strength measurements were taken for each subject as well as body composition, height and weight. All changes were recorded and compared before and after the intervention across groups.

Data Analysis. A two-way mixed ANOVA was performed to analyze the difference in running performance and difference in core strength supplementation and no core exercises. Pre and post test scores for all core strength and stability measurements were compared within and between the control and experimental groups to determine if changes in core function were evident. Running performance recorded in seconds was evaluated amongst the treatment and control group for improvements in speed. Effect size calculations were performed to evaluate the magnitude of the effects on core strength and on running performance. For purposes of statistical analysis, core tests performed in the sagittal plane (right and left side plank) and in the frontal plane (back extension, abdominal fatigue and pressure biofeedback unit) were combined to assess the simple effects when an interaction was identified. A Bonferroni correction was applied for the group of tests in the sagittal plane and frontal plane and the level of significance chosen was a $p < 0.025$ and $p < 0.017$, respectively.

Chapter IV

Results and Discussion

Introduction

The purpose of this study was to examine the effect of an eight week core training program on half marathon race performance. In addition to run time, individual core strength and stability were measured before and after the eight week intervention to determine whether core strength and stability affects running performance.

Results

Subject Characteristics. One subject from the control group and one subject from the training group were unable to complete the eight week intervention due to injury unassociated with the study and were subsequently excluded from data analysis. Of the 24 subjects remaining (16 female, 8 male), 13 (10 female, 3 male) underwent the eight week core training program and 11 (6 female, 5 male) served as a control group. Subjects were 38.1 ± 14.4 years old, 1.69 ± 0.08 meters tall and weighed 64.1± 9.7 kg. Body composition obtained from the Bod Pod ((BODPOD ® Gold Standard Body Composition Tracking System, Life Measurements, Inc, Concord, CA) showed percent fat of 22.5 ± 2.3% for all subjects with no significant changes at the studies completion. Subject characteristics are displayed in Table 1. All participants reported having minimal experience with the exercise equipment used in this study, no current injuries and were running an average of 20 miles per week for the study duration.

Table 1. Subject Characteristics

	Age (years)	Height (m)	Weight (Kg)	% Fat
Treatment Group	41.5 ± 13.2	1.68 ± 0.74	67.5 ± 17.4	24.0 ± 8.6
Control Group	34.2 ± 15.0	1.69 ± 0.75	60.70± 9.8	15.2 ± 6.4
Both Groups	38.1 ± 14.4	1.69 ± 0.76	64.1 ± 9.7	19.9 ± 8.8

Values are Mean ± SD

Core Strength and Stability. Core function tests were performed by all subjects before and after the eight week intervention to determine the effects of the core training program.

Lafayette Co. Stabilizer Platform. The Lafayette Co. Stabilizer Platform was used to measure individual core stability. All subjects performed this test prior to the eight week intervention and completed the same test within ten days of the study's completion. Performance scores on the stability platform for both groups are represented in Table 2.

Table 2. Lafayette Stabilizer Platform		
	Pre- Test	Post-test
Treatment Group	12.19 ± 3.44	12.95 ± 4.01
Control Group	13.02 ± 3.83	10.97 ± 3.31
Both Groups	12.57 ± 3.49	12.04 ± 3.69
Values are Mean ± SD seconds		

Data analysis showed a significant interaction was identified between group and time on the stabilizer platform, ($F[1,22]= 5.29$, $p=0.031$, $\eta^2_{partial} = 0.19$). The simple effects assessed showed no significant difference from pre-test to post-test in the treatment group ($t(13)=-0.848$, $p=0.413$). A significant difference between pre-test and post-test was observed in the control group ($t(10)=2.577$, $p=0.28$). Analysis of these effects showed that the treatment group exhibited no significant improvement in performance on the stability platform while the control group decreased the duration of stability during this test (Figure 1).

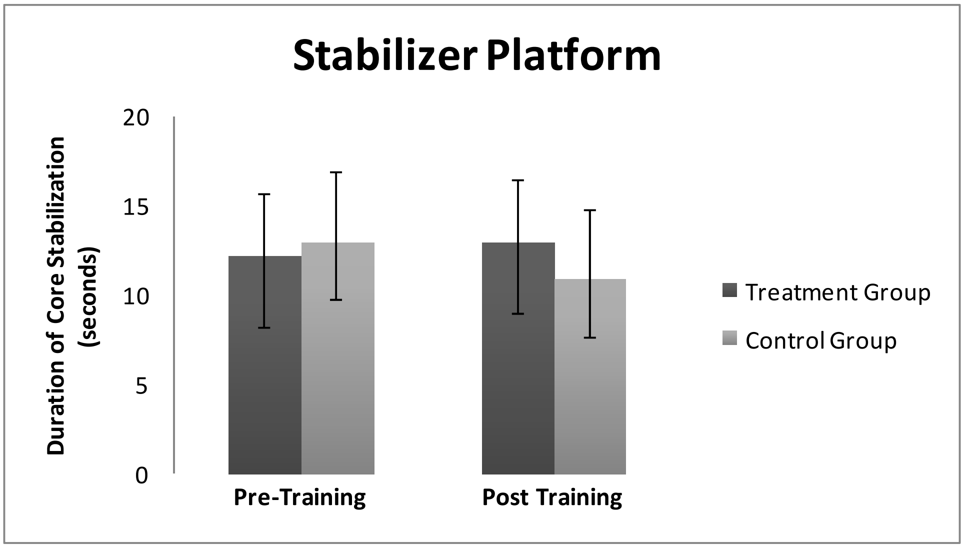

Figure 1. Mean (± SD) duration of balance on the Lafayette Stabilizer Platform.

Side Plank. Duration of a side plank position on both the left and right side was measured before and after the intervention to measure core strength and stability in the frontal plane. Across both groups side plank performance on the right side was 75.38 ± 28.25, with 75.32 ± 30.45 seconds for the left side during the pre-test and post-test times were 88.86 ± 35.72 (right) and 90.5± 36.97 (left) seconds. The treatment group performance for the pre-test was 68.09 ± 30.36 (right) and 67.24 ± 31.99 (left) and the post-test 93.84 ± 40.81(right) and 92.46 ± 42.44(left) seconds. Pre-test scores for the control group were 83.99 ± 25.65 (right) and 84.86 ± 28.50 (left) and post-test scores were 82.98 ± 31.51 (right) and 88.94 ± 33.34 (left) seconds. Participant scores on right side plank are displayed in Table 3 and scores for left side plank in Table 4. Data analysis showed a significant group by time interaction for the right side plank (F[1,22]= 6.102, p= 0.022, $\eta^2_{partial}$ =0.22) and left side plank times (F[1,22]= 5.455, p=0.029, $\eta^2_{partial}$ = 0.20).

Table 3. Right Side Plank		
	Pre-Test	Post-Test
Treatment Group	68.09 ± 30.36	93.84 ± 40.84
Control Group	83.99 ± 25.65	82.98 ± 31.51
Both Groups	75.38 ± 28.25	88.86 ± 35.72
Values are Mean ± SD seconds		

Table 4. Left Side Plank		
	Pre-Test	Post-Test
Treatment Group	67.24 ± 31.99	92.46 ± 42.44
Control Group	84.86 ± 28.50	88.94 ± 33.34
Both Groups	75.32 ± 30.45	90.5 ± 36.97
Values are Mean ± SD seconds		

From the alpha level of 0.05, a Bonferroni correction was applied for the test of simple effects and a statistical significance value of $p<0.025$ was used for core strength and stability measures performed in the frontal plane. The test for simple effects for right side plank time showed a significant difference between pre and post-test performance for the treatment group ($t(13)=-2.913$, $p=0.013$). No significant difference was observed for the control group ($t(10)=0.188$, $p=0.854$). Analysis of these effects suggest that the treatment group increased the duration of time spent holding the plank position on the right side while the control group showed no significant improvement as shown in Figure 2. Similarly, the simple effects for left side plank show similar results with a significant difference found for the treatment group ($t(13)= -3.419$, $p=0.005$) and no significant difference found in the control group ($t(10)=-0.903$, $p=0.388$) as observed in Figure 3.

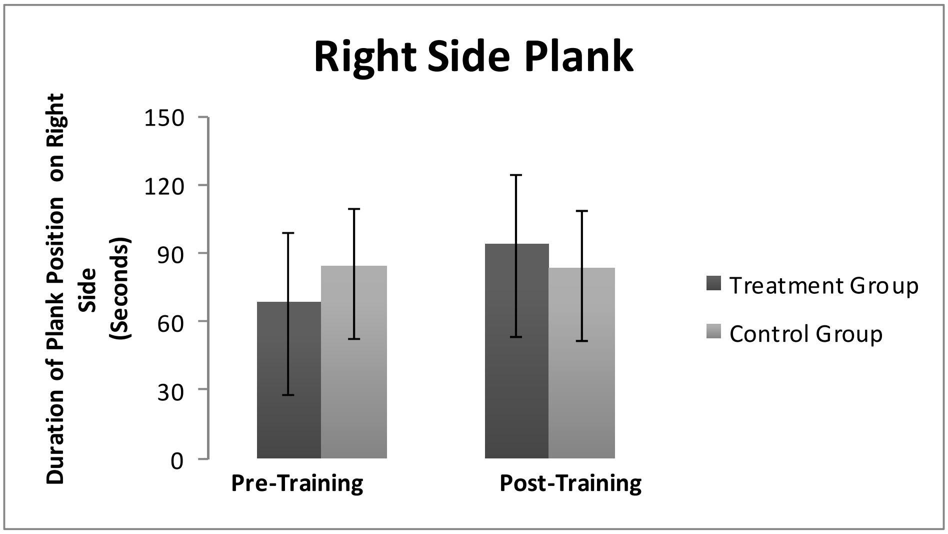

Figure 2. Mean (± SD) duration of right side plank.

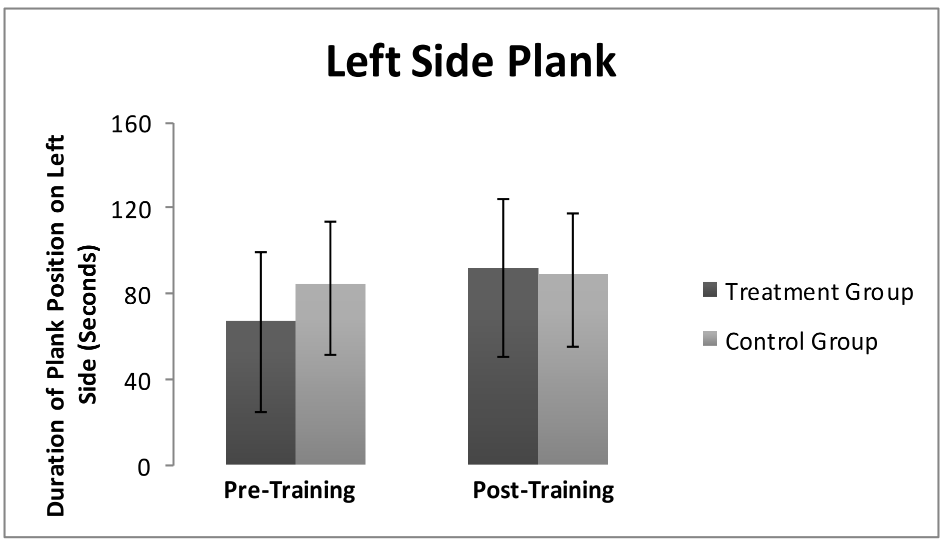

Figure 3. Mean (± SD) duration of left side plank.

Pressure Biofeedback Unit. The Pressure Biofeedback Unit (PBU) was used to measure function and lumbo-pelvic stability in the sagittal plane. The score obtained on the PBU during the pre-test across groups was level 2.81 ± 0.89 and 3.79 ± 1.29 for the post-test. Subjects in the treatment group had greater improvements from the pre-test (2.31 ± 0.63) to the post-test level 4.23 ± 1.30 compared to the control group level 3.18 ± 0.98 and 3.27 ±1.19. PBU scores for each group are represented in Table 5.

Table 5. Pressure Biofeedback Unit		
	Pre- Test	Post-Test
Treatment Group	2.31 ± 0.63	4.23 ± 1.30
Control Group	3.18 ± 0.98	3.27 ± 1.19
Both Groups	2.81 ± 0.89	3.79 ± 1.29
Values are Mean Level out of 5 ± SD		

Data analysis showed a significant interaction between the PBU test and group was also observed (F[1,22]= 20.155, p=<0.001, $\eta^2_{partial}$ =0.48). A Bonferroni correction was applied for the test of simple effects and a statistical significance value of p<0.017 was used for core strength and stability measures performed in the sagittal plane. The simple effects showed that the treatment group had no significant improvement in their performance (t (13)=-0.848, p=0.413). There was also no significant improvement found in the control group (t(10)=2.577, p=0.028) displayed in Figure 4.

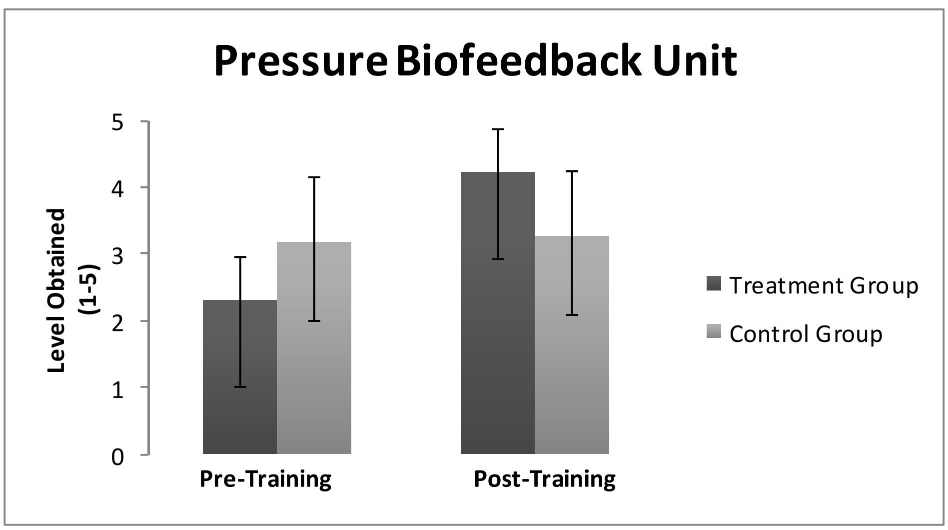

Figure 4. Mean (± SD) level obtained on the Pressure Biofeedback Unit Test.

Back Extension. The Biering-Sorensen test was used to measure back extensor fatigue as a measure of core strength in the frontal pane. Pre-test values for back extension were 114.31 ± 45.61 s and the post-test values were 141.01 ± 56.06 s. The treatment group showed pre-test scores of 106.20 ± 49.98 s and post-test scores of 143.64 ± 63.71 s. The control group scores were 123.89 ± 42.54 s and 137.90 ± 51.52 s for pre and post-tests respectively as seen in Table 6.

Table 6. Back Extension		
	Pre-Test	Post-Test
Treatment Group	106.20 ± 49.98	143.67 ± 63.71
Control Group	123.89 ± 42.54	137.90 ± 51.52
Both Groups	114.31 ± 45.61	141.01 ± 56.06
Values are Mean ± SD seconds		

Data analysis revealed no significant group by time interaction was found between groups for back extension performance before and after the intervention ($F[1,22]= 1.350$, $p=0.258$, $\eta^2_{partial} =0.06$,) with data shown in Figure 5. A significant effect of test was observed for back extension ($F[1,22]= 6.515$, $p=0.018$, $\eta^2_{partial} =. 23$), however, the main effect of group was not significant ($F[1,22]=0.097$, $p=0.759$, $\eta^2_{partial} =0.10$).

