2007

Does Core Strength Training Influence Running Kinetics, Lower Extremity Stability, and 5000m Performance in Runners?

Kimitake Sato

DOES CORE STRENGTH TRAINING INFLUENCE RUNNING KINETICS, LOWER EXTREMITY STABILITY, AND 5000M PERFORMANCE IN RUNNERS?

A Thesis

Submitted to the Faculty of the Department of Sport and Exercise Sciences

In Partial Fulfillment for the Degree of Master of Science in Movement Science

Barry University

By

Kimitake Sato, BA, CSCS, PES

Miami Shores, FL

April, 2007

BARRY UNIVERSITY
MIAMI SHORES, FLORIDA

Date April 20, 2007

To the Dean of the School of Human Performance and Leisure Sciences:

I am submitting herewith a thesis written by *Kimitake Sato* entitled "*Does core strength training influence running kinetics, lower extremity stability, and 5000m performance in runners?*" I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science with a major in *Movement Science.*

____

Dr. Monique Mokha, Thesis Committee Chair

We, members of the thesis committee,
have examined this thesis
and recommend its acceptance:

____

____

____

Accepted:

____

Chair, Department of Sport and Exercise Sciences

Accepted:

____

Dean, School of Human Performance and Leisure Sciences

TABLE OF CONTENTS

ACKNOWLEDGEMENT

My graduate education at Barry University was a great experience. People who have known me since I was a little troubled kid, would have never imagined that I seek an advanced degree. Many people helped me along the way to get to where I am.

Dr. Monique Mokha, a committee chair, is the person whom I look up to since I came to Barry. Her professionalism and approach to guide me to what I have to get through in the sport science was very special. It was always the last minute to submit our work for conference presentations and other occasions, but we made them all worked out and never quit.

Dr. Kathy Ludwig, a committee member, and my favorite professor at Barry. She always gave me positive feedback to get through tough tasks. I loved her easy-going personality in and out of classroom so that I can always go talk to her about any subject.

Dr. Artur Poczwardowski, a committee member, and my first graduate class professor. He was the one whom I learned from the most in the classroom. His intensity and respectful attitude towards students were something that I was so impressed about him. He also believed in my ability to do better jobs and made me fight through many tasks. I loved his passion to influence his students. In near future, I hope to do the same to people whom I will meet.

Dr. Ann Gibson, a committee member. I never took a class from her, but she was always the one who welcomed me to her office when I had questions. Her feedback and smile made me feel like I am no stranger to her. She is also the one I think of when I travel to mountains.

Dr. J.G. Cremades, who taught me a great deal of motor control / learning. This class is very important in health and fitness field that only few people recognize. The concepts I learned from him apply to my work in a daily basis.

I must say special thanks to my family and in-laws who live in Japan. My father, even though we don't see each other often, he is the one who knows what I need to hear at difficult times, and teaches me how to treat others. I truly believe that my work ethic came from him to always work hard to be the best that I can be. My mother who is passed, but always looking at me from the sky, she is the reason why I give my best to make her proud. All the other family members always have warm welcome atmosphere for me wherever I go back to Japan.

I would also like to thank Standlick family, my second family and home. Ed, Nina, and Nick have been the ones who know about me more than anybody since I came to the US. They have been taken care of me like their true son, and brother. Their love and kindness are always in my heart.

Local running communities in south Florida supported my continuous love and research in running. Without their help and interests, my idea towards running studies was impossible to conduct.

Lastly, I would like to thank my wife, Chika. Those people who know and see her on campus, should be able to tell that she is my true supervisor in my life. Her endless love and support helped me get through the graduate work. She understands what I want to achieve in life and she gives her 100% to support. I often think that I am the luckiest guy to meet a person like her to share a lot of ups and downs.

There are a lot more people who have been influential to my life. I must be so fortunate to meet these people whom I can learn from. I could not have done any better than what I did during my two and a half years at Barry. That is because so many of "good people" guide me to be a better person.

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Core strength training (CST) has been a popular training method in the health and fitness industry. Although strong core muscles are believed to help athletic performance, only few scientific studies have been conducted to identify the effectiveness of CST on improving athletic performance. The purpose of this study was to identify the effects of a 6-week CST program on running kinetics, lower extremity stability, and running performance in competitive and recreational runners. Twenty-eight healthy adults (age; 36.9±9.4yrs, height; 168.4±9.6cm, mass; 70.1±15.3kg) volunteered for this study. After a screening process, they were randomly assigned to one of two groups. A test-retest design was used to assess the differences between CST (n_{exp}) and no CST (n_{con}) on ground reaction force (GRF) measures, lower extremity stability scores, and 5000 meter (m) running performance. Tests were performed before and after 6-wks of training. Variables of the GRF were determined by calculating peak impact vertical GRF (vGRF), peak active vGRF, duration of the breaking horizontal GRF (hGRF), and duration of the propulsive hGRF as measured while running across a force plate. Lower extremity stability in three directions (anterior, posterior, and lateral) was assessed using the star excursion balance test (SEBT). Running performance was determined by 5000 m run times measured on outdoor tracks. Six 2 (pre, post) X 2 (exp, con) mixed-design ANOVAs were used to determine how CST influenced each dependent variable, $p < .05$. A significant interaction was found in 5000 m running time, $p < .05$. No significant

interactions were found for other variables, $p > .05$. However, the experimental group showed greater improvement in SEBT score. Although CST did not significantly influence kinetic variables in the experimental group, the peak impact vGRF did not excessively increase and the peak active vGRF did not change while 5000m running performance improved. Possible limitations such as dissimilar running velocities between pre- and post-training GRF tests and the weather conditions during 5000 m run test may have affected the outcome of the study. Based on the results of this study, it is recommended performing CST to improve core muscular strength and possibly better lower extremity control. Since the participants were novice level at CST, the training may have raised awareness of an upright position or good running posture during run for the experimental group.

CHAPTER I

INTRODUCTION

Core strength training (CST) is widely practiced by professionals with the goals of enhancing core stability and increasing core muscular strength, thereby improving athletic performance. It is believed that in order to improve athletic performance and prevent injuries, CST is one of the vital components in the strength and conditioning field. Core-related exercises such as Swiss-ball training, balance training, weight training, and yoga have become popular physical activities even among general populations in the recent years. Limited scientific studies have been conducted to determine the effect of CST on lower extremity muscular strength and athletic performance such as running and swimming (Cosio-Lima, Reynolds, Winter, Paolone, & Jones, 2003; Scibek, Guskiewicz, Prentice, Mays, & Davis, 2001; Stanton, Reaburn, & Humphries, 2004). Researchers found significant increases only in core muscular strength and no significant change in the lower extremity strength, mechanics or performance. This type of research indicates that CST is a useful tool for strengthening core muscles, but the carryover to performance needs further investigation.

Approximately 30 million Americans run for recreation and competition and about one-forth to one-half of the runners experience running-related injuries annually (Novacheck, 1998; Taunton, Ryan, Clement, McKenzie, Lloyd-Smith, & Zumbo, 2002). Running is a popular physical activity for people of all ages. At the same time, a large number of common running-related injuries are reported annually. Contributing factors to overuse injuries are including training errors, types of ground surfaces, running shoes and orthotics, anatomical structures in the lower extremity, as well as kinetics and kinematics of running mechanics (Boyer & Nigg, 2004; Dixon, Collop, & Batt, 2000; Ferber, McClay-Davis, & Williams, 2003; Stackhouse, McClay-Davis, & Hamill, 2004; Taunton et al., 2002). Presently, training error may be the number one factor causing the overuse injuries. It is believed that many injured runners could have avoided the injuries by training differently such as varying intensity, eliminate mileage increase, and running on softer surfaces (Hreljac, 2004).

In a biomechanical analysis of running, kinetic variables such as high vertical ground reaction forces (vGRFs) and horizontal GRFs (hGRFs) have been shown to be associated with overuse injuries (Bus, 2003; Gottschall & Kram, 2005; Hreljac, 2004). Hreljac (2004) stated that vGRF increases from 1.5 (walking/jogging) to 5 (sprinting) times the body weight (BW) at both impact (heel contact) and active (push-off) phases of foot contact. He also stated that high impact vGRFs are often linked to overuse injuries dues to the high stress to joints and muscles. Aging, lack of joint stability, muscle weakness, harder running surfaces, and high arches are found to be indications of increasing impact vGRFs as well (Bus, 2003; Dixon et al., 2000; Ferber et al., 2003; Taunton et al., 2002). Downhill running trials (-9, -6, and -3 degrees) also increased peak impact vGRF to 2.5 BW from 1.7 BW (a flat surface) (54%, 32%, and 18%, respectively) even though running velocity and active vGRF did not change (Gottschall & Kram, 2005). Furthermore, the three downhill running trials also increased posterior breaking hGRFs by 73%, 46%, and 27%, respectively, as compared to the flat surface which indicates loss of anterior propulsive hGRFs while running velocity was kept the same and active vGRFs were relatively consistent. Although hGRFs have not been studied as closely as vGRFs, the longer length of posterior hGRFs was captured during downhill running, which may indicate an increased risk of overuse injuries.

Adequate stability in the lower extremity may have an important role in running efficiency. Poor stability may be linked to injuries both on the athletic fields and in daily living. As previous lower extremity injuries such as ankle sprains or overuse injuries often contribute to create muscular imbalances and poor proprioception, proper rehabilitation is needed to regain stability (Olmsted, Carcia, Hertel, & Shultz, 2002). One of the purposes of engaging CST is to increase stability and strength of the mid-section of the body. CST may not contribute to an increased muscular strength level of the lower extremity but may improve the stability level due to better stability of the mid-section and upper extremities.

Statement of the Problem

Core strength training (CST) has been a buzz term in the fitness industry for a decade, and many physically active people engage in CST as their supplemental workout.

Although strong core muscles are believed to help athletic performance, few scientific studies have been conducted to identify the effectiveness of CST for improving athletic performance (Cosio-Lima et al., 2003; Scibek et al., 2001; Stanton et al., 2004). These past studies revealed that CST is useful in enhancing core muscle strength, but thus far not in influencing biomechanics or athletic performance. Only one study has involved runners, and it did not measure kinetic variables such as GRFs (Stanton et al., 2004).

Running has been a popular physical activity around the world. At the same time, a large number of common running-related injuries have been reported annually. If CST can contribute to improving running kinetics, the risk of running related injuries may be also reduced while improving a runner's speed and distance.

Purpose of the Study

The purpose of this study was to determine whether 6-weeks of CST can enhance ground reaction force efficiency, stability of the lower extremity, and overall running performance in runners.

Significance of the Study

CST is a great training tool for improving or maintaining the strength level in the mid-section of the body. Also, CST has been effective in the rehabilitation field to recover from previous musculoskeletal injuries to regain muscular strength. If CST enhances balance and stability level of the lower extremity, running mechanics may become more efficient. If stronger core muscles can change running mechanics to reduce foot impact and breaking forces, and increase active and propulsive forces, it may lead to an improved overall running performance and minimized risk of running-related injuries. Lastly, if CST contributes to improving running efficiency, CST could be done year-round and be recommended to coaches and physical education teachers for inclusion in their training modules.

Limitations

This study was subject to the following limitations:

1. Weather conditions during the 5000 m run in pre- and post- training tests may affect performance differently.

2. Psychological influence such as motivational level and competitive mind to do better than before (Sahrmann core stability test, star excursion balance test (SEBT), ground reaction force (GRF) test, and 5000 m run).

3. Some participants may learn to perform core strength exercises faster than others during the first week of treatment period.