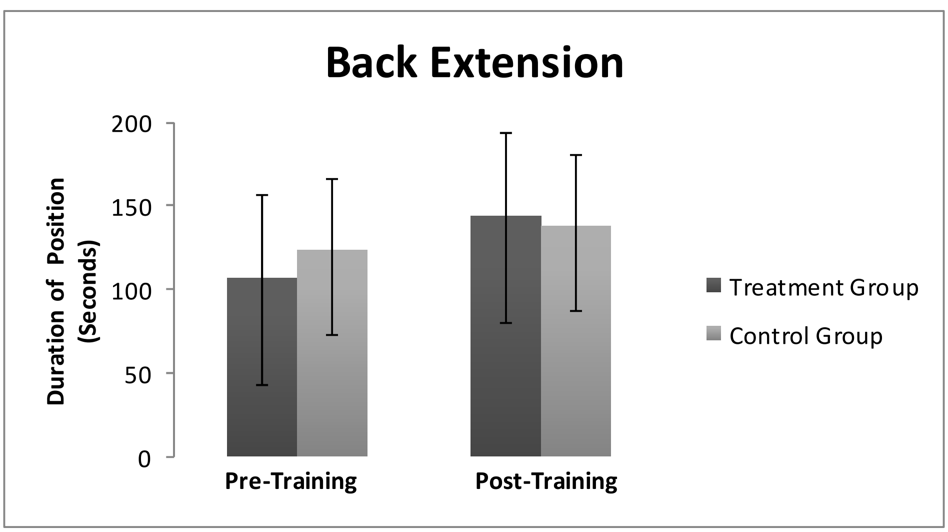

Figure 5. Mean (±SD) duration in seconds for back extension.

Abdominal Fatigue. As one of McGill's four core strength measurements the abdominal fatigue test was used to measure individual core strength in the sagittal plane. Performance on the abdominal fatigue test is displayed in Table 7.

Table 7. Abdominal Fatigue		
	Pre-Test	Post-Test
Treatment Group	175.76 ± 112.69	248.91 ± 128.27
Control Group	166.16 ± 93.58	182.78 ± 95.48
Both Groups	171.36 ± 100.12	218.60 ± 114.50
Values are Mean ± SD seconds		

Data analysis suggested no significant group by time interaction was identified for the abdominal fatigue test (F[1,22]=1.505, p=0.233, $\eta^2_{partial}$ =0.06) shown graphically in Figure 6. No significant main effect of test (F[1,22]= 3.795, p=0.064, $\eta^2_{partial}$ =0.15) or group (F[1,22]=0.965, p= 0.337, $\eta^2_{partial}$ =0.04,).

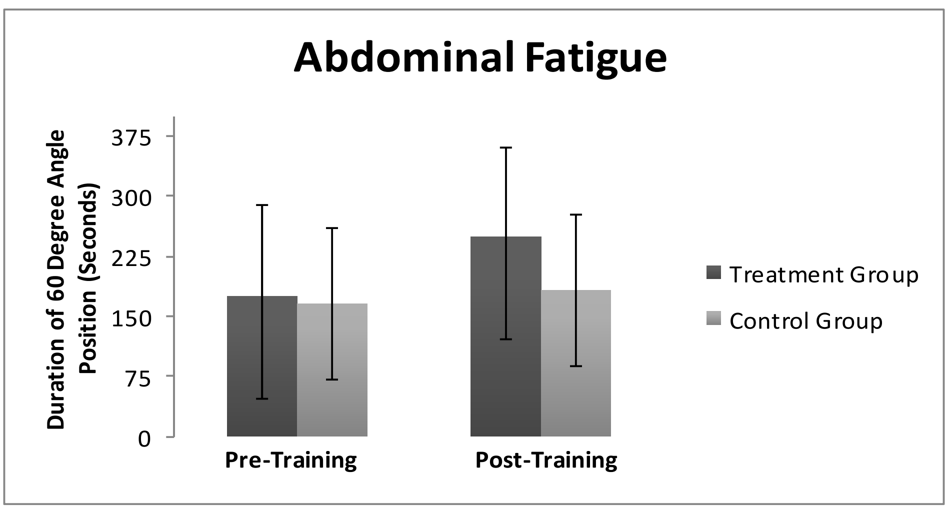

Figure 6. Mean (± SD) duration of abdominal fatigue test.

Running Performance. Half marathon run performance was obtained for all subjects before and after the eight week intervention to determine the effect of core strength on run time. The completion time across both groups, shown in Table 8, was

1:56:50 ± 0:18:39 h:min:s for the pre-test and 1:56:00 ± 0:18:40 h:min:s for the post-test. Pre-test values for the treatment group were 2:03:44 ± 0:19:27 h:min:s and post-test times were 2:01:26 ± 0:20:17 h:min:s. Recorded times for the control group were 1:48:41 ± 0:14:33 h:min:s for the pre-test and 1:49:34 ± 0:14:56 h:min:s for the post-test.

Table 8. Running Performance

	Pre-Test	Post-Test
Treatment Group	2:03:44 ± 0:19:27	2:01:26 ± 0:20:17
Control Group	1:48:41 ± 0:14:33	1:49:34 ± 0:14:56
Both Groups	1:56:50 ± 0:18:39	1:56:00 ± 0:18:40
Values are Mean ± SD h:min:s		

Data analysis showed no significant interaction was found between core strength and run time (F[1,22]= 4.197, *p*= 0.053, $\eta^2_{partial}$ = 0.16) as displayed in Figure 7. No significant main effect of test (F[1,22]= 0.836, *p*= 0.371, $\eta^2_{partial}$ =0.04) or group (F[1,22]= 3.470, *p*= 0.76, $\eta^2_{partial}$ =0.14) on half-marathon run time.

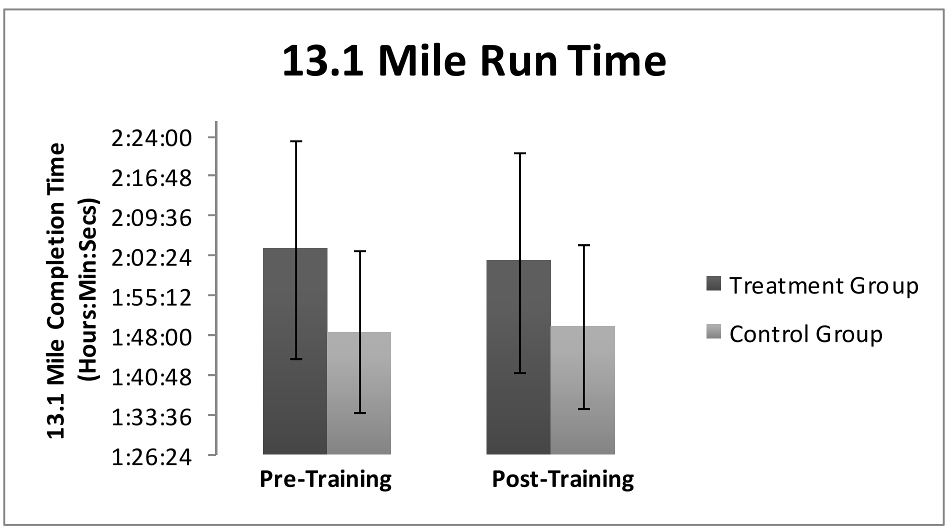

Figure 7. Mean (± SD) half-marathon run time.

Further analysis was performed to determine the percent change in run time before and after the eight week intervention. Run time percent change improvement for the treatment group was 1.76% ± 3.79%, indicating a reduction in total time and -0.79% ± 1.66% for the control group, suggesting an increase in total run time (Figure 8).

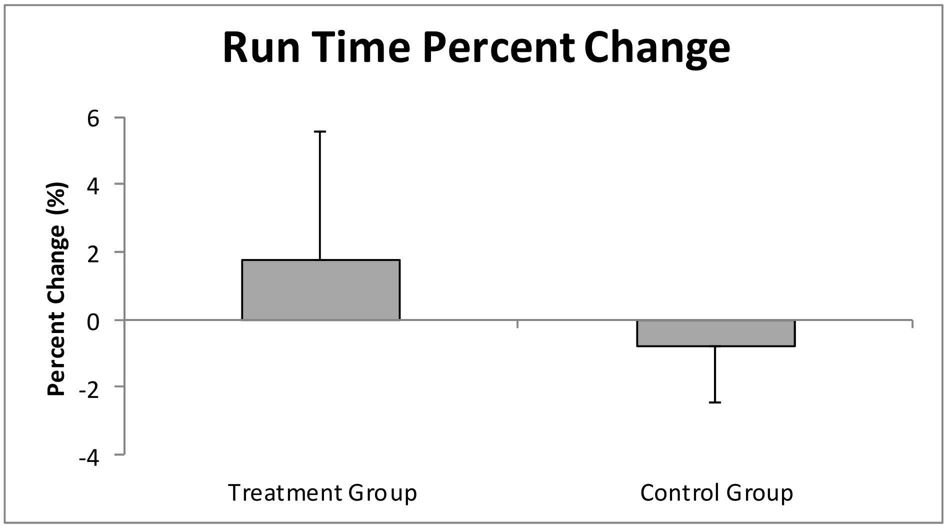

Figure 8. Percent change in total run time.

Discussion

In this study, the effect of core strength on running performance was investigated. Individuals running an average of 20 miles per week with minimal resistance training and core exercise experience were used and randomly assigned to either the control or treatment group. The hypothesis was based on the concept that the core musculature is an active component of the running motion and improving strength and stability of these muscles by engaging in an eight week training program to target such muscles would improve half marathon run time. Therefore, it was predicted that an effect of core strength on running performance would be observed. A main effect of group on run time was expected, where individuals in the treatment group would yield greater improvement than those in the control group. Furthermore, an interaction and main effect of group was anticipated for the core function measures including back extension, side plank, abdominal fatigue, pressure biofeedback unit score and the Lafayette Stabilizer platform values and core strength.

Contrary to the hypothesis, there was no effect of the core strengthening program on run time. No significant effects of time and the core training program on run performance were observed in either group. These results suggest eight weeks of core training did not produce a significant improvement in half marathon run time.

Several probable limitations may explain why an interaction was not observed between group and time on run time. When the group means were plotted for the pre-test and post-test, the graph indicates that greater improvement in run time was seen in the treatment group as seen in Figure 7. Improvement in run performance (decrease in total time) was observed in the treatment group, where the control group increased the total run time, as observed by the percent improvement graph (Figure 8). While the raw data suggests that an interaction may be present, the large standard deviation prevented the finding of statistical significance. It may also be attributed to the lack of statistical power created from a small sample size (n=24, treatment n=13 and control n=11) impacting the results. The $\eta^2_{partial}$ value was equal to 0.16, indicating that 16% of the variance in run time can be explained or accounted for by participation in the core exercise program. The eight week study duration, totaling 24 training sessions, may not have been long enough to produce a statistically significant result on running performance.

While no significant interaction was found between core strength and run time for the treatment and control group, individual results suggest an improvement in run time for those who participated in the eight week training program. Ten of the thirteen participants in the treatment group improved race time while only two of the eleven participants in the control group showed improvement. However, when comparing initial scores of each group the control group started the study with higher core function scores and faster run times compared to the treatment group. This may suggest that individuals in the treatment group had larger room for improvements and the core exercises were training inadequate core function which translated to a greater improvement in run time.

Differences between groups at the start of the study may be explained by gender distribution, as the treatment group had a larger number of females than males and the control group had a larger number of males than females. Leetun et al. (2004) suggested that men demonstrated greater core stability when compared to their female counterparts when testing core function and injury risk. Another potential explanation is that participants in the treatment group met with researchers each week while the control group only met with researchers during pre and post-tests which may have contributed to overall effort of the subjects during testing sessions.

As expected, an interaction was found between group and time for side plank, PBU and the Lafayette stability platform. The results demonstrated that the treatment group improved performance on the side plank and PBU while the control group showed little improvement on either of these tests. Stanton et al. (2004) reported after six weeks of core training the PBU test level went from an 0.5 to 1.5 in the treatment group while no significant performance difference was observed in the control group suggesting that the core exercise program was effective in improving core strength performance on this particular test. Similar to the present study's results, Tse et al. (2005) found an interaction and a main effect of test for right and left side plank and concluded that increased performance and strength for the side plank was significant only in the treatment group.

A group by time interaction was also observed for the performance on the Lafayette Co. stability platform for the control group only. This suggests that the treatment group maintained their performance on this test while the control group reduced the duration they were able to maintain their balance on the platform. Liemohn et al. (2010) suggested that this test may have a practice effect which could have influenced the results. However, each participant performed this test only once before and after the intervention so a practice effect is unlikely. Few studies have used the Lafayette stabilizer platform to compare core stability before and after a core exercise program, however, Liemohn et al. (2010) determined that the use of this test is a reliable measure of core function.

In disagreement with the hypothesis, no group by time interaction was found for back extension or the abdominal fatigue test. Tse et al. (2005) reported no significant differences between pre and post-test performance scores on the abdominal fatigue test for both the treatment and control group. The authors also cited a significant improvement on the back extensor test for the control group compared with the treatment group, however, the difference between the groups was not significant.

The current study did not account for participant's race calendar, diet, or sleeping habits all of which can influence performance, however, the primary research question was addressed. The findings of this study support the conclusion that core exercise training can increase strength and stability of the core musculature and improve performance on core function tests. Significant improvements in running performance were not seen in this study suggesting that supplementing a core training program may not elicit a change in run time for long distance runners. Performance measures are difficult to evaluate due to individual variability including motivation, effort, and fatigue status making it a challenge to researchers attempting to assess improvements. Previous researchers have speculated that improved athletic performance may be a result of reduced risk of injury prompted by the increase in core strength after engaging in regular core exercises.

It is important to acknowledge that trained distance runners were used in this study and that these results are limited to such individuals. In an attempt to improve running performance it may be suggested that distance runners engage in cross-training to condition the appropriate muscles used while running and use core exercise to improve strength of the core musculature to help reduce the risk of lower extremity injury.

Chapter V

Summary, Conclusions, and Recommendations

Summary

Endurance events have grown in popularity evidenced by the increase in long distance race registration, running clubs and media attention. As the population of long distance runners increases, the interest in improving running performance receives more attention from recreational runners, athletes, coaches and researchers. Running requires activation of the core musculature including abdominals, back, and gluteals to stabilize the upper body from the moments and reaction forces of the lower limbs. Increasing core strength and stability may result in greater reaction force absorption translating to improved performance (Behm et al., 2009).

Training the core has become a topic of interest to various populations. Literature addressing core strength and running performance, especially long distance, is limited and often inconclusive. Performance variables and the effect of core strength on these measures have been investigated in various athletic populations including running, rowing, football and swimming (Sato and Mokha, 2009, Tse et al., 2005, Scibek et al., 2001, Nesser and Lee, 2009). Authors of such studies have drawn the conclusion that exercises targeting the specific core muscles do increase strength and stability of the core, however, this increase in strength does not always translate to a subsequent increase in performance (Tse et al., 2005, Scibek et al., 2001, Nesser and Lee, 2009).

The purpose of the present study was to examine the effect of an eight week core training program on core strength and stability and running performance. The original hypothesis of this study was that core strength would influence run time. It was also hypothesized that eight weeks of core training would increase strength and stability of the core musculature and reduce half marathon run time indicating a positive improvement in running performance. Research regarding the effectiveness of core training on performance variables has provided contradictory results and no study has investigated the effect of core strength on running performance in long distance runners. This study was designed to provide insight into the effect of core strength on reducing half marathon run time in well-trained runners. This information could be valuable to practitioners, coaches, and all levels of athletes interested in a training supplementation to aid in a faster race time.