4. Training sessions of the experimental group were not supervised by the investigator.

5. Diet was not controlled.

6. Minor individual differences could be seen in core strength prior to the study.

Delimitations

This study was subject to the following delimitations:

1. Shoes.

   (a) All participants wore the exact same brand/type of shoes at the time of pre- and post- treatment tests.

   (b) All participants wore the shoes that were less than 30 miles old prior for the pre-testing.

   (c) If any participants used orthotics or braces during running, they must continue doing so during pre- and post- tests.

2. Participants.

   (a) All participants were experienced runners (3+ years).

   (b) All participants consistently have run at least 15 miles per week or more.

   (c) All participants had no head or running-related injuries for at least 3 months prior to the screening.

   (d) All participants do not currently participate in core-related training.

   (e) All participants were not familiar with SEBT.

3. Tests.

   (a) 5000 m run was done at an accurately measured outdoor track.

   (b) Sahrmann core stability test was done at the Barry University Biomechanics Laboratory.

(c) The SEBT was done at the Barry University Biomechanics Laboratory.

(d) The GRF test was done at the Barry University Biomechanics Laboratory.

Assumptions

This study was subject to the following assumptions:

1. All participants understood the directions given in the study.

2. All participants ran 5000 m to the best of their abilities at the time of the pre- and post-treatment tests.

3. The experimental group followed the training schedule as instructed.

4. The control group followed their normal training routine without modification during the study.

5. Both groups of participants were not permitted to modify their running mechanics/styles.

Research Hypotheses

1. CST decreases peak impact vertical GRF (vGRF).

2. CST decreases the duration of posterior direction of horizontal GRF (hGRF).

3. CST increases peak active vGRF.

4. CST increases the duration of propulsive direction of hGRF.

5. CST improves the stability level of lower extremity measured by 1-leg SEBT.

6. CST contributes to improved 5000m running time.

Definition of Terms

Active vGRF: Upward energy generation force (Robertson, Caldwell, Hamill, Kamen, & Whittlesey, 2004, p.94).

AMTI force plate: A metal plate which measures the ground reaction force in three directions (vertical and two horizontals) (4507, Advanced Mechanical Technology, Inc., Watertown, MA).

Anterior propulsive hGRF: A horizontal force directed forward (Robertson et al., 2004, p. 94).

Balance: "The ability to sustain or return the body's center of mass or line of gravity over its base of support" (Clark, 2001, p.368).

Contact phase: Ground contact during running to absorb shock at initial contact and generate energy to propel forward direction (Novacheck, 1998).

Core strength training (CST): Exercises to improve strength level of mid-section of the body.

Iliotibial band (IT band) syndrome: "An overuse inflammatory condition due to friction (rubbing) of a band of tendon over the bone of the knee" (Medical College of Wisconsin [MCW], May 1999).

Impact vGRF: Downward energy absorption force (Robertson et al., 2004, p. 94).

Kinematics: The branch of mechanics that deals with motion without reference or mass (Adrian & Cooper, 1995).

Kinetics: The study of forces and their effects on the body (Whiting & Zernicke, 1998).

Kinetic chain: “It is made up of the muscular system (functional anatomy), articular system (functional biomechanics), and neural system (motor behavior)” (Clark, 2001, p.371).

Ground reaction force (GRF): The three-dimensional points of pressure to the ground during the stance phase (foot contact) which is measured by the force plate (Robertson et al., 2004, p.94).

Overuse injuries: The accumulation of micro trauma on the body’s tissues from repetitive motion (Andrews & Fleisig, 1998).

Plantar faciitis: “An inflammation (irritation and swelling with presence of extra immune cells) of the thick tissue on the bottom of the foot that causes heel pain and disability” (MCW, May 1999).

Posterior breaking hGRF: A horizontal force directed backward (Robertson et al., 2004, p. 94).

Range of motion (ROM): “The degree of movement that occurs at a joint” (Baechle & Earle, 2000, p.322).

Shin splints: “Pains in the front of lower legs caused by exercise, usually after a period of relative inactivity” (U. S. National Library of Medicine and the National Institute of Health, 2004).

Star excursion balance test (SEBT): A movement assessment to measure the lower extremity stability and dynamic balance. (Hertel, Miller & Denegar, 2000)

Stress fractures: A hairline crack in the bone that develops because of repeated or prolonged forces against the bone (U. S. National Library of Medicine and the National Institute of Health, 2004).

Stride frequency: “The number of strides taken in a given amount of time or distance” (Brown, Ferrigno, & Santana, 2000, p.20).

Stride length: “The distance covered in one stride” (Brown et al., 2000, p.20).

Swing phase: Free from ground contact during running (Novacheck, 1998).

CHAPTER II

LITERATURE REVIEW

The purpose of this study was to determine whether 6-weeks of core strength training (CST) can enhance ground reaction force (GRF) efficiency, stability of the lower extremity, and overall running performance in recreational and competitive runners. In this study, an experimental group of runners performed a series of core strength exercises. The results from CST may influence selected kinetic variables, stability of the lower extremity measured by using 1-leg SEBT, and 5000m running time.

This chapter was divided into the following sections; (a) general running mechanics, (b) specific running mechanics, (c) causes of running-related injuries, (d) core strength training and its effects to postural control and athletic performance, (e) tests of core strength and stability of the lower extremity, and (f) summary.

General Running Mechanics

The biomechanics of running has been studied over 40 years since the rapid growth of participation in distance running since the late 1960s (Novacheck, 1998). Running velocity depends on stride length (distance covered in one stride) and stride frequency (number of strides taken in a given amount of time or distance) (Brown et al., 2000, p 20). Stride length varies on height or the leg length of individuals as well as on running mechanics and velocities. Stride frequency also depends on running mechanics and velocities. Although there is no scientific evidence on optimal stride length and frequency, many running coaches suggest that optimal stride frequency in long distance running is from 170 to 180 steps per minute.

A gait cycle for running is simply categorized into two phases: (a) swing phase (see Figure 1) and (b) contact phase (see Figure 2) (Novacheck, 1998).

Figure 1 Right leg is going to swing phase of running.

Figure 2 Left leg is in contact phase of running.

The swing phase of running is basically free from ground contact and the level of muscle activity is lower during the swing phase than during contact phase according to the electromyography (EMG) data (Ounpuu, 1990). In addition, the average duration of the swing phase increases as running velocity increases from walking (0.38 seconds (sec) at 1.2m/s) to running (0.42 sec at 3.2m/s), and running to sprinting (0.44 sec at 9.0m/s) due to the stronger push-off at the end of the contact phase (Mann & Hagy, 1980; Novacheck, 1998).

The contact phase of running is to absorb shock during initial foot contact and generate energy to propel forward direction (Novacheck, 1998). The duration of the contact phase in running ranges from 0.28 sec (3.2m/s) to 0.23 sec (3.9m/s), on average (Novacheck, 1998). Within the contact phase, there is energy absorption (also referred as impact vertical GRFs (vGRFs)) and energy generation (also referred as active vGRFs) (see Figure 3 & 4).

Figure 3 Energy absorption (heel contact) at contact phase.

Figure 4 Energy generation at contact phase.

Energy absorption occurs during the initial foot contact which returns the same amount of energy back to the body from the ground, called impact vGRFs (Robertson et al., 2004, p. 94) (see Figure 5).

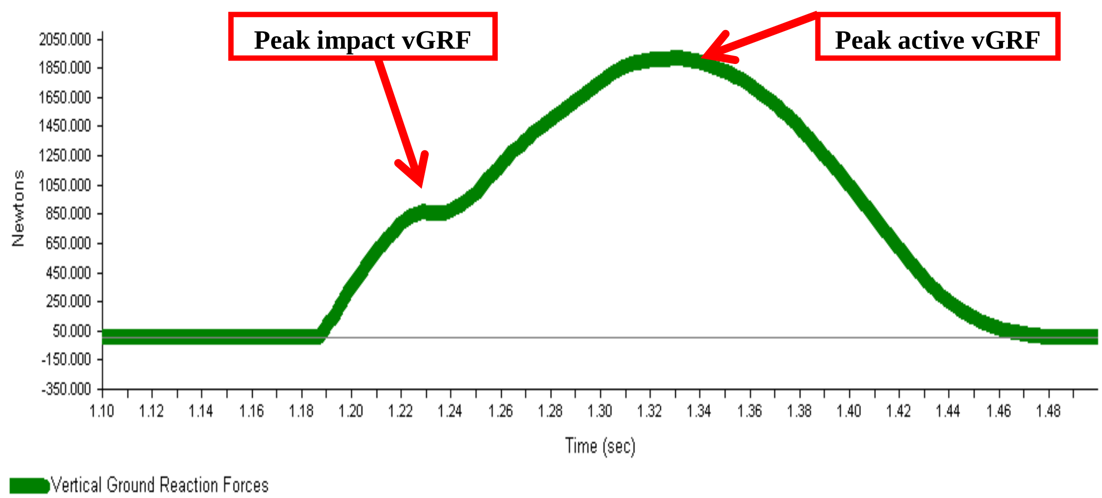


Figure 5 Vertical ground reaction forces.

Peak impact vGRF is expected to range from 1.5 to 5 times the person's body weight (BW) in walking/jogging to sprinting, and up to 2 times the BW during running from 3.2

to 3.9 m/s (8:20 to 6:55 minutes per mile pace) (Hreljac, 2004; Novacheck, 1998). Energy generation is a force production that thrusts opposite to the energy generation (vertically and horizontally) in order to propel the runner forward, also called active vGRF (Robertson et al., 2004, p. 94) (see Figure 5). Peak active vGRF is similar or slightly higher than peak impact vGRF (Novacheck, 1998).

During the contact phase, there are also horizontal GRFs (hGRFs) that can be captured by a force plate. The phase of the first half of foot contact on a flat surface, is the posterior breaking force, also called breaking hGRFs. The second half of foot contact captures propulsive force, also called anterior propulsive hGRFs (Gottschall & Kram, 2005) (see Figure 6).

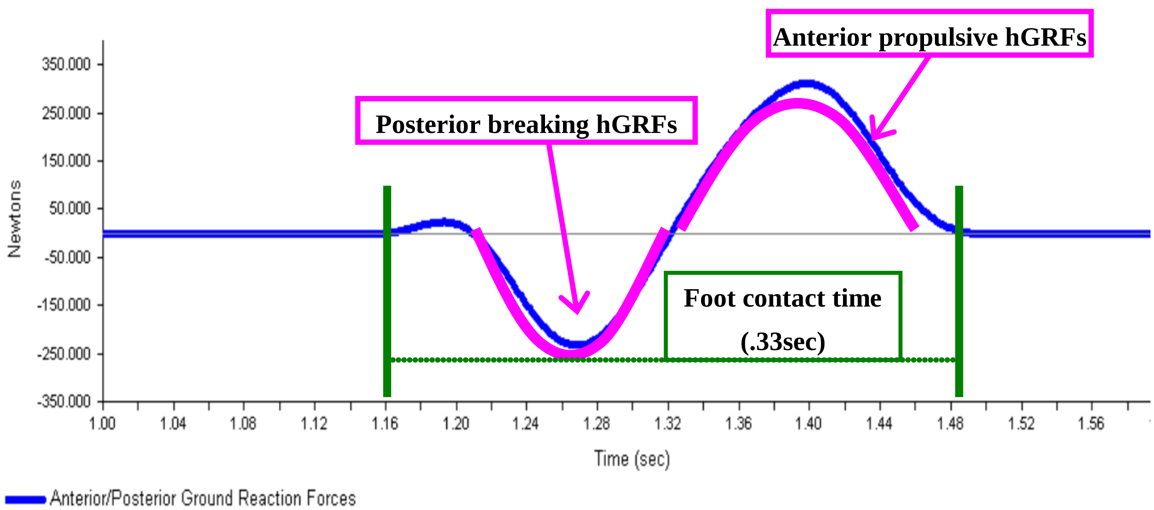


Figure 6 Horizontal ground reaction forces.