Conclusions

The data from this study indicate that eight weeks of core training does improve core strength and stability of the pertinent core musculature. The effect of increased core strength and stability on long distance running performance was found to be not significant. The treatment group did have a reduction in half marathon completion time, however, the difference between the groups was not significant. These results are in agreement with past research indicating improvement in core strength and function measures with no significant change in performance (Tse et al., 2005, Scibek et al., 2001, Nesser and Lee, 2009). Research has also shown that core training can have a significant influence on 5000-m and shuttle run performance suggesting that core exercises may be an effective training supplementation for improving performance in certain athletic populations and events (Sato and Mokha, 2009, Yaggie and Campbell, 2006).

Improving core strength and stability is effective in reducing the risk and occurrence of lower extremity and low back injury in athletes. While the current study did not find a significant change in run time it may appropriate to approach core exercises as a supplement to improving performance by way of running injury free for a longer period of time. Further research is necessary to determine whether reduced injury risk transfers to improved performance or whether improved core strength results in reduced injury rate.

Recommendations

Further research is warranted to determine the benefits of improving core strength and stability in a population of long distance runners. Research has suggested that engaging in regular core exercises can increase strength and stability of the core musculature and reduce the risk of injury which could translate to improved performance. Determining which set of core exercises best condition the core musculature may be necessary to establish an effect on running performance. Prospective studies could compare the use of core specific exercise and multi-joint core lifts to determine which is more effective in training the core musculature and if there is a difference in how this affects run performance. This would provide insight into which exercises may be most beneficial for developing exercise programs for runners.

Runners should take caution when implementing a core exercise program into their training routine and acknowledge that the benefits regarding performance are variable amongst individuals and they may or may not see an improvement in run time. However, the use of core exercises may help reduce the risk of injury which could lead to optimal health for the race season. Until further results are obtained, those interested in core training can utilize such exercises to improve strength and stability, which may reflect improvements in posture, spinal health and greater reaction force absorption **(**Sato and Mohka, 2009).

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Appendix A.

Informed Consent

Volunteer copy / Investigator copy

WESTERN
WASHINGTON UNIVERSITY
An equal opportunity university

Department of Physical Education, Health & Recreation 516 High Street, Bellingham, Washington 98225-9067
(360)650-3105 Fax (360) 650-7447

INFORMED CONSENT FORM
WESTERN WASHINGTON UNIVERSITY

Title of Investigation: The Effect of Core Strength on Running Performance of Long Distance Runners

Investigator: Megan Cleveland
Department of Physical Education, Health and Recreation
516 High St.
Western Washington University
Bellingham, WA 98225-9067
Phone: (360) 280-5067
clevelm@students.wwu.edu

Advisor: Kathy Knutzen
Phone: (360) 650-3055
Kathy.Knutzen@wwu.edu

This is to certify that I, ____, hereby agree to participate as a volunteer in a scientific investigation as an authorized part of the education and research program of Western Washington University under the supervision of graduate student Megan Cleveland.

Purpose of the Study:

The study in which I will be participating is designed to explore the relationship between core strength and running performance and to determine what relationship, if any, exist between core function and running speed.

Procedures to be followed:
I understand that males and females between the ages of 18 to 65 will be invited to participate in this study. I understand that in order to participate in this study:

- I must be over the age of 18 years.
- I must be free of injury to the muscles, bones, or joints of the upper and lower extremity.
- I must have full range of motion of my trunk, shoulder, elbow, wrists, hips, knees, and ankles.

- I must be running on average at least 20 miles per week.
- I must have participated in one organized half marathon race in the last year.
- I must be willing to dedicate three days/week over 8 weeks to the study program.
- I must be willing to attend 4 separate testing sessions.

I understand I will be participating in one of two groups listed below:

- Group A: A group that will participate in core strength exercises 3 days/week accumulating approximately 45 minutes, as well as maintaining at least 20 miles per week of running for 8 weeks with two testing dates before and after the 8 week program.
- Group B: A group that will participant in running at least 20 miles per week for 8 weeks with testing dates before and after the 8 week program.

I understand that this study will require me to complete forms before the first testing date and that I must attend all tests and training sessions. The activities in this study will be as follows:

1. Test Sessions: (time commitment ~5 hour)
    - Prior to testing:
        - I will read and sign the informed consent form.
        - I will read and complete the medical background form and the hold harmless agreement.

    - I will be tested in the following areas:
        - **Physical Examination:** This will include measurements of my height and weight.
        - **Body Composition:** Before completing this test, I will be asked to refrain from eating 4 hours prior to testing and to void my bladder upon arrival at the test. The test will include sitting in a BOD POD chamber with a nose clip and swim cap applied. The BOD POD is an enclosed space that will measure my body composition via air displacement. I will be asked to sit in the chamber and it will not feel any different than sitting outside the chamber. I may experience discomfort due to the enclosed space but there is a window that will allow me to signal the experimenters if I am bothered by the confined space.

          Two trials of 45 seconds each will be taken and a third trial will be taken with inconclusive results. A final trial will be taken as I sit quietly and breathe normally through a disposable tube for 4-5 breathes followed by two quick light pants with the airway blocked.

        - **Core function:** This will include 3 different tests. I will receive a detailed explanation of testing procedures and protocol before the tests are conducted and will be given the opportunity to ask questions as they arise. I will also be provided sufficient time to familiarize myself with all of the exercises prior to starting each test.

- **Lafeyette Co. Stabilizer Platform:** I will be instructed to assume a four point position on my hands and knees to perform the core stability test. I will perform a contralateral arm and leg extension exercise to a metronome and the time I am able to maintain my balance in 30 seconds will be recorded.
- **Sahrmann's Test:** I will have a stabilizer pressure biofeedback unit placed in the lordotic curve of my back to perform the Sarhmann core function tests. I will advance to the next level of testing as long as the pressure difference is no more than 10mmhg.
- **McGill's Core function test**: I will perform back extension, side plank on both right and left sides and an abdominal fatigue test. These tests will all be measured using a stopwatch and my time in each position will be recorded.

▪ **Half marathon run performance:** I will be expected to complete two 13.1 mile races before and after the 8 week program. This test will be conducted at Lake Sammish in Bellingham Wa at 8am.
  - I will arrive to this test 30 minutes prior to the start to allow for enough prep time. I will be given a number to wear on my front side visible to the experimenter at all times. My time will be recorded using a stop watch.

o I understand that maximal effort is expected for all the tests to ensure the most accurate data is collected.

2. Training Sessions: (time commitment ~15- 30 minutes one day per week)

o I will be randomly assigned to one of two groups and my participation will require 8 weeks of documenting my current training program. I understand that my allocation to the exercise program will be random- I have an equal chance of being placed in group A or B. Both groups will involve the completion of at least 20 miles per week of running on the days of my choice. I am able to participate in daily physical activity outside of the 20 miles/week and I will be expected to document all activities along with mileage and days that I exercise.

o I will be asked to follow the procedures below if I am enrolled in the ***training program*** only:

▪ The training program will take place at Western Washington University unless otherwise arranged by the investigator. The program will run for 3 days/week for 8 weeks. I will be asked to leave the program if I miss 3 consecutive sessions or four sessions total.

- I will meet the investigator on a weekly basis to receive new core exercises as well as turn in my activity log.
- Each training session will provide an overview of the core exercises I will be performing on a given week. The investigator will demonstrate all exercises. I will perform all exercises with the investigators approval before leaving the training sessions.
- I will receive any progression tools that I need and do not have access to at home or in a gym.
- I will maintain on average at least 20 miles per week of running.

Discomforts and Risks:

I understand that the procedures to be used in this study are considered to be safe. The risks associated with the evaluation of body composition in the Bod Pod and core function and height are considered to be minimal.

I understand that, as with any exercise program, there are risks of injury due to accidents during the exercise activities. There is a risk of transient muscle soreness that is a normal result of the beginning of many exercise programs and I understand that I might experience some muscle soreness that should disappear after a period of rest between sessions. Additionally, I realize that there may be minimal risk, such as discomfort or pain as a result of injury to involved musculature, joints or connective tissue. These are risks associated with any physical activity. If I experience pain, I am aware that I may withdraw from participation in this study at any time, without penalty.

If I feel I cannot or should not perform two half marathon races, maintain an average of 20 miles per week of run training and meet with the investigator weekly to discuss my training routine and perform core function testing, I should not participate in this study.

Benefits to Me:

I understand that there are no direct benefits to me as a result of participating in this study, however, the results may help me to gain information of my current core function and possibly improve my running performance.

Potential Benefits to Society:

By participating in this study I will be contributing to research that aims to advance our understanding of both core function and running performance. The results identified in this study may be helpful in prescribing exercises for long distance runners interested in potentially improving their racing speed.

Statement of Confidentiality:

I understand that any data or my answers to questions will remain confidential with regard to my identity. Only the investigator and his/her assistants will have access to my identity and to information that can be associated with my identity. In the event of publication of this research, no personally identifying information will be disclosed.

The investigation and my part in the investigation have been defined and fully explained to me by Megan Cleveland or her assistant and I understand his/her explanation. The procedures of this investigation and a description of any risks and discomfort have been discussed in detail with me and I understand that a copy of the signed consent form will be provided to me.

Right to Ask Questions:

I have been given an opportunity to ask whatever questions I may have had and all such questions have been answered to my satisfaction.

I understand that I am free to deny any answers to specific items or questions in interviews or questionnaires. If I have any questions about this study, I can contact Megan Cleveland at the contact information listed on the front page of this consent form.

I understand that for additional information about my rights as a research participant, I may contact the WWU HSRC Administrator, at:

Janai Symons
HRSC Administrator
Research and Sponsored Programs
Old Main Building 530
Western Washington University
Bellingham, WA 98225-9038
360-650-3082
janai.symons@wwu.edu

Event of injury:

I understand that emergency medical care will be summoned in the event of injury resulting from this study. In the event of adverse effects related to this study, I understand that I shall contact the office listed above. I also understand that I am not waiving any rights that I may have against WWU for injury resulting from negligence of the University or investigators.

Voluntary Participation:

I understand that my participation in this study is voluntary, and that I may withdraw from this study at any time by notifying the investigator. I also understand that my participation may be terminated by the investigator if I do not fit any of the pre-determined subject categories or if he or she feels that my personal well-being is in question.

This is to certify that I am over the age of 18 years, and I consent to and give permission for my participation as a volunteer in this program of investigation. I understand that I will receive a signed copy of this consent form. I have read this form, and understand the content of this consent form.

____

Volunteer Date

I, the undersigned, have fully explained the investigation to the above subject.

____

Investigator Date

Audiotaping, Videotaping, and Photography

By initialing on the lines below, I am indicating that I give the research team permission to (please initial all that apply):

______Photograph, audiotape and/or videotape my participation in this study.

______Use photographs, audiotape or videotape recordings of me when they present this research in educational and professional venues, *even if I am personally identifiable*.

______Use photographs, audiotape or videotape recordings of me when they present this research in educational and professional venues, *only as long as I am not personally identifiable*.

Appendix B.

Human Subject's Application

<u>*Human Subjects Application, Megan Cleveland:*</u> *The Effect of Core Strength on Running Performance.*

What is your research question, or the specific hypothesis?

This study was designed to determine if the addition of core strength exercises into a running program will influence running performance. Specifically, does a progressive core strengthening program positively influence performance in a half marathon?

2. What are the potential benefits of the proposed research to the field?

The role of core strength in improving running performance is not well researched especially with regards to healthy trained athletes. Specifically, there has been little research published examining the role of core strength in improving running performance of long distance runners. Conclusions gathered from this study will help eliminate some of the uncertainty behind the effects of core exercises and running performance. A better understanding of the relationships between the core and long distance running performance would be valuable in designing exercise prescriptions for long distance runners, modifying individual training programs, and developing strategies for improving racing time.

3. What are the potential benefits, if any, of the proposed research to the subjects?

The results from this study may help establish whether core strength has an effect on running performance. This information will be helpful to aid in exercise prescription for runners who may be interested in potentially improving their racing time.

4. Answer a), then answer either b) or c) as appropriate.
a. Describe how you will identify the subject population, and how you will contact key individuals who will allow you access to that subject population or database.

The subject population for this study will consist of 30, 18-65 year old long distance runners recruited to participate as either part of the control group (n=15) running at least 20 miles per week or the treatment group receiving 8 weeks of core exercise progressions in addition to running at least 20 miles per week(n=15).

b. Describe how you will recruit a sample from your subject population, including possible use of compensation, and the number of subjects to be recruited.

No compensation was used in recruiting subjects for this study. Volunteers will be directly solicited from the Greater Bellingham Runners club as well as Fairhaven's Runners Clubs. Members of the Bellingham community will also be invited to participate as representatives of the running population.

c. Describe how you will access preexisting data about the subjects.

5. Briefly describe the research methodology. Attach copies of all test instruments/questionnaires that will be used.

Note: All attachments must be in final form; drafts are unacceptable.

All subjects were briefed on the testing procedures, participant expectations and given an overview of risk and benefits of volunteering. The opportunity to ask questions was provided during all testing and instructional sessions and the investigator presented sufficient answers to all questions. Body composition, height and weight were all recorded prior to testing core strength and running performance. A stadiometer was used to measure subject height (vertex on top of head to floor). Height was recorded in inches with the shoes off. The BodPod (BODPOD ® Gold Standard Body Composition Tracking System) was calibrated before each testing day, following the written instructions provided by the company for proper use. Subjects were asked to have minimal food and drink before testing for best results. All jewelry was removed, tight fit clothing, such as a swimming suit, was worn for the test and a spandex hat was worn to keep all hair eliminating air pockets within the hair. The BodPod test reported body fat, body density and weight.

Individual core strength was measured using the McGill's 4 core function tests and a pressure biofeedback unit. The four tests include the extensor test (back extensor test), flexor test (abdominal fatigue) and side bridge tests. The back extensor tests used is the Biering-Sorensen test where the upper body is extended out over a table with the lower legs secured. The arms are folded across the chest with the hands held on opposite shoulders. The test is terminated when the subject falls below the horizontal position and time is recorded. The abdominal fatigue test is performed by having the subject sit on a bench with a back support that is at a 60 degree angle. Both the knees and hips are flexed at 90 degrees and the feet are fixed securely to the bench with a strap and towel. The arms are folded across the chest with the hands placed on opposite shoulders. Subjects lean against a 4 inch thick rubber pad that is wedged between their back and the 60 degree back rest. Subjects are instructed to maintain their body position once the supporting wedge is removed to initiate the test. The test is ended when the upper body can no longer maintain a 60 degree angle. The side bridge test starts with the subject lying on either side with the legs extended. The top foot is placed in front of the lower foot for added support. Subjects are instructed to support themselves on only the elbow, forearm and feet. The hips are raised off the floor and a straight body position is maintained in the frontal plane. The non-supporting arm is held across the chest with the hand placed on the opposite shoulder. The test is terminated when the hips begin to sag and body position cannot be maintained or when the lower leg starts to rest on the floor. Performance on each test was recorded with a stopwatch in seconds.