It is also important to understand two types of foot strike patterns that have been studied in the biomechanics of running. Rear-foot strikers (RFS) engage the energy absorption at initial heel contact, whereas mid-foot strikers (MFS) and forefoot strikers (FFS) are able to run without excessive amount of energy absorption due to the absence of rear-foot contact during the contact phase (Oakley & Pratt, 1988). RFS may be forced to change kinetically and kinematically during running due to the excessive peak impact vGRF. As mentioned above, MFS and FFS are not engaging in impact vGRFs; thus, a full contact phase is captured as less foot contact time on the ground and a shorter or no energy absorption phase (Kerr, Beauchamp, Fisher, & Neil, 1983). This type of foot control is recognized as one of the characteristics in elite runners. Approximately 80 percent of all runners are RFS and the remainders (20 percent) are considered to be MFS or FFS (Kerr et al., 1983). In order to run efficiently, runners are advised to spend less time during the contact phase (Novacheck, 1998).

Since a forefoot strike pattern is not necessarily a genetic motion, but rather automatic, RFS may be instructed to run as FFS. Williams, McClay, and Manal (2000) studied the differences between RFS who were instructed to run with FFS pattern, and those of preferred FFS. The results showed that many variables were found to be similar such as dorsiflexion, plantar eversion excursion and velocity, and knee flexion excursion and internal rotation at foot strike. Significant differences were found in peak active vGRF (FFS: 2.82 BW vs. preferred FFS: 2.43 BW) and ankle plantar flexion moment (FFS: -1.83 Nm/(kg x ht) vs. preferred FFS: -1.41 Nm/(kg x ht)). They concluded the study by stating that RFS can adapt to FFS as instructed, but it did not promise a running efficiency similar to natural FFS.

Specific Running Mechanics

Proper running mechanics require a balance of muscle strength, flexibility, and total body coordination (Santana, 2000a). If one anatomical segment is not effectively functioning, then other muscles must compensate to move the body from point A to point B. Clark (2001) stated that compensation patterns stress the entire kinetic chain of the body. Ineffective muscle functions may overload the soft tissues causing fatigue and faulty movement patterns.

Running economy is often referred to as low energy cost of running. Low energy cost of running at given velocity has been accepted as the physiological criterion. Running economy in biomechanics is determined by factors such as optimal stride length and frequency, low peak impact vGRF, greater angular velocity during energy generation, and effective exploitation of stored elastic energy are considered (Anderson, 1996; Novacheck, 1998; Stanton, et al., 2004).

Analyzing specific running mechanics is a key component to understanding a runner's overall mechanical efficiency or abnormal movement pattern. The force plate has been a popular instrument to capture valid kinetic data such as three planes of GRFs (a vertical direction and two horizontal directions) (see Figure 7).

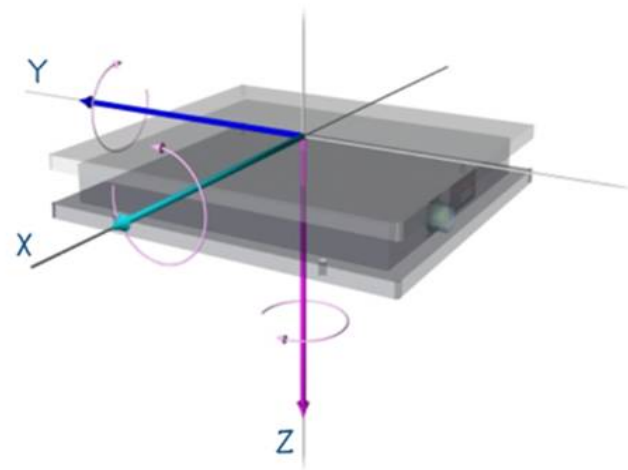


Figure 7 Force plate.

The force plate also captures the center of pressure (CoP) of the contact foot identifying the center and direction of weight shifting to analyze balance ability in static and dynamic manners (Hreljac & Stergiou, 2000; Li & Hamill, 2002; Mercer, Bates, Dufek, & Hreljac, 2003).

Kinetic measures

Under the review of Novacheck (1998), many running-related injuries are associated with kinetic data such as various types of GRFs. Especially, high impact vGRF is believed to be one of the common indicators for running-related injuries (Hreljac, 2004) (see Figure 8).

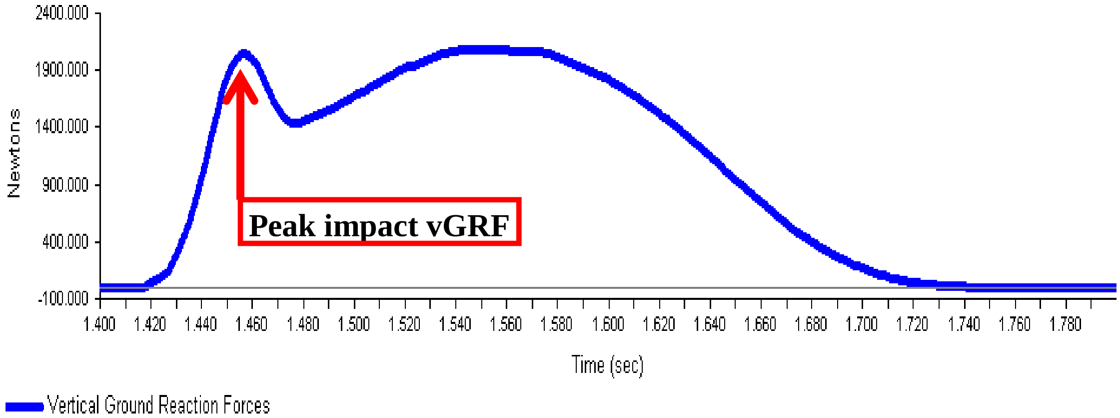


Figure 8 High peak impact vertical ground reaction force.

As mentioned earlier, stride length is a key component when analyzing running economy. A study found peak impact vGRF was decreased from 2.39 BW to 1.59 BW as stride length was shortened by -20% from preferred length (Derrick, Caldwell, & Hamill, 2000). They also found that if runners ran with longer stride lengths (+10% and +20% longer than preferred stride length), peak impact vGRF increased. Moreover, relatively high impact vGRFs are often captured with faster running speeds, slow jogging speeds (peak impact vGRF = 6.0m/s > 2.0m/s > 3.5m/s) (Keller, Weisberger, Ray, Hasan, Shiavi, & Spengler, 1996), stiffer ground surfaces (asphalt: 1.60 BW vs. rubber: 1.58 BW) (Dixon et al., 2000), downhill running (-9 degree: 1504±273 vs. 0 degrees: 974±193N) (Gottschall & Kram, 2005), from high-arch runners (high arch runners: 2.00 BW vs. low arch runners: 1.50 BW) (Williams, McClay, & Hamill, 2001), and in older male runners (older runners: 1.91 BW vs. younger runners: 1.70BW) (Bus, 2003). Although excessively high active vGRF was also considered to be one of the leading causes for running-related injuries in the past, recent studies found no significant changes in active vGRF as impact vGRF changes in various conditions such as uphill/downhill running (Gottshcall & Kram, 2005) and high/low arches (Williams, McClay, Sholz, Hamill, & Buchanan, 2004); thus active vGRF may not be an important factor in causing overuse injuries.

Higher and longer breaking hGRFs are often seen from downhill running up to 0.55BW at -9 degrees as compared to 0.35BW at 0 degrees surface (Gottschall & Kram, 2005). The investigators described how downhill running makes runners decelerate the momentum of gravity, which causes a higher and longer duration of breaking hGRFs. The results may indicate that higher and longer breaking hGRFs lead to greater stress on joints and muscles, and a higher metabolic cost at the same time. The investigators also explained that propulsive hGRF increases during uphill running (up to 0.5BW at +9 degrees) as compared to 0.3BW at 0 degree surface. Increased duration in propulsive hGRF equates to increased time of energy generation; therefore, it may be true that many elite runners engage in uphill running as a training tool in order to increase mechanical efficiency as well as cardio respiratory efficiency.

Finally, a higher loading rate of vGRF is seen in the softer mid-sole shoes and harder ground surfaces (Dixon et al., 2000; Hamill, Bates, & Holt, 1992). The significant reduction in the loading rate of vGRF for a rubber-modified surface as compared to conventional asphalt (47.7 vs. 51.4BW x S^{-1}, $p<.01$) was found (Dixon et al., 2000). Although varied responses in different surface stiffnesses were detected in the study, no significant kinematic differences were found. The results indicated that running kinematics were not necessarily influenced by the type of ground surface, but kinetic responses such as peak impact vGRF and loading rates do change depending on the stiffness of the running surface.

Interestingly, recent studies compared the differences between running in barefoot and in shoes to identify each condition's characteristics, and they found that the barefoot condition actually reduces impact vGRF and improves ankle coordination (Divert, Mornieux, Baur, Mayer, & Belli, 2005; Kurtz & Stergiou, 2004). Divert et al. (2005) found that running barefoot is less stressful to muscles and joints during treadmill running. The investigators found that the barefoot condition showed less contact and flight time ($p<.05$) and lower peak impact vGRF as compared to the shoe condition (1.48 vs. 1.70 BW, $p<.05$). It was concluded that a reduction in the time of foot contact and peak impact vGRF in the barefoot condition minimized the mechanical stress during the repetitive steps. Running barefoot may result in lower peak impact vGRF because of the changes in ankle coordination (Kurtz & Stergiou, 2004). Even though running in a barefoot condition may change gait to reduce impact vGRFs, it is not a realistic training method due to the limited number of locations for running barefoot.

Kinematic measures

The relationship between lower extremity mechanics such as joint coupling (e.g. hip internal rotation, knee flexion, tibia internal rotation, and foot eversion) and lower extremity injuries is a relatively a new topic being studied (DeLeo, Dierks, Ferber, & McClay-Davis, 2004). The inefficient running mechanics may be seen due to aging, gender differences, and degeneration of muscular strength and flexibility (Bus, 2005; Dixon, et al., 2000; Ferber et al. 2003; Hreljac, 2004). In addition, Bellchamber and Van Den Bogert (2000) studied the cause and effect relationship between tibial internal rotation and pronation of the foot during walking and running. They found that all participants exhibit clear power flow (proximal to distal) from tibia to foot during the contact phase of walking. However, they also found opposite power flow (distal to proximal) in the brief period of contact phase in some runners. This data may indicate different gait patterns as velocity changes.

Female runners reported twice the running-related injuries as male runners (Taunton et al., 2002). Ferber et al. (2003) reported that female runners used higher hip adduction and internal rotation and knee abduction angles compared to male runners. Female runners also showed higher muscle activation from the medial hamstring as compared to male runners ($31.73 \pm 9.90\%$ vs. $23.04 \pm 8.60\%$, $p<.01$), but other selected lower extremity muscles (lateral hamstring, lateral/medial gastrocnemius, soleus) did not show any significant activation differences (DeMont & Lephart, 2004).

One of the most significant anatomical differences between males and females is the quadriceps angle (Q-angle). The width of the pelvis determines the size of the Q-angle. Women tend to have a wider pelvis than men; therefore, the Q-angle is greater in women than in men (see Figure 9).