A pressure biofeedback unit was also used to measure core function. The test included an inflatable pad of a Stabilizer Pressure Biofeedback Unit (PBU) placed in the natural lordotic curve, while the subject lies supine and the unit is inflated to 40mmHg. The test consisted of 5 levels with each level increasing in difficulty. Level 1 required individuals to activate the abdominal musculature bracing the trunk in an isometric fashion without movement being produced. Once this is achieved the subject slowly raises one leg to a position of hip flexion, of 100 degrees, with comfortable knee flexion. The opposite leg is brought up to the same position in the same manner with a change in pressure on the PBU no more than 10 mmHg. A pressure reading greater or less than 10mmHG above or below this baseline indicates lumbopelvic stability was lost at this level. This level 1 position was used as the start position for subsequent levels of the test protocol. Level 2, from the start position, the subject slowly lowers one leg such that the heel contacts the ground. The leg is then slid out to full knee extension and then returned to the start position. Level 3, from the start position, requires the subject to slowly lower one leg reaching the heel 12 cm from the ground. The leg is then slid out to fully extend the knee and returned to start. Level 4, from the start position, the subject slowly lowers both legs so the heals contact the ground. The legs are slid out to extend the knees and returned to the start position. Level 5, from the start position, the subject slowly lowers both legs, heels reaching 12 cm from the ground, the knees are extended and brought back to the starting position. In order to attain each new level of the Sahrmann test, the lumbar spine position had to be maintained as indicated by a change of no more than 10 mmHg in pressure on the PBU.

Subjects also performed a stability test using the Lafayette Co. stability platform. For this test subjects are in a 4-point position, hands and knees, on the stability platform and contralateral knee and arm extension is required. Subject score is the number of seconds that balance was maintained in each 30 second test. After completion of the core function tests subjects were briefed on the running test and given written instructions for race day preparation, including a diet recording sheet, directions to the start line, a running course outline and maximal effort expectations.

Participants arrived in the morning no later than 30 minutes prior to the start of the half marathon running test. The 13.1 mile course was mapped out using a Garmin Forerunner 305, and performed twice for accuracy by the experimenter. The course included low traffic roads, some elevation gain and 2 laps around Lake Samish in Bellingham, Washington. Each subject was given a number to wear on their front side, visible to the experimenter for proper reporting of completion time. Participants were instructed to treat the half marathon as they would a race, and maximal effort was assumed from all subjects. The running test started with the sound of an air horn and two stop watches were used to record completion time, the average of the two times was used for data analysis. Water and first aid was provided every 3 miles and a bathroom was located at the start/middle/finish. Hammer Nutrition Gel (Hammer Nutrition Products ®) packs were offered at mile 6 along with lemon-lime flavored cytomax (CytoSport®). Completion time was documented after the participant had fully crossed the finish line with both feet. Post- race refreshments were provided including gatoraide, bananas, watermelon and crackers. Following the pre-test run and core strength measurements, participants were randomly assigned to two groups, treatment and control.

Subjects in the treatment group performed core exercises three times per week. Subjects met with the experimenter in groups or individually to receive the exercises for a given week. Tutorial in proper form and execution of the 10 different exercises was provided to ensure the subjects were comfortable performing the exercises on their own. Core exercises for the first week were performed on a stable surface, such as the ground or floor and were meant to allow the participants to gain stability before progressing to an unstable surface. If subjects did not have access to a gym with the appropriate tools for exercise progressions they were provided to individuals by the experimenter. Core exercises included back extensions, bridge, forward/side T's, plank holds, side plank, push-ups, lunges, squats, bird dog and abdominal crunches, see Table 1 for exercise description and progressions. The core exercise program was performed 3 days per week resulting in approximately 30 minute sessions for 8 weeks. Progressions included utilizing an unstable surface, to incorporate balance and activate more of the core musculature. As subjects became confident in utilizing the instability components, exercise advances were made by changing the surface or weight was added by use of dumbbells. If weight was added it did not exceed more than 15 pounds to ensure there was minimal increased risk of injury. A sample progression is provided in Table 2.

Participants in both groups were given exercise logs to track their weekly running mileage. Subjects were expected to run at least 4 days per week, accumulating on average 20 miles**.** All subjects were asked to wear a heart rate monitor to be sure they were working in their optimal target range and report their mileage and heart rate for each run. All other forms of exercise were reported so that they could be accounted for in the results. At the end of the 8 week intervention, all subjects completed the same half marathon course that was run before the intervention. Subject's race time was recorded using a stop watch. Core strength measurements were taken for each subject as well as body composition, height and weight. All changes between pre and post intervention were recorded and compared.

Table 1. Core Exercise Descriptions

Exercise	**Description**
Plank (prone)	Elbows/hands directly below shoulders, raise up on forearms and toes/knees. Keep head aligned with spine, contract gluteals and pull stomach up and in. Maintain straight line between upper and lower body
Side Plank (left & right)	Elbow/hand directly under shoulder, raise up on forearm and side of feet/knees. Head stays in line with the spine, pull hips up, stomach up and in and contract the gluteals. Maintain straight line between upper and lower body. Switch sides.
Bird dog	Start in prone 4-point position on hands and knees. Extend opposite arm and leg out keeping foot flexed, lower back down to start and switch sides. Keep stomach pulled in tight to maintain stability and proper alignment in spine.

Push-ups	Start with hands directly below the shoulders, feet/knees hip width apart. Arms fully extended, drop to the floor, until nose touches or elbows come to 90 degrees of flexion, push back up into starting position. Stomach pulled up and in throughout range of motion.
Squats	Feet are hip width apart, legs fully extended. Lowering the body down, flex at the knee to 90 degrees, keeping shoulders back and spine straight. Engage stomach muscles throughout the movement, contract gluteals and hamstrings as the legs extend back to start position. Important to keep knees directly behind toes at all times during flexion.
Lunges	One leg is forward and the other is positioned behind the body. Contract the stomach muscles and drop the body straight down, being sure not to lean forward, keeping the COM directly between the two legs. Both knees should come to 90 degrees of flexion, contract gluteals, quads and hamstrings to extend back to start position. Switch forward legs.
Forward T's	Shift weight into one leg, flex at the knee and hip in the free leg in front of the body. Raise the arms directly above the head or keep them resting on the hips, engage the back muscles and abdominals, lean forward keeping arms align with head and trunk, extend the flexed leg back behind the body. Return to start position. Repeat on other side.
Side T's	Shift weight into one leg, keeping the arms raised over head or resting on the hips, raise the other leg laterally. Contract the muscles in the supports leg as well as the stomach muscles throughout the entire movement. Return to start. Switch supporting legs.
Bridge	Lying supine on the floor, arms resting at the side of the body, raise hips up keeping shoulders on the floor. Contract the gluteal muscles and hamstrings.
Abdominal Crunches	Various exercises laying supine on the floor with either upper, lower or both portions of the body flexing/extending. Requires abdominal muscle contraction, as well as bracing and hollowing of the trunk.

Table 2. Core Strength Progression

Exercise	Beginner (1-2)	Intermediate (3-5)	Advanced (6-8)
Plank (prone)	**Week 1:** Forearms & knees/toes: 4 x until fatigue **Week 2**: Forearms & toes- roll forward/back on toes: 4 x until fatigue	**Week 3:** Forearms & toes- alternate leg lift: 4 x until fatigue **Week 4:** Forearms on stability ball & toes on floor: 4 x until fatigue **Week 5:** Hands & toes: 4 x until fatigue	**Week 6:** Hands & toes- alternate leg lift: 4x until fatigue **Week 7:** Hands on stability ball & toes on floor or hands on BOSU& toes on floor: 4 x until fatigue **Week 8:** Hands on floor & toes on stability ball- alternate lateral leg extension: 4 x until fatigue
Side Plank	**Week 1**: Forearms & knees/feet: 4 x until fatigue **Week 2:** Forearms & feet- lift top leg: 4 x until fatigue	**Week 3:** Forearm & feet- roll down: 3 x until fatigue **Week 4:** Forearm & feet- roll down w/dumbbell 3-5lbs.: 4 x until fatigue **Week 5:** Hands& feet: 4 x until fatigue	**Week 6:** Hands & feet- lift top leg: 4 x until fatigue **Week 7:** Hands & feet- roll down: 3 x until fatigue **Week 8:** Hands & feet- roll down w/dumbbell 3-5 lbs.: 4 x until fatigue
Bird Dog	**Week 1:** Hands & knees- alternating sides: 3 x until fatigue **Week 2:** Hands & knees crunch in legs- forward and Hands & knees crunch in legs-across: 4 x until fatigue for each exercise	**Week 3:** Hands & knees- 3-5 lb dumbbells in hands: 3 x until fatigue **Week 4:** Lie prone on stability ball, alternating arm & leg extension: 4 x until fatigue **Week 5:** Hands & knees, extend opposite arm & leg, abduct both arms & legs laterally and return to start: 4 x until fatigue	**Week 6:** Hands on floor & knees on dynadisks, alternating arm & leg extension: 3 x until fatigue **Week 7:** Hands & toes- alternating sides: 4 x until fatigue **Week 8:** Hands & toes- crunch in legs- forward/across: 5 x until fatigue
Push-ups	**Week 1:** Hands & knees/toes: 3 x until fatigue **Week 2**: Hands & knees/toes: 4 x until fatigue	**Week 3:** Hands on BOSU knees on floor: 4 x fatigue **Week 4:** Hands on BOSU toes on floor: 4 x until fatigue **Week 5**: Hands & Knees, and Hands on BOSU, knees on floor shifting weight side to side: 3 x until fatigue	**Week 6**: Hands & toes: 4 x until fatigue **Week 7:** Hands on BOSU, toes on floor: 4 x until fatigue **Week 8:** Hands & toes and Hands on BOSU toes on floor shifting weight side to side: 3 x until fatigue for each exercise

Squats	**Week 1:** Feet hip width apart on Floor & wall sits- body weight: 4 x until fatigue **Week 2:** Feet hip width apart on floor & wall sits- 10-12 lb dumbbell: 5 x until fatigue	**Week 3:** Static sumo squat shifting body weight side to side: 4 x until fatigue **Week 4:** Squats on BOSU- round side: 4 x until fatigue **Week 5:** Single leg squats on floor- switch sides: 3 x until fatigue	**Week 6:** Squats on BOSU- flat side and static squat weight shift side to side: 4 x until fatigue **Week 7:** Single leg squats on BOSU- flat side- switch sides: 3 x until fatigue **Week 8:** Squats on BOSU- flat side w/weights 8-12 lb dumbbell and static squat weight shift side to side: until fatigue
Forward T & Side T	**Week 1:** Foot on ground & hands at hips, lean forward & extend back leg, return to start- switch sides: 4 x until fatigue, both sides **Week 2:** Foot on ground & arms overhead lean forward & extend back leg, return to start- switch sides: 4 x until fatigue	**Week 3:** Foot on ground & one hand overhead with 3-5 lb dumbbell: 4 x until fatigue **Week 4:** Foot on airex pad & hands on hips: 3 x until fatigue **Week 5:** Foot on foam roll & hands at hips: 4 x until fatigue	**Week 6:** Foot on airex pad & one arm overhead with 3-5 lb dumbbell: 4 x until fatigue **Week 7:** Foot on BOSU & hands at hips: 4 x until fatigue **Week 8:** Foot on BOSU & hands overhead with 3-5 lb dumbbell: 4 x until fatigue
Back Extension	**Week 1:** Lie prone on floor, raise both arms & both legs: 4 x until fatigue **Week 2:** Lie prone on floor, scissor arms & legs: 3 x until fatigue	**Week 3:** Lie prone on floor, raise arms & legs, lateral pull down with arms: 3 x until fatigue **Week 4:** Lie prone on floor, raise arms & legs, lateral pull down with arms using resistance bands: 4 x until fatigue **Week 5:** Lie prone with hips on ball, flex arms at head, raise trunk up. Roll out onto hands, feet on the floor & raise legs up: 3 x until fatigue	**Week 6:** Place circle resistance band around ankles. Lie prone on floor, raise arms & legs. Push legs out laterally against resistance band and back together: 4 x until fatigue **Week 7:** Lie prone with hips on ball, resistance band around wrist, raise trunk up, lateral pull with arms using resistance band. Roll out onto hands, resistance band around ankles. Start with feet on the floor & raise legs up, push legs out laterally against resistance band and back together: 4 x until fatigue **Week 8:** Lie prone on BOSU, scissor arms & legs: 3 x until fatigue

Bridge	**<u>Week 1:</u>** Lie supine w/knees bent arms at side. Raise the hips upward: 4 x until fatigue **<u>Week 2:</u>** Lie supine w/knees bent, arms at side. Raise one leg straight up in the arm and raise hips: 4 x until fatigue	**<u>Week 3:</u>** Lie supine w/knees bent arms at side. Place a resistance band above the knees-raise hips upward: 3 x until fatigue **<u>Week 4:</u>** Lie supine w/knees bent, arms at side. Place resistance band above the knee and a medicine ball between the thighs, raise hips upward: 4 x until fatigue **<u>Week 5:</u>** Lie supine with legs out on ball, arms at side. Raise hips upward. Balance challenge by bringing arms across the body or held out above head: 3 x until fatigue	**<u>Week 6:</u>** Lie supine with legs out on ball, arms at side or across chest. Raise hips upward and alternate leg raises: 3 x until fatigue **<u>Week 7:</u>** Lie supine with legs out on ball, arms at side or across chest. Raise hips upward, dig heels into ball and roll ball in and out: 4 x until fatigue **<u>Week 8:</u>** Lie supine with back on bench and knees bent. Place dishcloth under the feet. Raise hips upward and extend/flex the legs: 4 x until fatigue
Lunges	**<u>Week 1:</u>** Walking lunge, knees flexed to 90 degrees, raise up and pull leg through to 90 degrees of hip flexion: 4 x until fatigue **<u>Week 2:</u>** Walking lunge with trunk rotation, knee flexed to 90 degrees: 4 x until fatigue	**<u>Week 3:</u>** Start in neutral position on an aerobics step. Step one leg back behind the body, bend legs to 90 degrees, extend supporting limb on step and pull back leg through to 90 degrees of hip flexion: 3 x until fatigue **<u>Week 4:</u>** Place one leg on bench behind the body and one leg in front. Keeping back leg on the bench bend legs until reaching 90 degrees of flexion and raise back up- switch sides: 4 x until fatigue **<u>Week 5:</u>** Place front foot on BOSU, extend back leg, flex both legs to 90 degrees- repeat on other side: 3 x until fatigue	**<u>Week 6:</u>** Place one leg on bench behind the body and one leg out in front on a dynadisk. Keeping back leg on bench and front leg on the dynadisk, bend legs to 90 degrees of flexion and raise back up- switch sides: 4 x until fatigue **<u>Week 7:</u>** Place both front and back legs on dynadisks, bend legs to 90 degrees- repeat on other side: 3 x until fatigue **<u>Week 8:</u>** Place both front and back legs on dynadisks, 8-12 pound medicine ball in hand, bend legs to 90 degrees, rotate medicine from side to side for 30 seconds and raise back up- repeat on both sides: 4 x until fatigue

Abdominal Crunches	**Week 1:** Lie supine with knees bent & feet on the floor, keeping hands on head and elbows abducted to 90 degrees, refraining from horizontally adducting, flex at trunk, lifting shoulders and upper body off of the floor: 4 x until fatigue **Week 2:** Lie supine, flex hip and knees to 90 degrees. Keeping upper body stationary on the floor, drop one leg to the floor touching the heal to the ground, flex back up to starting position- switch sides: 4 x until fatigue	**Week 3:** Lie supine, with knees and hips flexed to 90 degrees. Keeping hands on head and elbows abducted to 90 degrees, refraining from horizontally adducting, flex at trunk, lifting shoulders and upper body off of the floor- laterally rotate to one side as the opposite leg is extended out. Keep the extended leg as close to the floor as possible. Return to start position with legs on floor and alternate extended leg: 4 x until fatigue **Week 4:** Sit on floor, with knees bent & feet on the floor. Roll the upper body back toward the floor and hold at 60 degree angle, return to start position: 4 x until fatigue **Week 5:** Sit on floor with knees bent & feet on the floor. Roll the upper body back toward the floor and rotate laterally to one side hold, return to start and switch sides: 4 x until fatigue	**Week 6:** Sit on stability ball, roll out until the low back is in contact with the ball, keep knees flexed at 90 degrees and contract gluteals to raise hips up. , Keeping hands on head and elbows abducted to 90 degrees, refraining from horizontally adducting, flex at trunk, lifting shoulders and upper body off of the ball: 4 x until fatigue **Week 7:** Sit on floor with stability on bent knees & supported with hands. Roll back to the floor keeping the stability ball between the hands and feet on the floor, extend the ball overhead as the back & shoulders come in contact with the ground. Flex the trunk to return to start position: 4 x until fatigue **Week 8:** Sit on floor with stability ball on bent knees & supported with hands. Roll back to the floor keeping the stability ball between the hands and feet on the floor, laterally rotate the trunk to one side extend the ball overhead as the back & shoulders are almost touching the ground. Flex the trunk to return to start position- repeat on both sides: 4 x until fatigue

6. Give specific examples (with literature citations) for the use of your test instruments/questionnaires, or similar ones, in previous similar studies in your field.