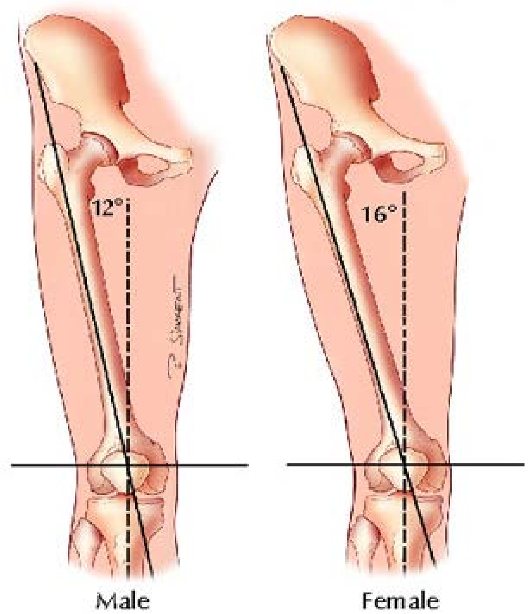


Figure 9 Quadriceps angle for male (L) and female (R).

Heiderscheit, Hamill, and Coldwell (2000) studied the influence of Q-angle on lower extremity running kinematics. Assuming that a greater Q-angle is a contributing factor to internal rotation of the lower extremity, the study found that the high degree of Q-angle group exhibited higher percentage of maximum tibial internal rotation later in the contact phase (39.5$\pm$16.3%) as compared to the low Q-angle group (28.8$\pm$10.7%).

However, other kinematic measures such as maximum rear-foot eversion angle did not show any differences between the groups.

It is evident that abnormal anatomical structures affect running mechanics (Williams et al., 2004). As the various types of running mechanics are also linked to different types of running-related injuries, abnormal foot structure is another factor associating with certain lower extremity injuries (Williams et al. 2001). Williams et al. (2004) described mechanical characteristics of arch structures where high-arch (HA) runners exhibit greater leg stiffness than low-arch (LA) runners (7.17 kN/m $_{X}$ kg vs. 6.46 kN/m $_{X}$ kg; $p<.03$). This indicates that HA runners have a rigid mechanism to dynamically control postural alignment during running. In addition, HA runners exhibited a greater incidence of lateral ankle sprain (HA: n=8; LA: n=1) and bony-injuries (HA: n=14; LA: n=7) than low-arch runners who reported more medial knee injuries (patellar tendonitis) and soft tissue injuries (HA: n=42; LA: n=56).

Leg length discrepancy contributes to back, ankle, and foot injuries according to the study done by Wen, Puffer, and Schmalzried (1997). Further, Lun, Meeuwisse, Stergiou, and Stefanyshyn (2004) reported that statically standing position of lower extremity alignment of injured runners and non-injured runners did not show any significant differences. However, when runners who were diagnosed with patellofemoral pain syndrome (*n*=6), were compared to other participants, differences were found in ankle dorsiflexion, knee geru varum, and forefoot varus during running.

Running-related injuries

Hreljac (2004) stated that excessive distance of running mileage or rapid mileage increase contributes to overuse injuries in the lower extremity. The following symptoms are common overuse running-related injuries: (a) iliotibial-band syndrome, (b) tibial stress syndrome, (c) patellofemoral pain syndrome, (d) Achilles tendonitis, and (e) plantar fasciitis. He also described that the majority of the causes of those overuse injuries are the results of training errors associated with increasing weekly mileage too rapidly and running at maximum effort on every run.

Repetitive stress such as running can be modified by: (a) footwear or orthotics and (b) ground surfaces. Although the design and functionality of running shoes have improved substantially, types of running shoes (well-cushioned, firmer mid-sole, and valgus) and their characteristics are still not certain to prevent common running-related injuries. On the other hand, it is evident that harder running surfaces increase vGRFs to stress joints and muscles (Hardin, Van Den Bogert, & Hamill, 2004; Kerdok, Andrew, Biewener, McMahon, Weyand, & Herr, 2002).

The effects of shoes and orthotics on running-related injuries

It is important to review the effects of the running shoes and their relation to foot mechanical efficiency as well as injury prevention. As mentioned above, the effects of shoes on foot mechanics and injuries remains unknown even though past studies revealed the kinetic and kinematic changes in the lower extremity with various types of shoes and orthotics (O'Connor & Hamill, 2004; Van Gheluwe, Kerwin, Roosen, & Tielemans, 1999). In general, HA runners are recommended to wear well-cushioned shoes, whereas LA, pronated, and heavy body mass runners are recommended to wear stability or motion-control shoes (O'Connor & Hamill, 2004; Pribut & Richie, 2004; Williams, et al. 2004). Proper fit in the heel is also an important factor to eliminate slipping during the contact phase of running (Van Gheluwe et al., 1999). Moreover, in order to improve foot control during the contact phase, different types of orthotics are popular supplemental tools. Orthotics are found to change peak rear-foot eversion (Bates, Osternig, Mason, & James, 1979), total rear-foot range of motion (Baitch, Blake, Finegan, & Senatore, 1991), and rear-foot eversion velocity (Smith, Clarke, Hamill, & Santopietro, 1986).

For RFS, running involves a series of heel strikes on the ground. If a runner wears the wrong type of shoes (e.g., a low arch, heavy weight runner wearing light-weight and well-cushioned shoes), the shoe would not last as long as it is suggested. Running shoes are advertised to last about 300 – 400 miles (Pribut & Richie, 2004).

However, the peak plantar pressure increased on average by 100% after 300 miles and structural damage such as holes and deformations occurred in the foam of the shoes at the same time (Verdejo & Mills, 2004). The investigators highly recommend changing running shoes even before reaching 300 miles to minimize stress resulting from repetitive high impact and to maintain proper foot mechanics. The investigators explained that well-cushioned shoes that are so soft that they are likely to cause runners to lose efficient foot control during the contact phase (Pribut & Richie, 2004). Boyer and Nigg (2004) found that soft material in the mid-sole of running shoes increases muscle activity including vibration in lower leg muscles. Pronation is believed to be one of the mechanisms to absorb and generate energy while also leading to possible injuries when pronating excessively. Prescribed orthotics or stability shoes can help control the speed and degree of pronation (Perry & Lafortune, 1995). According to O'Connor and Hamill (2004), greater pronation leads to greater energy absorption in the foot inverter muscles and tendons but excessive amounts of pronation and eversion cause high stress in the lower leg muscles and tendons. Their results also stated that when participants wore valgus (cushioned) shoes, the range of motion in the frontal plane of ankle joints (12.8 vs. 9.1 degrees), peak eversion angle (-8.5 vs. -5.0 degrees), and peak eversion velocity (-335.4 vs. -253.8 degrees/seconds) were all higher than varus (motion control) shoes ($p<.05$).

The age of the running shoes also changes depending on the level of humidity and temperature (Wilk & Valdez, 2002; Dib, Smith, Bernhardt, Kaufman, & Miles, 2005). Wilk and Valdez (2002) described that a humid climate contributes to shoe's breakdown by overstretching the shoe's upper aspect while over compressing the lower aspect of the shoes. Moreover, cold temperatures reduce the shock attenuation (higher peak deceleration) in some shoes, depending on what type of material is in the sole of the shoes (Dib et al., 2005). Even though these finding may not relate to every runner, runners who are in extreme climates such as in the southern United States need to take it into consideration.

The level of cushioning/stability, and width of front-/rear- foot compartment depends on an individual's running mechanics and foot structure. It is also obvious that consumers look for cushioning comfort as well as price when purchasing running shoes. However, it is important to educate them to purchase running shoes that are suitable for their foot type and running mechanics.

The effects of ground surface on running-related injuries

Running on a softer surface is recommended to minimize repetitive shocks for runners. Hardin et al. (2004) found that harder surfaces contributed to lower oxygen consumption and heart rate compared to similar running on a softer surface. Softer surfaces create greater leg stiffness, but no significant mechanical differences were found for runners performing on various stiffness of surface (Kerdok et al., 2002). This indicates that softer running surfaces require higher energy generation in order to maintain running speed as compared to the harder surfaces. It is logical that running on sand allows a soft landing but it also requires stronger push-off repetitively, which ultimately may lead to a higher oxygen consumption and heart rate.

Choosing a running surface may depend on personal preference to some extent just like choosing the brand of running shoes. Runners with an optimal degree of muscular strength in the lower extremity may be able to run on harder surfaces economically. On the other hand, runners who are willing to develop running stamina, may prefer softer surfaces on which to practice running mechanics without a high degree of foot impact forces.

Core strength training and its effects on postural control and athletic performance

In order to properly train core muscles, a basic understanding of the core's muscle structure and its functionality is essential. The main function of the core musculature is to stabilize the spinal alignment. If core muscles are too weak or tight, a postural alignment becomes imbalanced, which causes stress to various locations in the body (see Figure 10) (Clark, 2001).

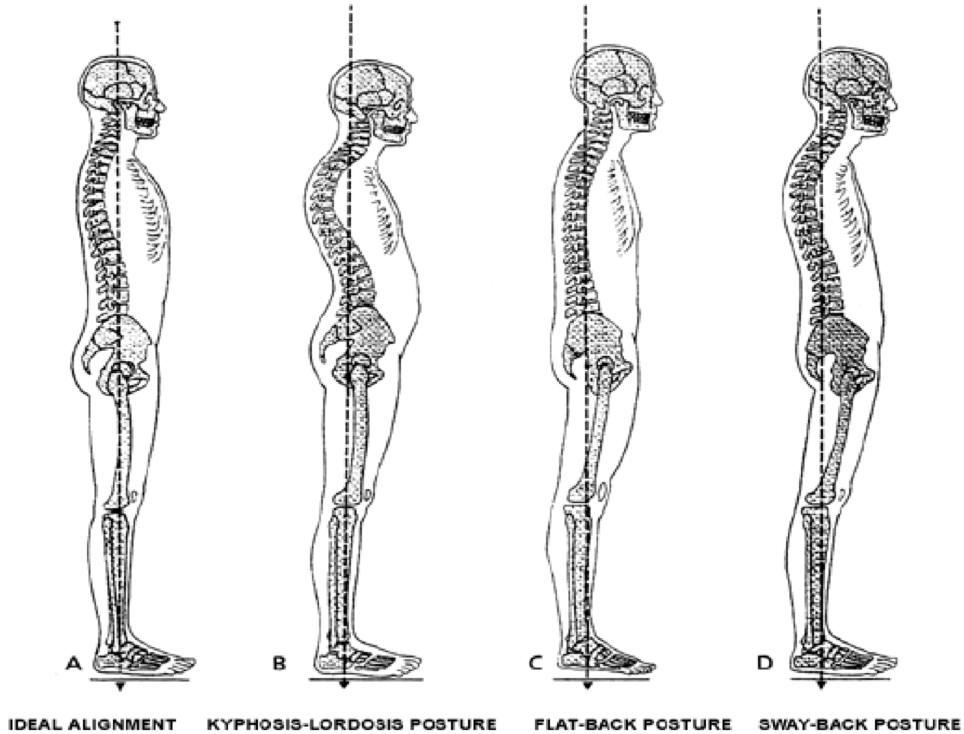


Figure 10 Various postural alignments (far left is ideal).

In order to maintain ideal postural alignment, core strength training (CST) may be necessary on a daily basis. Core muscles are simply divided into four sections: abdominals, hip flexors, back extensors, and hip extensors (see Figure 11) (Brittenham & Brittenham, 1997; Santana, 2000b).

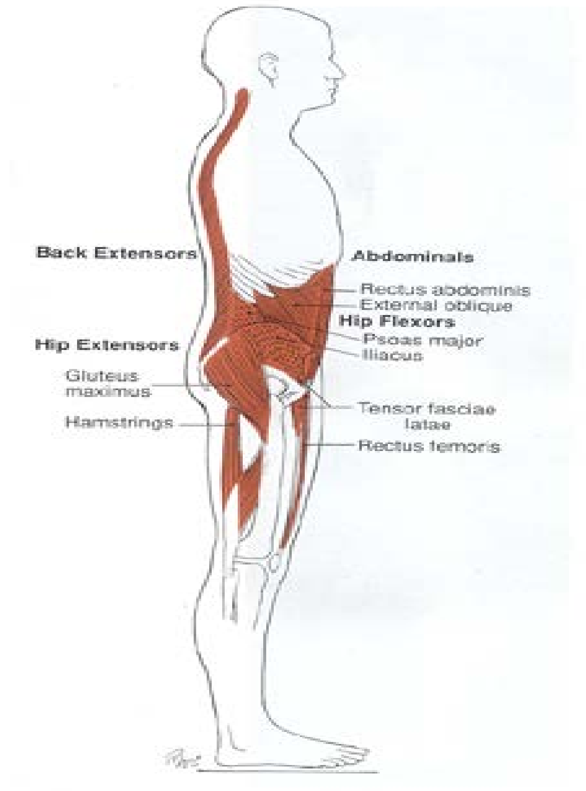


Figure 11 Core muscles.

Those muscle groups stabilize the body to minimize postural sway. Postural control is often measured either in a static or dynamic position. Although running is a series of repetitive dynamic movements, if a runner has a static postural control deficiency, he/she may most likely lack dynamic postural control (Clark, 2001). Postural instability has been shown to cause increasing postural sway after a 2-mile run (Pendergrass, Moore, & Gerber, 2003). Increased postural sway may also lead to inefficient running mechanics. The effects of CST may play a role on running mechanics as well as postural control. If CST contributes to maintain the stability level of the mid-section and upper extremities, kinetic variables such as vGRFs and hGRFs may contribute to decrease peak impact vGRF and duration of posterior hGRF, and to increase active vGRFs and duration of anterior hGRF.

Presently, only few studies have investigated the effect of CST on athletic performance. Stanton et al. (2004) studied the effects of Swiss-ball training on core stability and running economy as measured by VO_{2max} and postural control during running. The results showed that Swiss-ball training improved overall core strength as measured by the Sahrmann test, but had no direct relationship to VO_{2max} and running posture after six weeks of training (six exercises, two training sessions per week). Another study showed the effects of Swiss-ball training on core muscle strength in swimmers, but the improvement did not relate to swim performance (Scibek et al., 2001). Moreover, Nadler, Malanga, Bartoli, Feinberg, Prybicien, and Deprince (2002) examined the influence of CST on low back pain and hip strength differences in collegiate athletes. The study showed no significant difference in the level of low back pain after CST, but showed improvement in the level of hip muscle strength (hip extensors and abductors).

Leetun, Ireland, Wilson, Ballantyne, & McClay-Davis (2004) tested the strength level of selected core muscles to identify a risk of lower extremity injuries in male athletes. The results showed that those who did not sustain an injury had significantly stronger hip abduction (32.6 % vs. 31.6 % of BW) and external rotation (21.6 % vs. 20.6 % of BW). The investigators stated that core stability has an important role on injury prevention, and improved core muscular strength may contribute to a reduced risk of lower extremity injuries. However, there is no current literature stating that stronger core muscles reduce the risk of athletic injuries or improve performance. At the same time, stronger muscles can also over-compensate for the weaker muscles in certain movements which may lead to muscular imbalance or tissue overload (Clark, 2001); thus, the relationship between the level of muscle strength and risk of injuries remains uncertain.

Overall, running mechanics seem to change from the experience or possibly from daily behavior. Therefore, CST may not be a main factor contributing to any kinematic changes, but improved core muscle strength reduces postural sway, which ultimately may change selected kinetic measures.

Stability tests of core and lower extremity

Sahrmann core stability test

The Sahrmann core stability test was selected to measure the level of core strength during screening. This test has not been reviewed scientifically but was used in one study in order to measure core stability level to identify the effect of short-term Swiss ball training (Stanton, et al., 2004). Their previous pilot work reported a reliability coefficient of .95 with a standard error of measurement of 7.7% for this test.

Star excursion balance test (SEBT)

The SEBT was selected to measure the stability of the lower extremity during pre-training and post-training. The advantage of using the SEBT is to identify: (a) dynamic postural control, (b) range of motion of the lower extremity, and (c) strength of the lower extremity. SEBT is best described as a functional test that quantifies lower extremity reach while challenging on individual's limits of stability (Olmsted et al., 2002). SEBT is a low cost, simple, clinical test for assessing functional impairments in a variety of the lower extremity conditions such as patellofemoral pain syndrome (Earl, 2002) and quadriceps strength deficit (Miller, 2001). Kinzey and Armstrong (1998) tested the reliability of the SEBT by using the intra-class correlation coefficient, and it ranged from .67 - .87, respectively, with and without practice sessions. The investigators recommended providing a learning period to a performer before being evaluated. A recent study (Gribble & Hertel, 2003) revealed relationship between the leg length and excursion distance during SEBT in anterior, lateral and posterior direction (r^2=0.23, p<.05). Thus, when using the SEBT, leg length should be accounted for when measuring the stability level of the lower extremity.

Summary

Many researchers have targeted specific variables of running mechanics to identify how overuse injuries occur or how to improve performance by utilizing CST with kinetic and kinematic measures. Further, some researchers analyzed running mechanics and their relation to various anatomical structures, types of running shoes, and different running surfaces.

Core strength has an important role in athletic conditioning. Although some studies showed that an improvement of core muscle strength has no relation to better performance or mechanical changes, strong core muscles are believed to help an athlete's movement efficiency. However, there is no definite finding about the effects of CST on improved performance and ground reaction force efficiency in runners. If core exercises help runners run more efficiently, their speed and endurance may improve in the long term.

CHAPTER III

METHODS

The purpose of this study was to determine the effects of six weeks of core-specific strength training on selected running kinetics, lower extremity stability, and running performance in recreational and competitive runners. The specific aim of this study was to determine how six weeks of core-specific stability training affect: (a) peak impact vertical ground reaction force (vGRF) in terms of body weight (BW), (b) duration of breaking horizontal GRF (hGRF) as a percentage (%) of time, (c) peak active vGRF in BW, (d) duration of propulsive hGRF in time %, (e) the level of the lower extremity stability in % (ratio of the length of the score in centimeter (cm) to one's leg length (cm)), and (f) 5000 meter (m) timed run in minutes and seconds. In accordance with these aims, the following methods were employed. Results of this study may prove useful in the role of CST in improving running performance and in understanding injury development in runners.

Participants

The participants of this study were 28 healthy, male and female runners, aged 20 to 50 years from the local Miami / Fort Lauderdale, Florida area (age = 36.89 ± 9.40 years; height = 168.39 ± 9.60 cm; weight = 70.10 ± 15.34 kg). Flyers (Appendix A) were posted at the Barry University campus and the local running and triathlon specialty stores in the area. General information about the study was explained to interested runners via email or local marathon training clinics. To qualify for the study, participants must meet the following criteria: (a) be injury-free (e.g., running-related or head injuries) for at least three months,

(b) be rear-foot strikers, (c) have run for more than three years, (d) constantly run at least 15 miles per week, (e) have had no more than three sessions in performing any targeted lower extremity stability tests such as the star excursion balance test (SEBT) during the past year, and (f) have had no more than three sessions in core-related training to supplement running performance during the past year. Screening for these criteria occurred in person, or via e-mail depending on the preference of the potential participant (Appendix B). Those who had their screening via email reported to the Barry University Biomechanics Laboratory for the core stability test as a part of screening within five days.

Sahrmann core stability test

This purpose of screening core strength prior to the treatment was to eliminate potential participants who already possessed a level III or better score when performing the Sahrmann core stability test; only one participant scored level III thus the potential participant was omitted from the study. By assessing the core stability level, 28 qualified participants possessed relatively weak core muscle strength prior to the training. The procedure of this test follows that of Stanton et al. (2004):

"Participants will be lying down on a table at supine position, and a blood pressure cuff (All Heart Standard Blood Pressure Cuff, Professional Appearance, Inc., Camarillo, CA) will be placed in the natural curvature of low back. The blood pressure cuff will be inflated 40mm Hg. The test will determine the core stability of five different difficulty levels (1 = weak to 5 = strong). The difficulty of the each level as follows:

Level 1: From a crook lying position, abdominal presetting is performed. This entails the participant activating the abdominal musculature to brace the trunk in an isometric fashion without movement being produced (Allison, Godfrey, & Robinson, 1998). Once this is achieved, the subject slowly raises one leg to a position of 100 degree of hip flexion with comfortable knee flexion. The opposite leg is then brought to the same position in the same manner with a change of not more than 10 mm Hg in pressure on the blood pressure cuff (see Figure 12). This position was employed as the start position for subsequent levels of the test protocol (see Figure 13). The pressure on the blood pressure cuff was noted and a reading greater or less than 10 mm Hg above or below this baseline indicated lumbopelvic stability was lost at this level. If the subject could maintain control on the initial, but not the final movement, the subject was graded at 0.5 for that test level. Level 2: From the start position, the subject slowly lowers one leg such that the heel contacts the ground. Then the leg is slid out to fully extend the knee, and then returned to the start position (see Figure 14). Level 3: From the start position, the subject slowly lowers one leg such that the heel reaches 12 cm above the ground. Then the leg is slid out to fully extend the knee and then returned to the start position (see Figure 15). Level 4: From the start position, the subject slowly lowers both legs such that the heels contact the ground. Then the legs are slid out to fully extend the knees and then returned to the start position (see Figure 16). Level 5: From the start position, the subject slowly lowers both legs such that the heels reach 12 cm above the ground. The legs are then slid out to fully extend the knees and then returned to the start position (see Figure 17). In order to advance to the next level, position of spine must be maintained by a change of no more than 10mm Hg in pressure."

Figure 12 Blood pressure cuff set to 40mm Hg.

Figure 13 Start position (level 1).

Figure 14 Complete position of level 2 (R-leg).

Figure 15 Complete position of level 3 (R-leg).

Figure 16 Complete position of level 4.

Figure 17 Complete position of level 5.

As mentioned above, participants who were able to perform level 3 or above, were excluded from this study. The qualified participants were separated randomly by using Statistical Package for the Social Sciences (SPSS) software (SPSS, Inc., Chicago, IL). The study was explained in detail and written informed consent (Appendix C) obtained from each participant.

Procedures

Participants reported to the Barry University Biomechanics Laboratory and selected outdoor tracks in South Florida for testing on two occasions: (a) pre-training, and (b) 6 weeks post-training. Tests for running kinetics, lower extremity stability, and running performance were performed identically at both sessions. The 5000 m run was not performed on the same day as the laboratory tests, but was performed within seven days.

Ground reaction forces

The participants were asked to place a reflective marker on the left shoe to measure running velocity calculated by Peak Motus software version 8.2 (ViconPeak, Centennial, CO). One camera was positioned on the left side of the force plate perpendicularly (see Figure 18). They warmed-up by running at a self-selected pace around the Barry University campus, and returned to the Biomechanics Laboratory to run across the force plate (see Figure 18).