Stabilizer Pressure Biofeedback Unit- Stanton et al. (2004) investigated the effect of short-term Swiss ball training on core stability and running economy. Eighteen male subjects were assessed before and after a training program for stature, body mass, core stability, EMG activity of the abdominal and back muscles, treadmill VO_{2MAX}, running economy and running posture. Core stability was evaluated using the Sahrmann core stability test. The inflatable pad of a Stabilizer Pressure Biofeedback Unit (PBU) is placed in the natural lordotic curve, while the subject lies supine and the unit is inflated to 40mmHg. In order to attain each new level of the Sahrmann test, the lumbar spine position had to be maintained as indicated by a change of no more than 10 mmHg in pressure on the PBU. Subjects also performed a Swiss ball prone stabilization test that required them to adopt a push up position with the elbows locked and the toes placed on the vertical apex of a Swiss ball. EMG and video analysis was collected to determine time to failure by observing the change in hip flexion angle as well as muscle activity during core testing. The participant was required to hold this position as stable as possible until failure to maintain the position was observed during subsequent video analysis. The treatment group underwent 6 weeks of Swiss ball training. Exercises were performed twice per week for approximately 25 minutes. The results showed that 6 weeks of Swiss ball training significantly improved performance on the Sahrmann test and Swiss ball prone stabilization test. The control group showed no significant performance difference on either the Sarhmann test or prone stabilization test. Participants in the control group were on average able to attain a level of 0.5 in the Sarhmann test and reached 20s before failure in the prone stabilization stability test. Individuals in the experimental group did show significant improvement on both core function tests. After 6 weeks the Sarhmann level went from an average 0.5 to 1.5 and the time to failure during prone stabilization went from 25s to 40s suggesting that the core strengthening exercise program was effective in improving core strength on these two specific tests. No significant results were found in VO_{2MAX}, running economy or running posture (Stanton et al. 2004).

Lafeyette Co. Stabilizer Platform- Liemohn et al. (2010) investigated the reliability a Lafayette Instrument Co. stability platform for measurement of core stability. Subjects are in a 4-point position, hands and knees, on the stability platform and contralateral knee and arm extension is required. Subject score was the number of seconds that balance was maintained in each 30 second test. The metronome was set at 40 beats/minute and subjects alternately raise their arms in the sagittal plane at the shoulder joint 10 times in each 30 second test. The 10 trials were performed on four different days to determine reliability and consistency of the testing procedures. Day one had the highest reliability however it represented the lowest means and the largest standard deviations. Therefore internal consistency reliability was calculated for testing days 2,3 and 4 and the results showed consistent trial means and reliability coefficients amongst the days. Administering 10 trials of the balance test on days 1 and 2 and 6 trials on day 3 is sufficient to obtain a test score with good consistency and reliability. The test score would be the mea of trials 2 through 6 on day 3 of testing with trial 1 representing a practice/warm-up trial (Liemohn et al. 2005; Liemohn et al. 2010).

McGill's Core function tests (back extension, side bridge and abdominal fatigue tests) - Carter, Beam, McMahan, Barr and Brown (2006) studied the effects of stability ball training on spinal stability. The static back endurance and side bridge tests were used to measure spinal stability during pre and post-testing. The treatment groups performed stability ball training sessions twice per week for 30 minutes. The exercises focused on targeting spinal stability by working abdominal and back muscles with stability balls. The results showed that the experiemental group significantly improved their performance on the static back endurance test (149.3 ± 72.3 pre to 194.6 ±56.7 post) and side bridge test (45.4s ± 39.4s pre to 71.3s ± 59.7s post) after the intervention. Control group performance decreased on the static back endurance test which may be explained by the reporting of back pain before participation in the study. Stabililty ball traning may be an appropriate intervention to decrease the risk of back pain and improve core stabilty and strength (Carter et al. 2006).

Mcgill et al. (1999) identified a number of tests as valid and reliable for showing endurance of the core musculature. The four tests include the extensor test (back extensor test), flexor test (abdominal fatigue) and side bridge tests which shown to have reliability coefficients between 0.97 and 0.99. The back extensor tests used is the Biering-Sorensen test which has also been shown to be consistently reliable as a measure of low back extensor endurance. During each test subjects should be reminded that these are maximum effort tests and they should maintain each position for as long as possible**.** Normal values for each of these tests are as follows in seconds: Side bridge 83-86, abdominal fatigue test 34, and back extension 173 (Mcgill at al. 1999). The Mcgill tests have been utilized by many research teams in combination with other tests to evaluate subject's core strength and endurance (Tse et al. 2005; Leetun et al. 2004).

7. Describe how your study design is appropriate to examine your question or specific hypothesis. Include adescription of controls used, if any.

The research was a pretest-posttest randomized group's design. It was implemented to assess the effect of core strength on running performance in long distance runners. All subjects were randomly assigned to one of two groups, control (n=15) and treatment (n=15). Each subject was tested at the beginning and end of the intervention. The treatment group, in addition to each individual's regular running routine, underwent 8 weeks of core training. The control group was expected to maintain running 20 mile per week average throughout the study. Random assignment was used for participant assignment to the two groups by drawing a number out of a hat, 1 indicating the control group and 2 the treatment group.

8. Give specific examples (with literature citations) for the use of your study design, or similar ones, in previous similar studies in your field.

Sato and Mokha 2009, demonstrated that there was a significant influence on 5000-m run times, demonstrating that core strength training significantly improved running times in the experimental group compared to the control group during a 6 week training program. The study included 28 recreational and competitive rear foot strike runners who were screened for core stability where runners who already possessed a high level of stability were eliminated. The study included a core strengthening program that consisted of abdominal crunches, back extension and hip raises on a stability ball, as well as 1-arm/1-leg raises and Russian twists to target the back, abdominals and hip extensor muscles. Exercises were performed for 6 weeks increasing the number of sets and repetitions every 2 weeks to challenge strength improvement. The control group was instructed to maintain their regular running routine. While both groups improved the run time only the experimental group was found to be significant. These results suggest that by improving core strength through regular core exercises running performance could be enhanced (Sato & Mokha, 2009).

Yaggie and Campbell (2006) investigated the effect of a four week balance training program on specified functional tasks; the shuttle run and vertical jump. This study utilized the BOSU, both sides up balance trainer, for testing balance. Thirty-six recreationally active subjects participated. Balance testing performed on a BOSU, vertical jump and shuttle run tests were performed before and after the intervention. Subjects incorporated balance training three times per week for 20 minutes with difficulty progressions each week. The balance training on the BOSU consisted of exercises progressing from simple to more complex over the four weeks. Exercises included single limb stance with or without torso rotation, rotary squat with or without jump, single leg jumps, v-sit with rotation and opposite leg and arm extension. Progressions and variations of exercises were presented each week to replace those already mastered. Results showed that balance training influences performance on the shuttle run, decreasing time in the pre and post-test compared to the control group who did not perform balance training. Shuttle run time decreased for the experimental group from pretest (13.16 ± 1.47) and post-test (12.45± 1.87. There were no significant improvements in vertical jump performance

Tse et al. (2005) examined the effectiveness of a core training program on improving muscle endurance in rowers and determined if changes in endurance effect aspects of performance**.** Forty-five subjects with an average of 1 year of rowing experience participated in the study. The treatment group participated in core training classes twice per week for 8 weeks, 14-16 sessions total, each lasting 30-40 minutes. Exercise intensity and duration progressed on a weekly basis. All subjects performed the same general circuit training which included one exercise for each major muscle group for 2 cycles of 12-15 repetitions per exercise at moderate intensity. Vertical jump, standing broad jump, 10-m shuttle run, 40-m sprint, 2kg medicine ball overhead throw and a 2,000m indoor rowing ergometer test were performed by all subjects. Core endurance and strength was measured using 4 tests, extensor test (back extensor test), flexor test (abdominal fatigue test) and side bridge test on both sides. The results showed a significant difference in core endurance, especially in side bridge tests, between the treatment and the control group. The abdominal fatigue test showed no significant differences between the two groups where mean values were 206.9 ± 92.1 (pre), 215.5 ± 62.7 (post) and 164.5 ± 7.2 (pre), 176.2 ± 48.9 (post) respectively for the treatment and control groups. The control group showed significant improvement on the back extensor test compared to the experimental group. While core exercises increased core muscle endurance there were no significant pre to post test changes for any of the physical performance tests or the rowing ergometer test. There is a possibility that core endurance does not play a major role influencing performance and that strength and power of the core have a more significant effect on performance (Tse et al. 2005).

9. Describe the potential risks to the human subjects involved.

As with any physical activity, subjects may experience discomfort, or pain as a result of injury to involved musculature, joints or connective tissue. Subjects participating in this study will be at reduced risk as they are accustomed to the movements and tests involved in the protocol.

10. If the research involves potential risks, describe the safeguards that will be used to minimize such risks.

Participants are currently undergoing in-season training, running at an average of at least 20 miles per week as well as completed at least one half marathon race in the last year. Thus, the movements included in this study should be familiar to the athletes and pose a minimal risk to participants. Subjects assigned to the treatment group will receive verbal and physical explanations of each exercise progression. An introductory period where subjects will receive education on the core muscles, proper hollowing and bracing techniques and correct body positions will occur before subjects are released to perform exercises at home. The investigator will be available for questions at any time if modification or further explanation is needed from any subject. Exercise progressions will be administered either individually or in small groups and proper technique and clear understanding will need to be demonstrated before release. Additionally, subjects will be allowed time as needed to practice and orient themselves with each of the examinations prior to the commencement of testing.

11. Describe how you will address privacy and/or confidentiality.

Each of the participants will be assigned a subject number upon the signing of their hold-harmless form. This number will be used for identification and analysis of the subject's performance variables. Furthermore, only the individuals conducting or assisting in the exercise testing will be allowed access to the information provided by each subject.

12. If your research involves the use of schools (pre-kindergarten to university level) or other organizations (e.g., community clubs, companies), please attach a clearance letter from an administrator from your research site indicating that you have been given permission to conduct this research. For pre-kindergarten to grade 12 level, an administrator (e.g. principal or higher) should issue the permission. For post-secondary level schools the class instructor may grant permission. *For Western Washington University, this requirement of a clearance letter is waived if you are recruiting subjects from a scheduled class.* If you are recruiting subjects from a

campus group (not a class) at Western Washington University, you are required to obtain a clearance letter from a leader or coordinator of the group.
N/A

13. If your research involves the use of schools (pre-kindergarten to university level) or other organizations (e.g., community clubs, companies), and you plan to take still or video pictures as part of your research, please complete
N/A

a) to d) below:
a. Who have you contacted at the school district or organization involved, to determine the policy on the use of photography in the school or organization?

b. Explain how your research plan conforms to the policy on the use of photography in the school or organization.

c. Attach a copy of the school district or organization policy on the use of photography at the schools or organization.

d. Explain how you will ensure that the only people recorded in your pictures will be the ones that have signed a consent form.

In addition, please attach the following information:

1. **A bibliography relevant to the subject matter of the proposed research.**
   See attached

2. **A copy of the informed consent form (a checklist is attached for you to use as a guide).**
   See attached
3. **A current curriculum vitae.**

4. A copy of the Certificate of Completion for Human Subjects Training from the online human subjects training module, foreach person involved in the research who will have any contact with the subjects or their data.(See "Training" at http://www.wwu.edu/depts/rsp/human.html) Human subject certification is valid for five years. After five years researchers must complete the certification again.

See Attached

5. If your subjects are required to turn in a physician clearance form prior to participation, include a copy of the blank form.

Appendix C.

Heath History Questionnaire

Department of Physical Education, Health & Recreation
Western Washington University

Health History

Name:__________________________Birthdate:______________
Address:______________________ City:_________ Zip:_______
Phone:______________ Age:_____ Height:______ Weight:_____

1. Do you currently have any injuries or medical conditions? If yes please list.

2. Are you currently receiving any medical treatment for any condition? Yes or No (please circle one)

    i. If yes, please explain.

3. Are you currently receiving any physical therapy or chiropractic treatment for any condition? Yes or No (please circle one)

    i. If yes, please explain.

4. Are you currently running? How often (miles/days per week)?

5. Is there any other condition not mentioned here that might affect your ability to exercise, or be aggravated by exercise? Yes or no (please circle one

    i. If yes, please describe.

6. What is your experience exercising with dumbbells, BOSU, DynaDisk and Airex pads?

Appendix D.

Core Function Data Collection Form

Pre-Test

Subject Name:_________________________

Subject Number:_______________________

Height:_________ Weight:________ Age:________

Core Function scores:

Lafayette Stabilizer Platform:_______ seconds
(# of seconds balance was maintained in 30 seconds)

Pressure Biofeedback Unit: (circle one) Level 1 2 3 4 5

Right side plank: _________ seconds

Left side plank: __________ seconds

Abdominal fatigue: ________ seconds

Back extension:___________ seconds

Investigator Signature:______________________
Date:______

Post-Test

Subject Name:_______________________________

Subject Number:____________________________

Height:__________ Weight:_________ Age:_________

Core Function scores:

Lafayette Stabilizer Platform:________ seconds
(# of seconds balance was maintained in 30 seconds)

Pressure Biofeedback Unit: (circle one) Level 1 2 3 4 5

Right side plank: __________ seconds

Left side plank: ___________ seconds

Abdominal fatigue: _________ seconds

Back extension:____________ seconds

Investigator Signature:___________________________
Date:_______

Appendix E.

Run Data Collection Form

Participant Name	Subject #	13.1 Run Time
	1	
	2	
	3	
	4	
	5	
	6	
	7	
	8	
	9	
	10	
	11	
	12	
	13	
	14	
	15	
	16	
	17	
	18	
	19	
	20	
	21	
	22	
	23	
	24	
	25	
	26	
	27	
	28	
	29	
	30	

Appendix F.

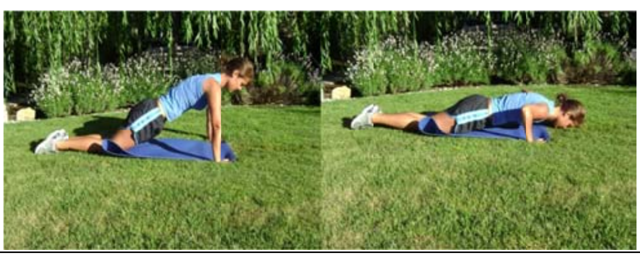
Activity Log Form

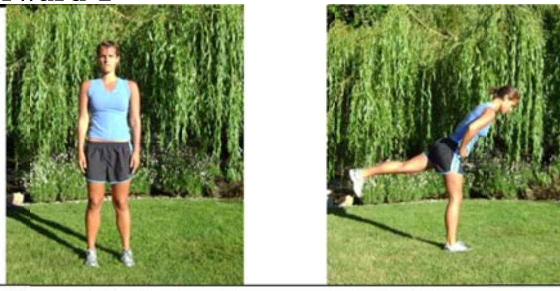
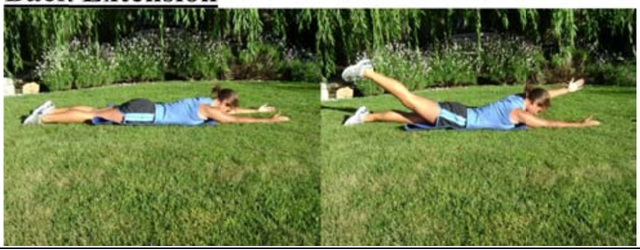
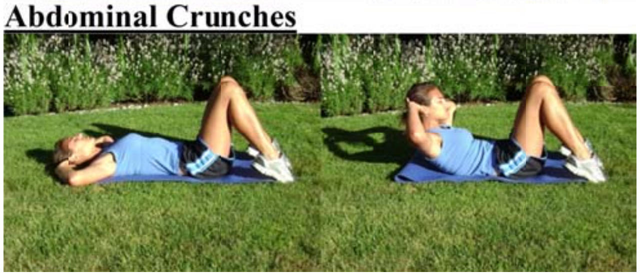
Activity Log Week #________							
	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
4:00AM							
5:00AM							
6:00AM							
7:00AM							
8:00AM							
9:00AM							
10:00AM							
11:00AM							
12:00PM							
1:00PM							
2:00PM							
3:00PM							
4:00PM							
5:00PM							
6:00PM							
7:00PM							
8:00PM							
9:00PM							
10:00PM							
11:00PM							
12:00AM							
1:00AM							
2:00AM							
3:00AM							

Appendix G.

Eight Week Core Progression

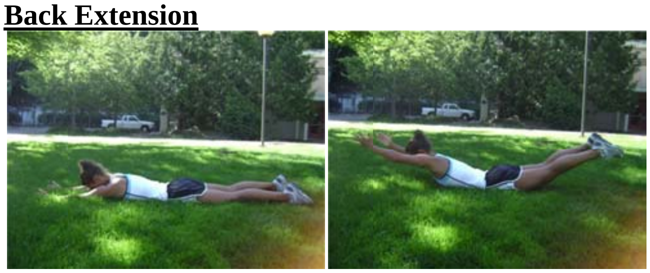
Week 1: 3x's each 3x/week

Exercise	Description
<u>Plank (Prone)</u> 	Forearms & knees until fatigue: record time
<u>Side plank</u> 	Forearms & toes until fatigue: record time
<u>Bird Dog</u> 	Hands & knees- alternating sides 2 minutes or until fatigue: record time
<u>Push Ups</u> 	Hands & knees Until fatigue: record number
<u>Squats</u>  	Feet hip width apart on Floor, lower down to 90 degrees of knee flexion and back up 2 minutes or until fatigue: record number

Forward T 	Foot on ground & hands at hips, lean forward & extend leg backwards, return to start - hold for 3 seconds- switch sides 1 minute on each side
Back Extension 	Lie prone on floor, raise opposite arm & leg, hold for 3 seconds- switch sides 2 minutes or until fatigue: record number
Bridge 	Lie supine w/knees bent, arms at side, bring feet in as close as possible to the butt. Raise the hips upward pushing heals into ground and contracting the glutes- you should be able to wiggle your toes. Until fatigue: record time
Lunges 	Walking lunge, knees flexed to 90 degrees, laterally rotate trunk bringing opposite elbow to knee, raise up and switch sides 2 minutes or until fatigue: record number
Abdominal Crunches 	Lie supine with knees bent & toes on the floor, keeping hands on head and elbows abducted to 90 degrees, refraining from horizontally adducting, flex at trunk, lifting shoulders and upper body off of the floor as high as possible 2 minutes or until fatigue: record number

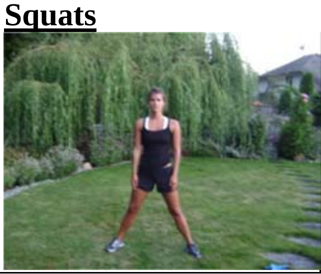
Week 2: 3x's each 3x/week

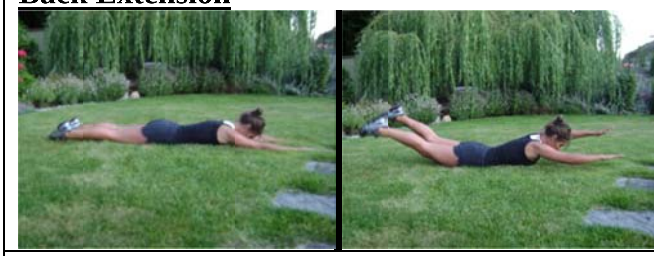
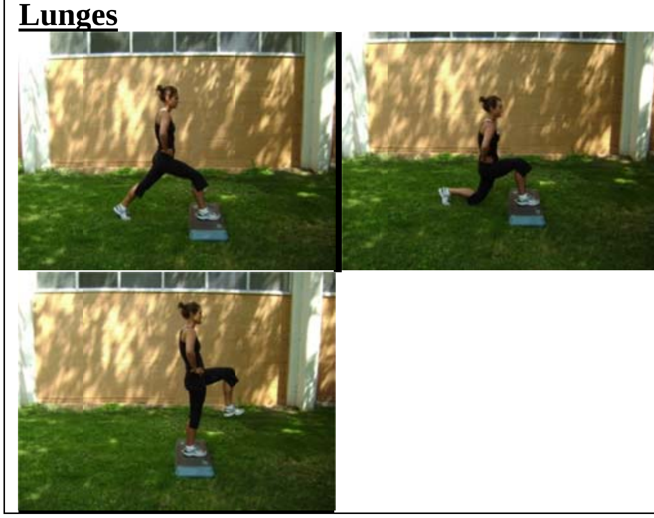
Exercise	Description
Plank (Prone) 	Forearms & toes Hold until fatigue- record time
Side plank 	Forearms & feet- lift top leg Hold until fatigue-record time
Bird Dog   	Hands & knees crunch in knee to elbow and extend out. Stay on one side and then switch 1 minute each side or until fatigue- record time
Push Ups  	Hands & knees/toes Until Fatigue- record number

Squats 	Wall Sits- hips and knees bend to 90 degrees and hold Hold until fatigue- record time
Forward T 	Foot on ground & arms overhead lean forward & extend back leg, return to start- switch sides 1 minute each side
Back Extension 	Lie prone on floor, raise arms & legs- hold Hold until fatigue- record time
Bridge 	Lie supine w/knees bent, arms at side. Place one foot on the opposite knee and raise hips up/lower down until just reaching the ground 1 minute each side or until fatigue
Lunges 	Static lunge, knees flexed to 90 degrees, raise up and pull leg through to 90 degrees of hip flexion 2 minutes or until fatigue

<u>Abdominal Crunches</u> 	Lie supine, flex hip and knees to 90 degrees, raise your tailbone up. Keeping upper body stationary on the floor, drop one leg to the floor touching the heal to the ground, flex back up to starting position-switch sides 2 minutes or until fatigue-record number

Week 3: 3x's each 3x/week

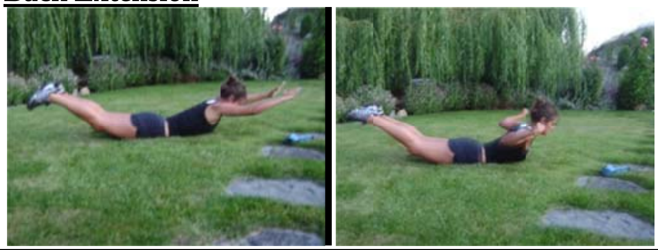
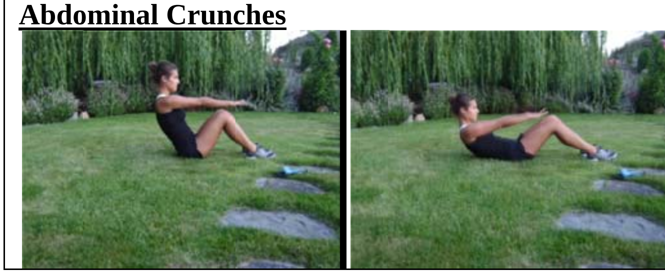
Exercise	Description
Plank (Prone) 	Forearms & toes- alternate leg lift Until fatigue: record time
Side plank  	Forearm & feet- roll down Until fatigue: record time
Bird Dog   	Hands & knees- Pull arm down into 90 degree angle and opposite leg into 90 degree angle 1 min each side/until fatigue: record time
Push Ups  	Hands on step & toes on floor Until fatigue: record number
Squats  	Static sumo squat- feet outside hips, toes pointed diagonally Until fatigue: record number

Forward T 	Place resistance band around hands- press hands outward against band. Foot on ground & arms overhead lean forward & extend back leg, return to start- switch sides 1 minute each side/until fatigue: record time
Back Extension 	Lie prone on floor, scissor arms & legs Until fatigue: record time
Bridge 	Lie supine w/knees bent, arms at side. Place resistance band above the knee, raise hips upward, abduct/adduct knees 1 minute each side/until fatigue: record time
Lunges 	Start in neutral position on a step. Step one leg back behind the body, bend legs to 90 degrees, extend supporting limb on step and pull back leg through to 90 degrees of hip flexion 1 minute each side/until fatigue: record number

Abdominal Crunches 	Lie supine, with knees and hips flexed to 90 degrees. Keeping hands on head and elbows abducted to 90 degrees, refraining from horizontally adducting, flex at trunk, lifting shoulders and upper body off of the floor- laterally rotate to one side as the opposite leg is extended out. Keep the extended leg as close to the floor as possible. Return to start position with legs on floor and alternate extended leg Until fatigue: record number

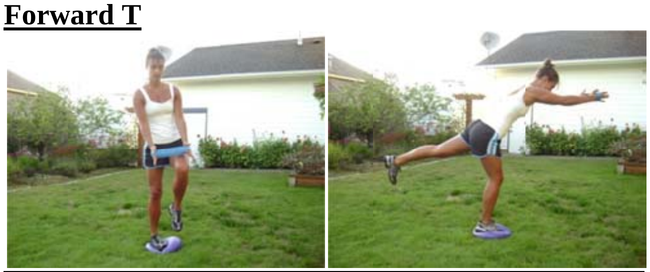
Week 4: 3x each 3x/week

Exercise	Description
Plank (Prone) 	Forearms & toes on floor walk feet in and out. Until fatigue: record time
Side plank  	Forearm & feet- lower/raise hips until just barely touching the ground Until fatigue: record time
Bird Dog  	Hands & knees- crunch in same arm & leg 1 minute each side/until fatigue: record time
Push Ups  	Hands on dynadisk toes/knees on floor Until fatigue: record number
Squats  	Single leg squats 1 minute each side/until fatigue: record number

Forward T 	Foot on dynadisk & hands on hips 1 minute each side: record time
Back Extension 	Lie prone on floor, raise arms & legs, lateral pull down with arms squeezing shoulder blades together and contracting glutes Until fatigue: record time
Bridge 	Lie supine w/legs extended out onto chair. Raise hips up pressing heals into the chair and contracting glutes (you can also do this with a stability ball to make it harder) Until fatigue: record time
Lunges 	Place one leg on chair behind the body and one leg in front. Keeping back leg on the chair bend legs until reaching 90 degrees of flexion and raise back up-switch sides 1 minute each side/until fatigue
Abdominal Crunches 	Sit on floor, with knees bent & feet on the floor. Roll the upper body back toward the floor as far back as you can while still being about to return to start position Until fatigue: record time

Week 5: 3x each 3x/week

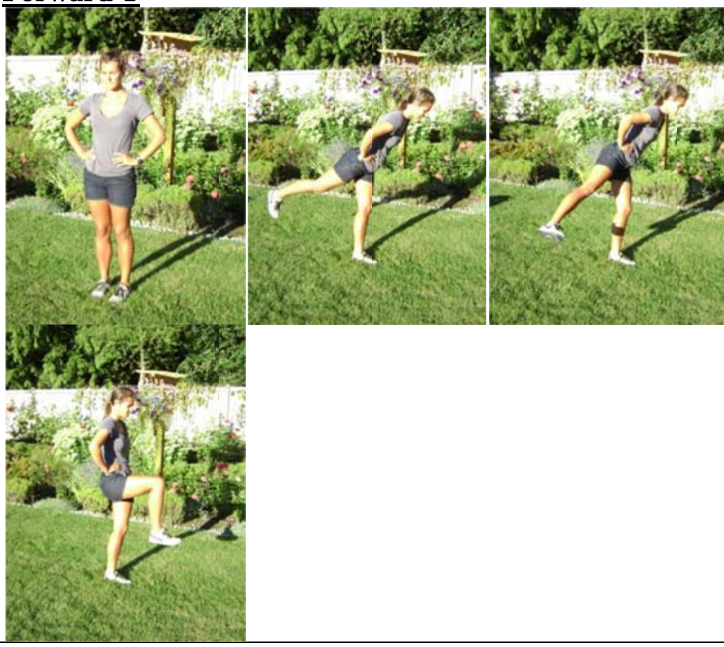
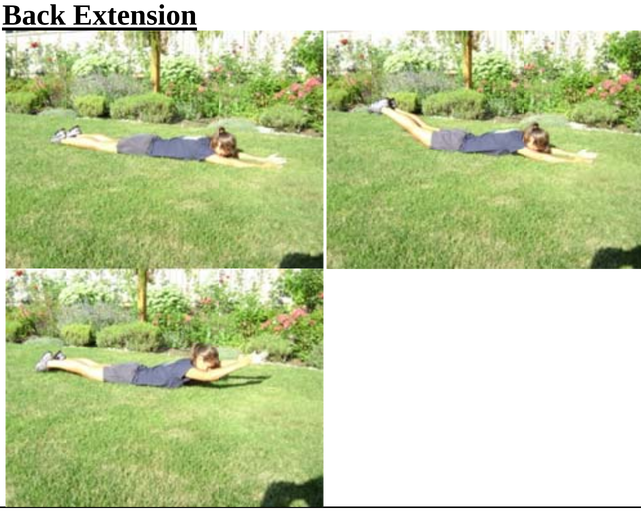
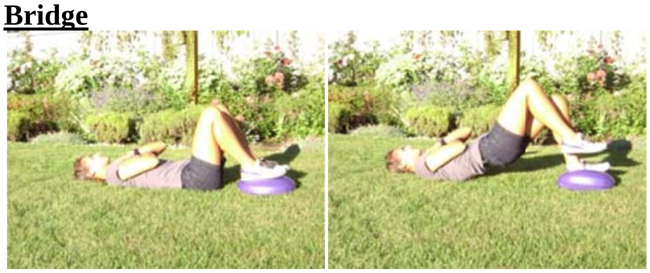
Exercise	Description
Plank (Prone) 	Hands- shoulder width apart in line with elbows & toes Until fatigue: record time
Side plank 	Hands & feet Until fatigue: record time
Bird Dog   	Hands & knees, extend opposite arm & leg, abduct both arms & legs laterally and return to start- keep foot dorsiflexed 1 minute each side/until fatigue: record time
Push Ups   	Hands & toes- lift one leg up- alternate leg lift with each pushup Until fatigue: record number