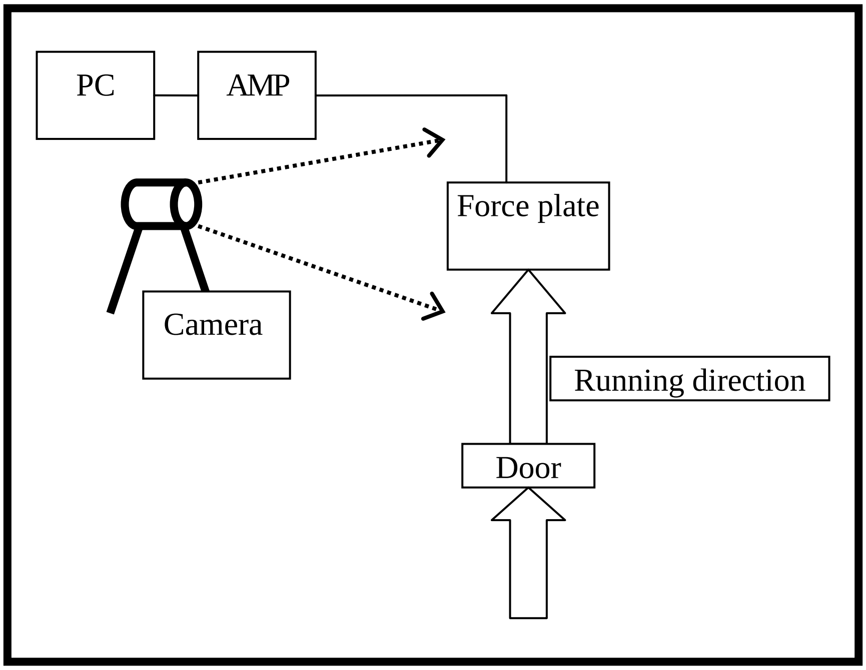


Figure 18 The layout of Biomechanics Laboratory.

This test simulated a real running situation; thus, if the participant broke stride on order to reach the force plate with proper foot placement, the data was excluded. The participant performed another trial by running out of the biomechanics laboratory and then reentering the laboratory as before. Participants were instructed to step on the force plate with their left foot. Bennell, Crossley, Wrigley, and Nitschke (1999) showed that the GRFs from left and right foot during running strongly correlated (.96); thus, only left foot kinetics were measured.

Star excursion balance test (SEBT)

Prior to the SEBT, the investigator measured each participant's leg length in order to calculate a ratio of leg length and a total score of the SEBT (Total SEBT reaching distance / leg length = score of the SEBT) (Gribble & Hertel, 2003). Leg length was measured from medial malleolus to Anterior Superior Iliac Spine (ASIS) of each leg in centimeters (cm) with a tape measure. This ensured the accuracy of performance among participants to analyze the level of lower extremity stability.

The stability of the lower extremity was recorded by using 1-leg SEBT. The barefoot condition was required to eliminate extra balance and stability from the shoes (Gribble & Hertel, 2003). First, all participants placed their left foot on the center of a 0 – 180 degree line. Then the participants reached out the toes of their right foot as far as possible to the direction of 0, 90, and 180 degree lines while maintaining balance. Then, participants switched to their right foot and followed the same sequence. Kinzey and Armstrong's study (1998) described that verbal instruction and visual demonstration should be given to the participants to increase their knowledge of the sequence of the movements. They found that the instruction and demonstration improved the reliability of the test (from .67 to .87) along with practice sessions prior to the test; thus, adequate amount of practice time was also provided.

In order to maximize the reliability of the measurement, the following detailed instructions were given identically to all participants: (a) placing the foot on the line with medial part of the stable foot while reaching laterally (90 degrees) (see Figure 19); (b) placing toes of the stable foot aligned on the line for the forward reach (0 degrees) (see

Figure 20); and (c) placing the heel of the stable foot on the line for the backward reach (180 degrees) (see Figure 21).

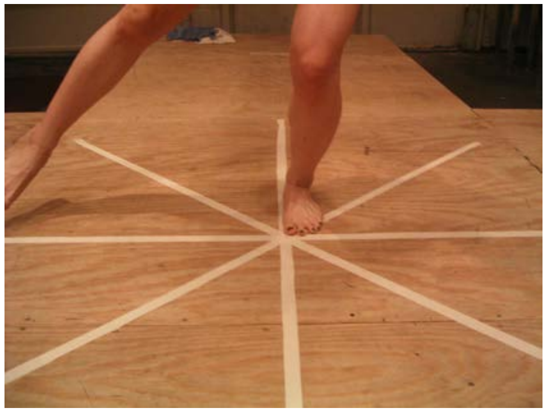


Figure 19 Stable foot (left) position for lateral reach

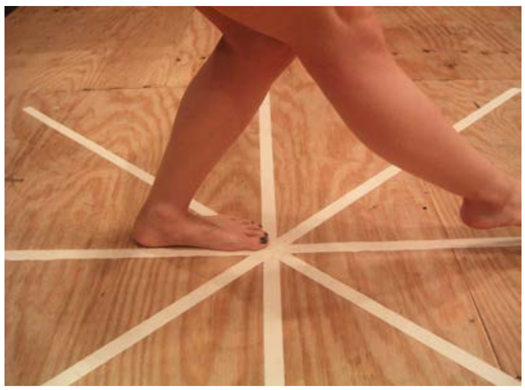


Figure 20 Stable foot (left) position for frontal reach

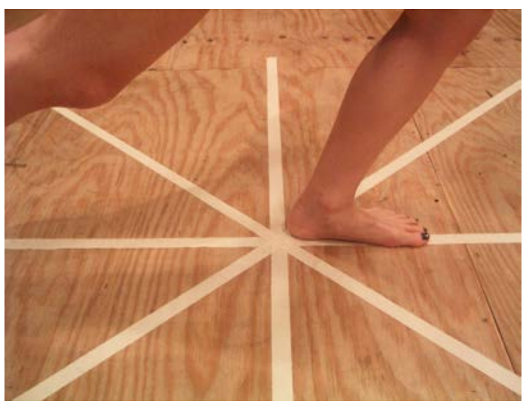


Figure 21 Stable foot (left) position for back reach

Participants lightly touched the tape at the furthest distance reached while being in a static position for at least three seconds to ensure their ability to stabilize their bodies according to Gribble and Hertel (2003). Each participant received two trials in each condition to reach with their toes in the guided directions. The length between the toes of the reaching foot and the starting position of the stable foot were measured manually with a tape measure according to the Gribble and Hertel (2003).

5000 m run

A 5000 m run was done at an accurately measured track in local Broward or Miami-Dade counties. Due to the time availability of each participant, the 5000 m run was done on a separate day. However, the 5000 m run was performed within seven days of the laboratory testing date (SEBT & GRF test) before and after the 6-wk training period.

After adequate amount of warm-up including jogging and stretching, the 5000 m run was timed by the investigator with two stopwatches (Minute Man, Nike, Beaverton, OR; and Polar S410, Lake Success, NY). The accurately measured track is 400m per lap; thus, all participants ran 12.5 laps to complete a total distance of 5000m. Upon the completion of this trial, the 5000 m run time was recorded in minutes and seconds (e.g., 5000 m = 19 minutes 43 seconds) and were written in each participant's testing chart. In addition, temperature and humidity level were also recorded during all participants' running trials.

Core strength training (CST)

Both groups performed pre- and post- training tests in the same order. The control group did not receive the CST protocol, and were instructed to maintain his/her training routine and report any alterations to the investigator. The experimental group received the CST program that consists of five core-related exercises performed four times per week for six weeks. The following five exercises were visually demonstrated and verbally instructed by the investigator after the pre-training test; (a) abdominal crunch on stability ball to target abdominal muscles (Appendix D), (b) back extension on stability ball to target back extensor muscles (Appendix D), (c) supine opposite 1-arm/1-leg raise to target back/hip extensor muscles (Appendix D), (d) hip raise on stability ball to target back/hip extensor muscles (Appendix D), and (e) Russian twist on stability ball to target abdominal muscles (Appendix D). These exercises were previously used in the past studies to determine the effects of CST (Cosio-Lima et al., 2003; Stanton et al., 2004). The exercises were relatively well-balanced targeting core muscles (abdominal, hip flexor/extensor, and back extensor muscles). Even though those exercises are at a relatively novice level according to Stanton et al. (2004), some exercises are considered as a challenge for those of who have no experience in CST. All exercises were fully instructed and demonstrated to ensure the understanding of the proper mechanics after the pre-treatment testing time by the investigator. In addition, the experimental group received a hard copy of exercise instructions including pictures and training log (Appendix E).

Stability balls were provided to the experimental group as the treatment is considered to be a home-based intervention. They were instructed to fill out the training log after each session and were also contacted by the investigator at the end of each week to ensure adherence or answer any concerns. Each CST session took approximately 20 to 30 minutes. The group performed each exercise for two sets of ten repetitions during the first two weeks of the treatment period. Then they performed each exercise for two sets of fifteen repetitions during the third and fourth weeks. Finally, they performed each exercise for three sets of twelve repetitions during the final two weeks of the treatment period. Approximately 30 to 60 second rest periods were permitted if desired. According to Cosio-Lima et al. (2003), the total session volume should increase to challenge strength improvement rather than performing the same volume throughout the treatment. Therefore, this study was designed to increase the volume of exercise sessions every two weeks.

Instrumentation

Sahrmann core stability test

The Sahrmann core stability test was used in a recent study to measure the level of core strength to identify the effect of Swiss ball training (Stanton et al., 2004). Their pilot data exhibited a reliability coefficient of .95 with a standard error of measurement of 7.7% for this test. This test requires a table for participants lying in a supine position, and a blood pressure cuff was placed in the natural curvature of the low back.

Star excursion balance test

The SEBT has been used in the clinical field to measure the functionality of the lower extremity (Cote, Brunet, & Gansneder, 2005; Gribble & Hertel, 2003; Gribble, Hertel, Denegar, & Buckley, 2004; Kinzey & Armstrong, 1998). Kinzey and Armstrong (1998) reported a reliability coefficient of .86 after a practice session. Olmstead et al. (2002) described that the SEBT is an economical, simple, and reliable instrument to measure the dynamic stability of lower body functionality. Pieces of tape were placed on the floor of the Biomechanics Laboratory to allow in eight directions. Four pieces of tape with a length of 152cm each were positioned so they bisected each other at 45 degree angles (see Figure 22). The distance from the point of intersection to the end of any piece of tape was 76cm.

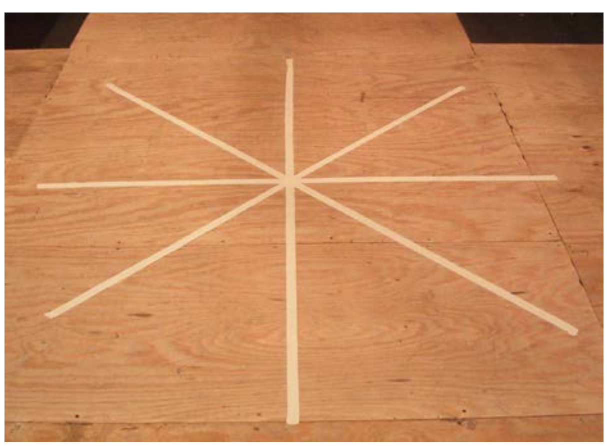


Figure 22 The layout of the star excursion balance test

Force plate

Ground reaction force (GRF) was measured by using the AMTI force plate (Advanced Mechanical Technologies, Inc., Watertown, MA) located in the floor of Barry University's Biomechanics Laboratory. The data was sampled at 600Hz. The force plate has been widely used and proven to be a reliable tool to identify the kinetic measurement such as three directions of GRFs (Bennell et al., 1999; Keller et al., 1996; White, Gilchrist, & Christina, 2002).

5000 m run

The 5000 m run was timed at accurately measured, selected local tracks in South Florida. Two stopwatches (Minute Man, Nike, Beaverton, OR; and Polar S410, Lake Success, NY) was used to record the time to the nearest second and the 5000m run time was recorded manually into each participant's testing chart.