Squats 	1 legged squat on dynadisk 1 minute each side/until fatigue: record time
Forward T 	Foot dynadisk- resistance band around hands pressing outward 1 minute each side/until fatigue: record time
Back Extension 	Place circle resistance band around ankles. Lie prone on floor, raise arms & legs. Push legs out laterally against resistance band Until fatigue: record time
Bridge 	Lie supine with feet on dynadisk. Lift one leg straight up lower up/down- cross arms over chest 1 minute each side/until fatigue: record time
Lunges 	Place front foot dynadisk, extend back leg, flex both legs to 90 degrees- repeat on other side 1 minute each side/until fatigue: record time

Abdominal Crunches 	Sit on floor with knees bent & feet on the floor. Roll the upper body back toward the floor and rotate laterally to one side hold, reaching elbow toward ground- return to start and switch sides

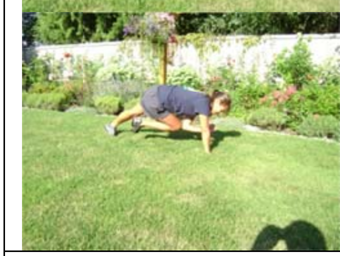
Week 6: 3x each 3x/week

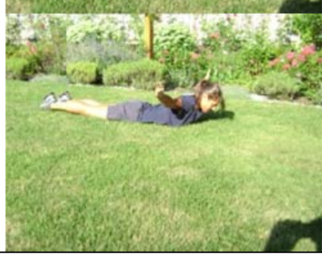
Plank (Prone) 	Hands & toes- alternate leg lift Until fatigue: record time
Side plank 	Forearm & feet- resistance band around ankles- lift top leg keep foot dorsiflexed Until fatigue: record time
Bird Dog  	Hands & toes- alternate opposite leg/arm lift Until fatigue: record time
Push Ups  	Hands & toes/knees- alternate arm raise Until fatigue: record number
Squats  	Squats with resistance band around legs- push out against resistance band Until fatigue: record number

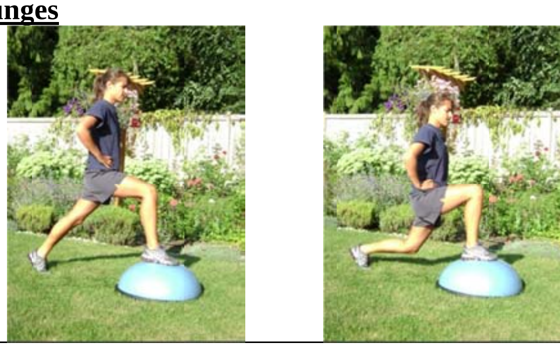
<u>Forward T</u> 	Extend one leg back- swing around to the front to a 90 flexion at hip and knee- keep foot dorsiflexed 1 minute each side/until fatigue
<u>Back Extension</u> 	Alternate leg and trunk lift Until fatigue: record time
<u>Bridge</u> 	Lie supine with feet on dynadisk- march legs up and down Until fatigue: record time

Lunges  	Place one leg on bench behind the body and one leg out in front on a dynadisk. Keeping back leg on bench and front leg on the dynadisk, bend legs to 90 degrees of flexion and raise back up- switch sides 1 minute each side/until fatigue
Abdominal Crunches   	Lie supine with knees bent- raise the trunk up so the shoulders come off the ground stay up and alternate side to side touching the hands to the heels. Until fatigue: record time

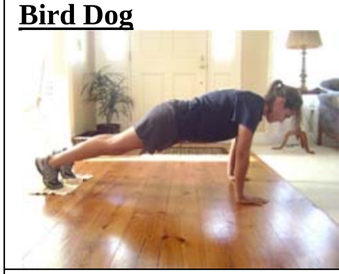
Week 7: 3x each 3x/week

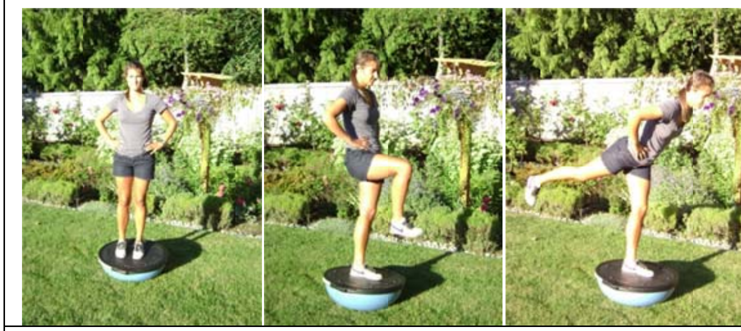
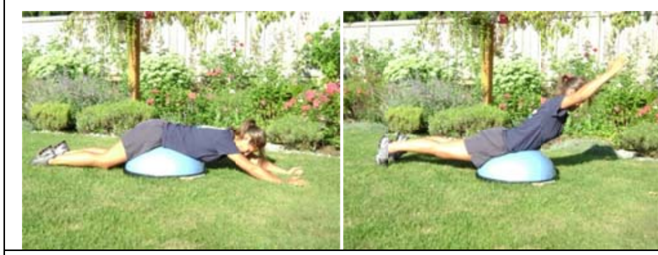
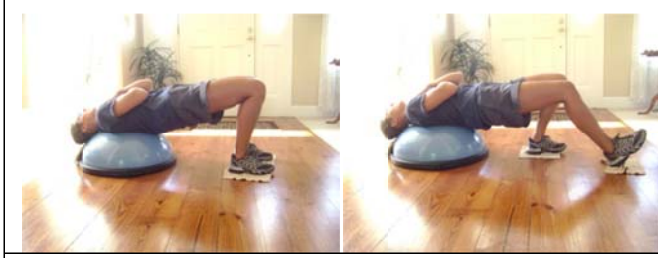
<u>Plank (Prone)</u> 	Hands & toes- roll forward and back on toes Until fatigue: record time
<u>Side plank</u> 	Forearm on BOSU Until fatigue: record time
<u>Bird Dog</u>   	Hands & toes-crunch opposite arm and leg in. 1 minute each side/until fatigue
<u>Push Ups</u>  	Hands on BOSU, toes on floor Until fatigue: record number

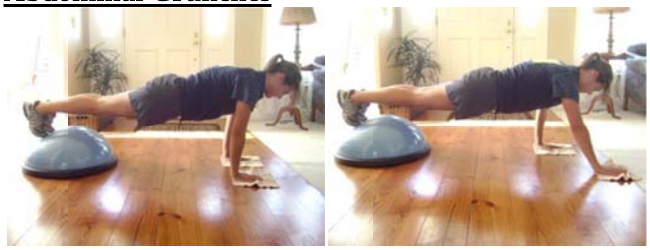
Squats  	squats on round side of BOSU- feet hip width apart until fatigue: record number
Forward T   	Foot on round side of BOSU & hands at hips 1 minute each side/until fatigue
Back Extension   	Lie prone- lift trunk off the ground, extend arms backward and circle forward keeping the trunk lifted Until fatigue: record time
Bridge  	Lie supine with feet on BOSU, arms at side or across ches- push heals into BOSU. Raise hips upward. Until fatigue: record time

Lunges 	Place front leg on round side of BOSU, bend legs to 90 degrees- repeat on other side 1 minute each side/until fatigue
Abdominal Crunches 	Sit on BOSU with hips and knees flexed arms out in front. Extend the legs out as straight as possible and bring back in- repeat Until fatigue: record time

Week 8: 3x each 3x/week

Plank (Prone)  	Hands on flat side of BOSU- feet on floor- crunch leg forward and toward opposite arm- alternate legs. Until fatigue: record time
Side plank 	Hands & Feet lift top leg Until fatigue: record time
Bird Dog  	Hands & toes- place dishcloth under feet. Alternate bringing legs forward to elbows. Until fatigue: record time
Push Ups  	Hands on BOSU toes on floor shifting weight side to side Until fatigue: record time
Squats  	Squats on BOSU- flat side. Bring foot out to edge of inner circle on BOSU Until fatigue: record time

Forward T 	Foot on flat side of BOSU & hands on hips (to make this harder bring arms up overhead) 1 minute each side/until fatigue
Back Extension 	Lie prone on BOSU, raise trunk upwards Until fatigue: record time
Bridge 	Lie supine with back on BOSU and knees bent. Place dishcloth under the heals. Raise hips upward and extend/flex the legs Until fatigue: record time
Lunges 	Side lunge on BOSU- stand with BOSU to one side- place foot on BOSU at 45 degree angle, shift weight over the BOSU and back to start 1 minute each side/until fatigue

Abdominal Crunches 	Feet on BOSU- place dishcloth under hands in push up position. Extend one hand out forward and bring back to start position- alternate sides. Until fatigue: record time

Appendix H.

Recruitment Flier

RUNNERS WANTED

Are you interested in potentially improving your half marathon racing time?

Runners are needed to participate in a graduate research study designed to investigate the effect of core strength on running performance.

Participant Requirements:

- 18 + years of age & willing to participate in an 8 week long study.
- Currently running, on average, 20 miles per week
  - willing to maintain this mileage for 8 weeks.
- Willing to run two 13.1 mile races 8 weeks apart.
- Willing to perform core function testing to determine core strength.
- If assigned to the treatment group willing to adhere to the supplementary training given by the investigator.

For more information please contact:

Megan Cleveland
360.280.5067
clevelm@students.wwu.edu

GRADUATE SCHOOL
Western Washington University

Appendix I.

Race Number

Western Washington University

1

Thesis Research

Appendix J.

Raw Data

Pre-Test								
Subject #	**Group (T/C)**	**Stab. Platform (s**	**R. Plank (s)**	**L. Plank (s)**	**PBU (Leve**	**Back Ex (s)**	**Ab. Fatigue (s)**	**Run Time h:m:s**
1	T	8.153	94.18	83.33	3	96.57	155.32	01:32.3
2	T	13.162	83.33	103.47	2	143.41	262.73	02:07.2
3	C	20.153	104.38	89.66	2	148.50	378.34	01:53.4
4	T	13.329	23.01	23.61	1	96.54	211.44	02:35.2
5	C	13.806	41.49	30.14	2	147.61	213.31	01:52.1
6	C	DID NOT FINISH--						
7	C	14.252	91.47	109.33	3	93.47	78.89	01:59.6
8	T	17.413	94.46	98.57	3	119.37	209.98	02:23.4
9	C	8.227	69.80	69.61	3	169.76	169.28	01:27.3
10	T	7.491	47.92	40.17	2	111.35	98.44	02:11.1
11	T	16.311	113.61	114.63	3	131.96	82.76	01:44.3
12	T	7.162	57.18	53.35	2	122.87	240.82	01:32.3
13	T	12.888	65.97	62.07	3	63.84	74.00	02:08.3
14	C	12.676	124.69	84.64	4	190.88	246.57	01:40.6
15	T	DID NOT FINISH--						
16	T	8.440	51.70	62.07	2	41.56	85.62	01:58.3
17	T	12.141	116.28	109.12	2	213.46	330.29	02:09.2
18	T	12.731	67.70	64.62	2	138.75	409.22	01:58.2
19	C	10.878	77.30	79.29	5	96.26	67.33	01:58.3
20	C	8.122	62.10	51.78	2	90.66	185.97	01:31.3
21	T	12.928	38.50	28.46	3	15.01	47.57	02:28.0
22	T	16.262	31.30	30.68	2	85.95	76.67	01:58.2
23	C	17.831	75.10	78.29	4	135.96	180.46	01:53.3
24	C	10.112	125.30	127.30	4	150.10	150.05	01:27.5
25	C	11.394	78.70	93.40	3	90.46	91.86	02:00.1
26	C	15.738	73.60	119.98	3	49.08	65.72	02:10.0
	Mean	**12.567**	**75.378**	**75.315**	**3**	**114.308**	**171.360**	**1:56:50**
	SD	3.492	28.25	30.45	1	45.61	100.11	0:18:39

Pre-Test								
Subject #	Group T	Stab. Platform (s	R. Plank (s)	L. Plank (s)	PBU (Leve	Back Ex (s)	Ab. Fatigue (s)	Run Time h:m:s
1	T	8.153	94.18	83.33	3	96.57	155.32	01:32.3
2	T	13.162	83.33	103.47	2	143.41	262.73	02:07.2
4	T	13.329	23.01	23.61	1	96.54	211.44	02:35.2
8	T	17.413	94.46	98.57	3	119.37	209.98	02:23.4
10	T	7.491	47.92	40.17	2	111.35	98.44	02:11.1
11	T	16.311	113.61	114.63	3	131.96	82.76	01:44.3
12	T	7.162	57.18	53.35	2	122.87	240.82	01:32.3
13	T	12.888	65.97	62.07	3	63.84	74.00	02:08.3
15	T	DID NOT FINISH---						
16	T	8.440	51.70	62.07	2	41.56	85.62	01:58.3
17	T	12.141	116.28	109.12	2	213.46	330.29	02:09.2
18	T	12.731	67.70	64.62	2	138.75	409.22	01:58.2
21	T	12.928	38.50	28.46	3	15.01	47.57	02:28.0
22	T	16.262	31.30	30.68	2	85.95	76.67	01:58.2
	Mean	**12.185**	**68.088**	**67.242**	**2**	**106.203**	**175.758**	**2:03:44**
	SD	3.307	29.17	30.74	1	48.02	108.27	0:19:27

Pre-Test								
Subject #	Group C	Stab. Platform (s	R. Plank (s)	L. Plank (s)	PBU (Leve	Back Ex (s)	Ab. Fatigue (s)	Run Time h:m:s
3	C	20.153	104.38	89.66	2	148.50	378.34	01:53.4
5	C	13.806	41.49	30.14	2	147.61	213.31	01:52.1
6	C	DID NOT FINISH---						
7	C	14.252	91.47	109.33	3	93.47	78.89	01:59.6
9	C	8.227	69.80	69.61	3	169.76	169.28	01:27.3
14	C	12.676	124.69	84.64	4	190.88	246.57	01:40.6
19	C	10.878	77.30	79.29	5	96.26	67.33	01:58.3
20	C	8.122	62.10	51.78	2	90.66	185.97	01:31.3
23	C	17.831	75.10	78.29	4	135.96	180.46	01:53.3
24	C	10.112	125.30	127.30	4	150.10	150.05	01:27.5
25	C	11.394	78.70	93.40	3	90.46	91.86	02:00.1
26	C	15.738	73.60	119.98	3	49.08	65.72	02:10.0
	Mean	**13.017**	**83.994**	**84.856**	**3**	**123.885**	**166.162**	**1:48:41**
	SD	3.647	24.46	27.18	1	40.56	89.22	0:14:33

Post-Test								
Subject #	Group (T/C)	Stab. Platform (s	R. Plank (s)	L. Plank (s)	PBU (Level	Back Ex (s)	Ab. Fatigue (s)	Run Time h:m:s
1	T	7.919	130.99	145.70	5	117.60	191.10	01:37.0
2	T	14.623	183.51	171.49	4	167.22	487.36	01:55.2
3	C	14.819	83.08	94.90	4	190.43	250.41	01:53.3
4	T	12.424	38.67	36.83	3	165.07	205.73	02:39.6
5	C	5.871	23.49	37.63	2	78.00	40.01	01:52.1
6	C	DID NOT FINISH--						
7	C	13.173	85.30	113.10	3	89.95	80.03	01:59.5
8	T	12.350	78.54	99.83	5	178.39	299.32	02:18.4
9	C	8.871	65.87	59.57	3	178.57	129.10	01:27.5
10	T	8.150	49.52	39.28	4	85.39	119.37	02:08.5
11	T	16.388	131.55	126.84	4	167.77	341.67	01:41.0
12	T	8.956	68.59	65.75	4	118.69	128.27	01:32.2
13	T	13.356	115.12	120.34	4	140.88	346.38	02:06.1
14	C	10.105	131.38	119.54	5	118.07	304.00	01:41.1
15	T	DID NOT FINISH--						
16	T	9.056	75.98	75.17	3	61.68	241.26	01:52.4
17	T	15.081	113.57	112.80	4	233.05	284.43	02:07.5
18	T	12.682	79.44	75.75	3	156.17	418.88	01:57.0
19	C	9.005	78.79	68.51	5	180.26	185.09	01:59.4
20	C	7.430	55.17	59.30	1	140.82	265.77	01:34.5
21	T	22.433	51.33	38.70	4	23.12	78.45	02:31.6
22	T	14.905	103.15	93.53	5	252.27	93.63	01:50.1
23	C	15.963	78.03	83.06	4	153.66	181.81	01:52.6
24	C	8.630	120.30	136.67	3	201.46	335.01	01:27.0
25	C	12.986	70.97	70.97	3	146.18	124.43	02:05.1
26	C	13.817	120.38	135.09	3	39.48	114.92	02:11.3
	Mean	**12.041**	**88.86**	**90.85**	**4**	**141.01**	**218.60**	**1:56:00**
	SD	3.688	35.72	36.97	1	56.06	114.50	0:18:40