Data Analysis

Ground reaction forces

The force plate was used to measure the following categories in this study: (a) peak impact vGRF (initial heel contact), (b) peak active vGRF (push-off phase), (c) duration of breaking hGRF, and (d) duration of propulsive hGRF (see Figure 23).

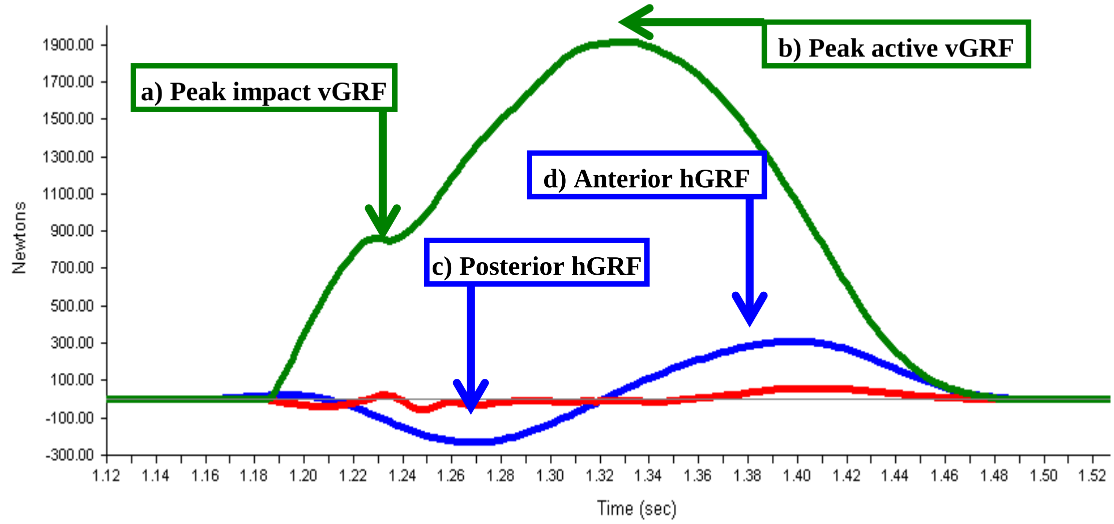


Figure 23 Kinetic variables of ground reaction forces.

All participants performed the test until normal running form and proper foot placement are captured. The Peak Motus software version 8.2 (ViconPeak, Centennial, CO) was used to compute the GRFs. The GRFs were normalized mathematically to each participant's BW for peak impact and active vGRFs (Newtons / 9.81m/s^2 / body weight). Duration of breaking hGRF and propulsive hGRF were standardized by percentage (e.g. total foot contact time = 0.30 seconds with 0.15 seconds of breaking hGRF and 0.15 seconds of propulsive hGRF; thus 50% & 50%). The GRFs were manually recorded in each participant's testing chart.

SEBT

The longest reaches in each direction were recorded during pre- and post-training tests. The length of reaches in all 3 directions (0, 90, & 180 degrees) from both feet were added and divided by the leg length (e.g. if a participant scores 20cm in front, 30cm in side, and 30cm in back is equal to a total of 80cm; divided by the leg length 80cm = 100%). According to the methods identified by Gribble et al. (2004), only 3 out of 8 directions were used in this study to reduce the chance of fatigue during the test. This procedure was suitable since the participants of this study had no familiarity with SEBT and an excessive number of trials could possibly cause fatigue during the test. The score of the SEBT was recorded manually in each participant's testing chart (Appendix F).

5000 m run

The 5000 m run were conducted only one time at each pre- and post-training test due to the maximal effort that all participants are expected to exert. The running time was recorded manually in minutes and seconds in each participant's testing chart.

Statistical Analysis

All dependent variables were input into Statistical Package for Social Sciences (SPSS) (SPSS Inc. Chicago, IL). SPSS has been a popular software to a variety of researches to organize and show statistical analysis (Thomas & Nelson, 2001). Six 2 x 2 (group by time) mixed design analysis of variance (ANOVA) with repeated measures were performed to determine any significant effect of CST on the dependent variables: (a) peak impact vGRF, (b) peak active vGRF, (c) duration of breaking hGRF, (d) duration of propulsive hGRF, (e) the scores of the SEBT, and (f) 5000m run time.

Significance was defined as $p < 0.05$.

CHAPTER IV

RESULTS

The purpose of the study was to determine the influence of core strength training (CST) on ground reaction forces (GRF), stability of the lower extremity, and run performance in recreational and competitive runners. The specific aim of this study was to determine how six weeks of core training would affect: (a) peak impact vertical GRF (vGRF), (b) peak active vGRF (c) duration of breaking horizontal GRF (hGRF), (d) duration of propulsive hGRF, (e) the level of the lower extremity stability measured by star excursion balance test (SEBT), and (f) 5000 meter (m) running time.

Summary of Results

A series of 2 X 2 (group and time) mixed-design analyses of variance (ANOVAs) were used to determine the effects of CST on running kinetics (four GRF variables), stability of lower extremity, and 5000m run time. In summary, CST had no significant influence on lower extremity stability scores measured by the SEBT or any aspects of the GRF variables (see Table 1). However, SEBT scores did improve more in the experimental group after the six weeks of training. Lastly, there was a significant interaction in 5000 m run time indicating that CST significantly improved running times in the experimental group after six weeks.

Table 1

Summary of the statistics on each variable

	Interaction	Main effect: time	Main effect: group
Peak impact vGRF	NS	NS	NS
Peak active vGRF	NS	NS	NS
Time in the breaking hGRF	NS	NS	*
Time in the propulsive hGRF	NS	NS	*
SEBT	NS	*	NS
5000 m run time	*		

Note. ***** denote significant difference, $p < .05$. NS denote not significant, $p > .05$.

Participants

Twenty-eight runners (men = 10, women = 18) volunteered to participate in this study (n_{con}=14, n_{exp}=14) and were all pre-tested. However, only 20 participants (men = 7, women = 13) completed the post-test (n_{con}=8, n_{exp}=12) due to scheduling issues (n = 4), unknown reasons (n = 3), or non-study related injury (n = 1). Demographic information for the 20 participants is shown in Table 2.

Table 2

Demographic information

	Experimental group n = 12	Control group n = 8
Age (yrs)	37.75 ± 10.63	39.25 ± 10.81
Height (m)	1.67 ± 0.10	1.67 ± 0.84
Weight (kg) *****	75.95 ± 16.89	63.03 ± 12.02
Average running pace ***** (min:sec)	10:45 ± 1:11	9:26 ± 0:47
Average weekly mileage (miles)	20.75 ± 6.66	23.75 ± 6.41
Sahrmann Core Stability Test (level)	1.54 ± 0.40	1.75 ± 0.38

Note: * denotes significant difference between the group, $p < .05$.
All were self-reported except weight and Sahrmann core stability test.

Ground reaction force (GRF) test

Peak impact vGRF

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group (exp, con) by time (pre, post) on peak impact vGRF. No significant interaction was found ($F(1,18)= 2.05$, $p>.05$). The main effect for time was not significant ($F(1,18)= 0.01$, $p>.05$), and the main effect for the group was not significant ($F(1,18) = 2.31$, $p>.05$). The peak impact vGRF was not influenced by the group or time (see Table 3).

Table 3

Peak impact vGRF for each group before and after time

	Experimental group n = 12	Control group n = 8
Pre-training	1.65 ± 0.38 BW	1.99 ± 0.38 BW
Post-training	1.74 ± 0.46 BW	1.89 ± 0.24 BW
Difference (pre - post)	+ 0.09	- 0.10

Peak active vGRF

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group (exp, con) by time (pre, post) on peak active vGRF. No significant interaction was found ($F(1,18)= 0.10$, $p>.05$). The main effect for time was not significant ($F(1,18)= 0.20$, $p>.05$), and the main effect for the group was not significant ($F(1,18) = 1.81$, $p>.05$). The peak active vGRF was not influenced by the group or time (see Table 4).

Table 4

Peak active vGRF for each group before and after time

	Experimental group n = 12	Control group n = 8
Pre-training	2.30 ± .36 BW	2.49 ± .26 BW
Post-training	2.31 ± .42 BW	2.52 ± .24 BW
Difference (pre - post)	+ 0.01	+ 0.03

Duration of the breaking hGRF

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group (exp, con) by time (pre, post) on the duration of the breaking hGRF. No significant interaction was found ($F(1,18)= .13$, $p>.05$). The main effect for time was not significant ($F(1,18)= 2.82$, $p>.05$). However, the main effect for group was significant ($F(1,18) = 5.16$, $p<.05$). The duration of the breaking hGRF was shorter in the experimental group regardless of six weeks of the training time (see Table 5).

Table 5

Duration of breaking hGRF for each group before and after time

	Experimental group n = 12	Control group n = 8
Pre-training	47.30 ± 5.91 %	53.11 ± 4.77 %
Post-training	49.33 ± 6.81 %	54.48 ± 4.76 %
Difference (pre - post)	+ 2.03	+ 1.37

(% as duration during a foot contact)

Duration of the propulsive hGRF

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group (exp, con) by time (pre, post) on the amount of time in the propulsive hGRF. No significant interaction was found ($F(1,18)= .16$, $p>.05$). The main effect for time was not significant ($F(1,18)= 2.61$, $p>.05$). However, the main effect for group was significant ($F(1,18) = 5.23$, $p<.05$). The duration of the propulsive hGRF was shorter in the control group regardless of six weeks of the training time (see Table 6).

Table 6

Duration of propulsive hGRF for each group before and after time

	Experimental group n = 12	Control group n = 8
Pre-training	52.70 ± 5.92 %	46.89 ± 4.77 %
Post-training	49.25 ± 6.70 %	45.52 ± 4.57 %
Difference (pre - post)	- 3.45	- 1.37

(% as duration during foot contact)

In present study, the propulsive hGRF was not analyzed. After normalizing the force to the body weight to be comparable between the groups, the number was relatively small and it did not seem important (see Table 7). The values were similar to the past study in flat-surface running (Gottschall & Kram, 2005).

Table 7

Peak propulsive hGRF for each group before and after time

	Experimental group n = 12	Control group n = 8
Pre-training	0.24 ± .02 BW	0.28 ± .01 BW
Post-training	0.27 ± .01 BW	0.26 ± .01 BW
Difference (pre – post)	+ 0.03	- 0.02

Additionally, while measuring the duration of hGRFs, it is important to note that the time of foot contact changed from pre-training GRF test to post-training GRF test (see Table 8).

Table 8

Time of foot contact for each group before and after time

	Experimental group n = 12	Control group n = 8
Pre-training	.293 ± .049 sec	.251 ± .039 sec
Post-training	.274 ± .051 sec	.242 ± .036 sec
Difference (pre - post)	- .019	- .009

Star Excursion Balance Test (SEBT) Scores

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group (exp, con) by time (pre, post) on SEBT scores. No significant interaction was found ($F(1,18)= 4.02$, $p>.05$). The main effect for time was significant ($F(1,18)= 30.59$, $p<.05$), and the main effect for the group was not significant ($F(1,18) = .23$, $p>.05$). SEBT scores increased in both groups over the 6 weeks (see Table 9).

Table 9

SEBT scores for each group before and after time

	Experimental group n = 12	Control group n = 8
Pre-training	198.75 ± 26.70 %	199.13 ± 26.34 %
Post-training	220.67 ± 26.90 %	209.38 ± 26.89 %
Difference (pre – post)	+ 21.92	+ 10.25

(% as a ratio of total reaching length / leg length)

5000 meter run time

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group (exp, con) by time (pre, post) on 5000 m run time. A significant interaction was found, (F(1,18)= 56.09, p<.05). Although the both groups displayed faster run time, the experimental group improved better than the control group (see Table 10).