Post-Test								
Subject #	Group T	Stab. Platform (s	R. Plank (s)	L. Plank (s)	PBU (Leve	Back Ex (s)	Ab. Fatigue (s)	Run Time h:m:s
1	T	7.919	130.99	145.70	5	117.60	191.10	01:37.0
2	T	14.623	183.51	171.49	4	167.22	487.36	01:55.2
4	T	12.424	38.67	36.83	3	165.07	205.73	02:39.6
8	T	12.350	78.54	99.83	5	178.39	299.32	02:18.4
10	T	8.150	49.52	39.28	4	85.39	119.37	02:08.5
11	T	16.388	131.55	126.84	4	167.77	341.67	01:41.0
12	T	8.956	68.59	65.75	4	118.69	128.27	01:32.2
13	T	13.356	115.12	120.34	4	140.88	346.38	02:06.1
15	T	DID NOT FINISH---						
16	T	9.056	75.98	75.17	3	61.68	241.26	01:52.4
17	T	15.081	113.57	112.80	4	233.05	284.43	02:07.5
18	T	12.682	79.44	75.75	3	156.17	418.88	01:57.0
21	T	22.433	51.33	38.70	4	23.12	78.45	02:31.6
22	T	14.905	103.15	93.53	5	252.27	93.63	01:50.1
	Mean	**12.948**	**93.843**	**92.462**	**4.000**	**143.638**	**248.912**	**2:01:27**
	SD	3.856	39.21	40.77	1	61.21	123.23	0:20:17

Post-Test								
Subject #	Group C	Stab. Platform (s	R. Plank (s)	L. Plank (s)	PBU (Leve	Back Ex (s)	Ab. Fatigue (s)	Run Time h:m:s
3	C	14.819	83.08	94.90	4	190.43	250.41	01:53.3
5	C	5.871	23.49	37.63	2	78.00	40.01	01:52.1
6	C	DID NOT FINISH---						
7	C	13.173	85.30	113.10	3	89.95	80.03	01:59.5
9	C	8.871	65.87	59.57	3	178.57	129.10	01:27.5
14	C	10.105	131.38	119.54	5	118.07	304.00	01:41.1
19	C	9.005	78.79	68.51	5	180.26	185.09	01:59.4
20	C	7.430	55.17	59.30	1	140.82	265.77	01:34.5
23	C	15.963	78.03	83.06	4	153.66	181.81	01:52.6
24	C	8.630	120.30	136.67	3	201.46	335.01	01:27.0
25	C	12.986	70.97	70.97	3	146.18	124.43	02:05.1
26	C	13.817	120.38	135.09	3	39.48	114.92	02:11.3
	Mean	**10.970**	**82.978**	**88.940**	**3.273**	**137.898**	**182.780**	**1:49:34**
	SD	3.159	30.05	31.78	1	49.12	91.04	0:14:56

Appendix K.

PASW Statistical Analysis Output

Statistical Output from PAWS

Abdominal Fatigue Statistical Data:

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Prestest_AbFat	Treatment	175.7585	112.69455	13
	Control	166.1618	93.57753	11
	Total	171.3600	102.26075	24
Posttest_AbFat	Treatment	248.9115	128.26535	13
	Control	182.7800	95.48182	11
	Total	218.6012	116.96336	24

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
test	Sphericity Assumed	24008.743	1	24008.743	3.795	.064	.147	3.795	.461
	Greenhouse-Geisser	24008.743	1.000	24008.743	3.795	.064	.147	3.795	.461
	Huynh-Feldt	24008.743	1.000	24008.743	3.795	.064	.147	3.795	.461
	Lower-bound	24008.743	1.000	24008.743	3.795	.064	.147	3.795	.461
test * Group	Sphericity Assumed	9521.996	1	9521.996	1.505	.233	.064	1.505	.217
	Greenhouse-Geisser	9521.996	1.000	9521.996	1.505	.233	.064	1.505	.217
	Huynh-Feldt	9521.996	1.000	9521.996	1.505	.233	.064	1.505	.217
	Lower-bound	9521.996	1.000	9521.996	1.505	.233	.064	1.505	.217
Error(test)	Sphericity Assumed	139190.788	22	6326.854					
	Greenhouse-Geisser	139190.788	22.000	6326.854					
	Huynh-Feldt	139190.788	22.000	6326.854					
	Lower-bound	139190.788	22.000	6326.854					

a. Computed using alpha = .05

Back Extension Statistical Data:

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Prestest_BackEX	Treatment	106.2031	49.97888	13
	Control	123.8855	42.54384	11
	Total	114.3075	46.59605	24
Posttest_BackEx	Treatment	143.6385	63.70537	13
	Control	137.8982	51.51708	11
	Total	141.0075	57.27011	24

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
test	Sphericity Assumed	7885.581	1	7885.581	6.515	.018	.228	6.515	.684
	Greenhouse-Geisser	7885.581	1.000	7885.581	6.515	.018	.228	6.515	.684
	Huynh-Feldt	7885.581	1.000	7885.581	6.515	.018	.228	6.515	.684
	Lower-bound	7885.581	1.000	7885.581	6.515	.018	.228	6.515	.684
test * Group	Sphericity Assumed	1634.433	1	1634.433	1.350	.258	.058	1.350	.199
	Greenhouse-Geisser	1634.433	1.000	1634.433	1.350	.258	.058	1.350	.199
	Huynh-Feldt	1634.433	1.000	1634.433	1.350	.258	.058	1.350	.199
	Lower-bound	1634.433	1.000	1634.433	1.350	.258	.058	1.350	.199
Error(test)	Sphericity Assumed	26627.380	22	1210.335					
	Greenhouse-Geisser	26627.380	22.000	1210.335					
	Huynh-Feldt	26627.380	22.000	1210.335					
	Lower-bound	26627.380	22.000	1210.335					

a. Computed using alpha = .05

Lafayette Stabilizer Platform Statistical Data:

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest_Stabilizer	Treatment	12.1855	3.44158	13
	Control	13.0172	3.82516	11
	Total	12.5667	3.56660	24
Posttest_Stabilizer	Treatment	12.9479	4.01299	13
	Control	10.9700	3.31346	11
	Total	12.0414	3.76684	24

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
test	Sphericity Assumed	4.917	1	4.917	1.106	.304	.048	1.106	.172
	Greenhouse-Geisser	4.917	1.000	4.917	1.106	.304	.048	1.106	.172
	Huynh-Feldt	4.917	1.000	4.917	1.106	.304	.048	1.106	.172
	Lower-bound	4.917	1.000	4.917	1.106	.304	.048	1.106	.172
test * Group	Sphericity Assumed	23.518	1	23.518	5.291	.031	.194	5.291	.595
	Greenhouse-Geisser	23.518	1.000	23.518	5.291	.031	.194	5.291	.595
	Huynh-Feldt	23.518	1.000	23.518	5.291	.031	.194	5.291	.595
	Lower-bound	23.518	1.000	23.518	5.291	.031	.194	5.291	.595
Error(test)	Sphericity Assumed	97.788	22	4.445					
	Greenhouse-Geisser	97.788	22.000	4.445					
	Huynh-Feldt	97.788	22.000	4.445					
	Lower-bound	97.788	22.000	4.445					

a. Computed using alpha = .05

Treatment Group Simple Effects:

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pretest - Posttest	-.76246	3.24261	.89934	-2.72195	1.19703	-.848	12	.413

Control Group Simple Effects:

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pre_Test - Post_Test	2.04718	2.63442	.79431	.27735	3.81701	2.577	10	.028

Left Side Plank Statistical Data:

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest_LSP	Treatment	67.2423	31.99343	13
	Control	84.8564	28.50383	11
	Total	75.3154	31.10728	24
Posttest_LSP	Treatment	92.4623	42.43940	13
	Control	88.9400	33.33509	11
	Total	90.8479	37.76325	24

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
test	Sphericity Assumed	2558.220	1	2558.220	10.485	.004	.323	10.485	.872
	Greenhouse-Geisser	2558.220	1.000	2558.220	10.485	.004	.323	10.485	.872
	Huynh-Feldt	2558.220	1.000	2558.220	10.485	.004	.323	10.485	.872
	Lower-bound	2558.220	1.000	2558.220	10.485	.004	.323	10.485	.872
test * Group	Sphericity Assumed	1330.930	1	1330.930	5.455	.029	.199	5.455	.608
	Greenhouse-Geisser	1330.930	1.000	1330.930	5.455	.029	.199	5.455	.608
	Huynh-Feldt	1330.930	1.000	1330.930	5.455	.029	.199	5.455	.608
	Lower-bound	1330.930	1.000	1330.930	5.455	.029	.199	5.455	.608
Error(test)	Sphericity Assumed	5367.687	22	243.986					
	Greenhouse-Geisser	5367.687	22.000	243.986					
	Huynh-Feldt	5367.687	22.000	243.986					
	Lower-bound	5367.687	22.000	243.986					

a.Computed using alpha = .05

Treatment Group Simple Effects:

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Pre_TestLT - Post_TestLT	-25.22000	26.59496	7.37611	-41.29117	-9.14883	-3.419	12	.005

Control Group Simple Effects:

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	Pre_TestLC - Post_TestLC	-4.08364	14.99290	4.52053	-14.15600	5.98873	-.903	10	.388

Right Side Plank Statistical Data:

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest_RSP	Treatment	68.0877	30.36319	13
	Control	83.9936	25.65387	11
	Total	75.3779	28.85628	24
Posttest_RSP	Treatment	93.8431	40.80926	13
	Control	82.9782	31.51349	11
	Total	88.8633	36.48651	24

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
test	Sphericity Assumed	1823.441	1	1823.441	5.212	.032	.192	5.212	.588
	Greenhouse-Geisser	1823.441	1.000	1823.441	5.212	.032	.192	5.212	.588
	Huynh-Feldt	1823.441	1.000	1823.441	5.212	.032	.192	5.212	.588
	Lower-bound	1823.441	1.000	1823.441	5.212	.032	.192	5.212	.588
test * Group	Sphericity Assumed	2135.103	1	2135.103	6.102	.022	.217	6.102	.656
	Greenhouse-Geisser	2135.103	1.000	2135.103	6.102	.022	.217	6.102	.656
	Huynh-Feldt	2135.103	1.000	2135.103	6.102	.022	.217	6.102	.656
	Lower-bound	2135.103	1.000	2135.103	6.102	.022	.217	6.102	.656
Error(test)	Sphericity Assumed	7697.438	22	349.884					
	Greenhouse-Geisser	7697.438	22.000	349.884					
	Huynh-Feldt	7697.438	22.000	349.884					
	Lower-bound	7697.438	22.000	349.884					

a. Computed using alpha = .05

Treatment Group Simple Effects:

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference: Lower	Upper			
Pair 1	Pre_TestRT - Post_TestRT	-25.75538	31.88300	8.84275	-45.02209	-6.48868	-2.913	12	.013

Control Group Simple Effects:

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Pre_TestRC - Post_TestRC	1.01545	17.87895	5.39071	-10.99579	13.02670	.188	10	.854

Pressure Biofeedback Unit Statistical Data:

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest_BFU	Treatment	2.3077	.63043	13
	Control	3.1818	.98165	11
	Total	2.7083	.90790	24
Posttest_BFU	Treatment	4.2308	1.30089	13
	Control	3.2727	1.19087	11
	Total	3.7917	1.31807	24

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
test	Sphericity Assumed	12.084	1	12.084	24.354	.000	.525	24.354	.997
	Greenhouse-Geisser	12.084	1.000	12.084	24.354	.000	.525	24.354	.997
	Huynh-Feldt	12.084	1.000	12.084	24.354	.000	.525	24.354	.997
	Lower-bound	12.084	1.000	12.084	24.354	.000	.525	24.354	.997
test * Group	Sphericity Assumed	10.001	1	10.001	20.155	.000	.478	20.155	.990
	Greenhouse-Geisser	10.001	1.000	10.001	20.155	.000	.478	20.155	.990
	Huynh-Feldt	10.001	1.000	10.001	20.155	.000	.478	20.155	.990
	Lower-bound	10.001	1.000	10.001	20.155	.000	.478	20.155	.990
Error(test)	Sphericity Assumed	10.916	22	.496					
	Greenhouse-Geisser	10.916	22.000	.496					
	Huynh-Feldt	10.916	22.000	.496					
	Lower-bound	10.916	22.000	.496					

a. Computed using alpha = .05

<u>Treatment Group Simple Effects:</u>

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	Pre_TestBT - Post_TestBT	-.76246	3.24261	.89934	-2.72195	1.19703	-.848	12	.413

Control Group Simple Effects:

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1	Pre_TestBC - Post_testBC	-.09091	.83121	.25062	-.64932	.46750	-.363	10	.724

Run Time Statistical Data:

Descriptive Statistics

	Group	Mean	Std. Deviation	N
Pretest_Run	Treatment	2:03:44.154	0:19:27.784	13
	Control	1:48:41.727	0:14:33.639	11
	Total	1:56:50.542	0:18:39.965	24
Posttest_Run	Treatment	2:01:26.923	0:20:17.892	13
	Control	1:49:34.273	0:14:56.243	11
	Total	1:56:00.292	0:18:40.127	24

Tests of Within-Subjects Effects

Measure:MEASURE_1

Source		Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared	Noncent. Parameter	Observed Power[a]
test	Sphericity Assumed	21365.399	1	21365.399	.836	.371	.037	.836	.141
	Greenhouse-Geisser	21365.399	1.000	21365.399	.836	.371	.037	.836	.141
	Huynh-Feldt	21365.399	1.000	21365.399	.836	.371	.037	.836	.141
	Lower-bound	21365.399	1.000	21365.399	.836	.371	.037	.836	.141
test * Group	Sphericity Assumed	107294.733	1	107294.733	4.197	.053	.160	4.197	.500
	Greenhouse-Geisser	107294.733	1.000	107294.733	4.197	.053	.160	4.197	.500
	Huynh-Feldt	107294.733	1.000	107294.733	4.197	.053	.160	4.197	.500
	Lower-bound	107294.733	1.000	107294.733	4.197	.053	.160	4.197	.500
Error(test)	Sphericity Assumed	562441.517	22	25565.524					
	Greenhouse-Geisser	562441.517	22.000	25565.524					
	Huynh-Feldt	562441.517	22.000	25565.524					
	Lower-bound	562441.517	22.000	25565.524					

a. Computed using alpha = .05

Run Time Percent Change Simple Effects:

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper			
Pair 1	PC_Treatment - PC_Control	2.54727	3.95242	1.19170	-.10800	5.20255	2.138	10	.058