Table 10

5000m run time for each group before and after time

	Experimental group N = 12	Control group n = 8
Pre-training	29:29 ± 2:38 min:sec	26:30 ± 1:59 min:sec
Post-training	28:42 ± 2:23 min:sec	26:13 ± 1:54 min:sec
Difference (pre – post)	- 0:47 (2.7% improvement)	- 0:17 (1.0% improvement)

CHAPTER V

DISCUSSION

Core strength training (CST) is believed to be an essential part of strength and conditioning training. However, limited scientific studies have been conducted to determine the effect of CST on core muscular strength, stability level of the lower extremity, and athletic performance (Cosio-Lima et al. 2003; Scibek et al. 2001; Stanton et al. 2004).

Running is a popular physical activity for people of all ages, and many runners train for optimal performance. Previous running related studies revealed biomechanical and physiological factors associating running activity to running related injuries, as well as how to prevent the injuries (Hreljac, 2004; Novacheck, 1998). However, no published studies exist investigating if a supplemental activity such as CST helps improve running performance. Therefore, it was necessary to analyze how CST affects running kinetics and performance. The purpose of this study was to determine the influence of CST on kinetic efficiency, stability, and performance in runners. It was expected that CST would positively influence running kinetics as measured by ground reaction forces (GRFs), stability of the lower extremity as measured by 1-leg star excursion balance test (SEBT), and 5000 meter (m) run time.

Summary of Findings

Six weeks of CST (four training sessions per week) were added to their normal running routine for those in the experimental group (n_{exp}). The control group (n_{con}) did not receive CST during the study period and continued their normal running activity. The following variables were measured before and after the training period, GRF variables: (a) peak impact vertical GRF (vGRF), (b) peak active vGRF, (c) duration of breaking horizontal GRF (hGRF), and (d) duration of propulsive hGRF, were used to measure running kinetics. The SEBT was used to measure the stability level of the lower extremity, and a 5000 m run was conducted to measure actual running performance.

1. The results did support the hypothesis that CST had positive affects on 5000 m run times. CST may have contributed to overall running performance.
2. The results did not support the hypotheses that training would affect the peak impact vGRF, the peak active vGRF, duration of breaking hGRF, duration of propulsive hGRF, and the SEBT score. CST did not significantly affect all kinetic variables and SEBT score. However, the SEBT scores did improve more in the experimental group after the six weeks of training.

Sahrmann core stability test

Core muscle strength was measured during a screening procedure to eliminate potential participants who possessed a high level of core strength. This procedure would ensure the potential for strength to be influenced by the CST. The group average showed that the control group scored slightly higher at the pre-training test (n_{con}: 1.75 $\pm$ 0.38 vs. n_{exp}: 1.54 $\pm$ 0.40). Previous studies have documented increases in core muscle strength with a similar workload. Thus, it was expected in this study to have similar improvements in our experimental group (Cosio-Lima et al., 2002; Stanton et al. 2004). Interestingly, both groups improved their Sahrmann score after six weeks. It is possible that a test-retest effect took place. This is a difficult test to perform, and although the primary investigator took every precaution to make sure the test was understood, this possibility cannot be overlooked. However, the experimental group did show a greater amount of improvement in their Sahrmann scores suggesting a possible positive effect from the CST (n_{exp}: 1.54 to 2.42; n_{con}: 1.75 to 1.94). The Sahrmann core stability test is a 5-scale test that determines the degree of stability a person possesses in the lumbar and pelvic region. If a person can perform level 1 and 2 (both feet are on the floor for support) but not level 3 (one foot comes off the floor), this indicates that a person cannot maintain his/her mid-section in an unsupported position (see Figure 15). Scoring high levels (level 4 and 5) in this test or improving through CST may explain that there is no or less excessive lumbar and pelvic movement, thus strong or better core musculature controls the lower extremity movements. This may lead to reduced unwanted movement such as postural sway or to better lower extremity control since a previous study has documented that near maximal running effort causes more body sway after the run (Pendergrass, Moore, & Gerber, 2003).

Vertical Ground Reaction Forces (vGRFs)

Peak impact vGRF

Peak impact vGRF is a commonly measured variable when studying the biomechanics of running (Derrick et al., 2000; Dixon et al., 2000; Gottschall & Kram, 2005; Hreljac, 2004; Keller et al., 1996; Williams et al., 2001). If the impact of the initial foot strike is too low (<1.5 BW), this could cause a high loading-rate relating to high active vGRF, but if it is too high (> 3.0BW), it could lead to over-use injuries by having high force of heel impact (Boyer & Nigg, 2004; Hreljac, 2004; Novacheck, 1998; Taunton et al., 2002). The normal range for initial foot strike is approximately 1.6 – 2.3BW based on previous studies with similar running velocities (Bus, 2005; Gottschall & Kram, 2005; Keller et al., 1996). In this study, the both groups were within the normal range of peak impact vGRF (n_{exp} = 1.65 and 1.74 BW; n_{con} = 1.99 and 1.89 BW). Even though the experimental group's number increased, it was not necessarily an excessive increase or outside the normal range. Therefore, the increase in the experimental group should not be a concern for potential over-use injuries based on the impact force. The experimental group increased peak impact vGRF (1.65 ± 0.38 to 1.74 ± 0.46 BW) after the training. In relation to the results of 5000m run time, the experimental group improved their time by an average of 47 sec. This faster running velocity at the post-training GRF test is somewhat understandable.

On the other hand, the control group decreased peak impact vGRF (1.99 ± 0.38 to 1.89 ± 0.24 BW) on average. In the control group, average running velocity for the post-training GRF test increased by 16 sec per mile pace as compared to the pre-training GRF test (0.09m/s faster). Since there was no manipulation given to the group, the possible indication of their decrement for the peak impact vGRF was from the self-consciousness of running mechanics during the six weeks, or during the post-training GRF testing. Since this type of training study in the field of running is limited, the explanation of this result (decrease in the peak impact vGRF even though the running velocity was faster when no treatment was given) is unknown.

As far as the relationship between the differences in running velocities (n_{exp} = 2.71m/s vs. n_{con} = 3.04m/s), it is understandable that the control group displayed slightly higher overall vGRFs (Hreljac, 2004; Novacheck, 1998). The GRF data for both groups were potentially affected by inconsistent running velocities between pre- and post-training GRF tests (n_{exp}: pre-test 2.64m/s, post-test 2.81m/s; n_{con}: pre-test 2.99m/s, post-test, 3.08m/s) as one of the limitations of this study. Faster running velocity correlates with higher peak impact vGRF due to the harder initial foot contact

(Gottschall & Kram, 2005; Keller et al., 1996). Even though all participants in the present study were instructed to run across the force plate at the same speed and as natural as possible (both during pre and post GRF tests), many participants, especially in the experimental group ran faster during the post-training GRF test. Since the running velocity increase may have caused the peak impact vGRF increase (average 0.17m/s faster and it is approximately 44 seconds per mile faster in the experimental group), it may be improper to compare our results of the kinetic variables to those from past studies that controlled running velocity by using a treadmill (Gottschall & Kram, 2005; Keller et al., 1996). We chose not to use a treadmill since treadmill running biomechanics have been found to differ from ground running biomechanics (Gottschall & Kram, 2005; Keller et al., 1996). Further control of running velocity may be required to get accurate GRF data to compare pre-and post-training data.

Peak active vGRF

The peak active vGRF is also a common variable being analyzed in running studies (Derrick et al., 2000; Dixon et al., 2000; Gottschall & Kram, 2005; Hreljac, 2004; Keller et al., 1996; Williams et al., 2001). This variable was measured to analyze the push-off force during the contact phase. Excessive amounts of the vertical active force are considered a negative effect for runners since it places high pressure on the mid- and fore-foot. The suggested peak active vGRF range is 2 to 3 BW according to previous studies using relatively similar running velocity (Hreljac, 2004; Novacheck, 1998; Taunton et al., 2002). If this force is too low, it can be interpreted that a runner is not producing enough force to propel forward, but t excessive force may lead to over-use injuries (Hreljac, 2004; Novacheck, 1998). In this study, the peak active vGRF was within the average range according to Novacheck (1998) for all participants.

The results showed that the peak active vGRF did not change significantly before and after the training period for both groups (see Table 4). It is questionable to state that CST may have been played a major role in this result for the experimental group. The purpose of incorporating CST was to increase core muscle strength to obtain better movement control especially in the lower extremity to optimize running kinetics. At the same time, the result may be a good indication for the experimental group that their average 5000 m run time improved while peak active vGRF did not change. Even though the hypothesis was to increase push-off force (from better body control) by performing core exercises, CST may have a role on this finding of consistent peak active vGRF, but improved 5000 m run time.

Horizontal Ground Reaction Forces (hGRFs)

The duration of breaking hGRF

When a foot lands in front of the center of gravity while running (which often happens during downhill running and at faster running velocities), it leads to a longer duration and higher force of breaking hGRF because the lower extremity becomes stiffer kinematically to accept the greater foot impact (Gottschall & Kram, 2005). Reducing the duration of breaking hGRF would help carry forward momentum. Therefore, it was necessary to determine if CST would positively affect this variable to reduce the duration. Gottschall and Kram (2005) reported that the ideal duration of breaking hGRF is approximately 50% or slightly lower for flat-surface running, but both groups in the present study showed slightly higher percentage of the variable after six weeks (see Table 5). Based on the statistics, there was no significant effect of CST in the experimental group (see Table 1). This may indicate that CST has no effect on the duration of breaking hGRF. However, if the running velocity were controlled for the both groups, the results may have been different.

The duration of propulsive hGRF

This variable is related to the duration of breaking hGRF since propulsive hGRF is a percentage of foot contact time. Increasing the duration of propulsive hGRF would help runners to carry momentum forward, becoming more economical in their running in kinesiological terms (Gottschall & Kram, 2005). A past study reported that the ideal duration of propulsive hGRF is approximately 50% or slightly longer for flat-surface running (Gottschall & Kram, 2005). Both groups in the current study slightly decreased the duration of propulsive hGRF after six weeks (n_{exp}: - 3.45%; n_{con}: -1.37%). As mentioned above, the outcome may not be influenced by CST. There was no significant effect of CST in the experimental group (see Table 1). It is unclear that how much or if the CST influenced the duration of propulsive hGRF in the experimental group.

By analyzing the total duration of hGRFs, the both groups ran in shorter time of foot contact at the post-training GRF test (n_{exp} = -.019 sec; n_{con} = -.009 sec). This may relate to the faster running velocity at the time of the post-training GRF test as compared to the pre-training GRF test. However, this data did not affect any aspect of hGRF data. The hGRFs were not analyzed since the numbers and the changes were relatively small (see Table 7). The values were similar to the past study in flat-surface running (Gottschall & Kram, 2005).

Star Excursion Balance Test (SEBT)

In this study, stability level of the lower extremity was measured with the SEBT. Even though there is no evidence relating to having good balance and stability on athletic performance, better stability of the lower extremity is believed among health and fitness professionals to be extremely important (Gribble et al., 2004). Better balance and stability also helps prevent potential injuries in a daily living. If CST improves stability of the lower extremity, CST may be appropriate to incorporate into training or rehabilitation program. The SEBT scores improved in the both groups possibly because of the test-retest effects; this may be the reason why there was no significant interaction effect for group by time. However, the experimental group improved the average SEBT score more than the control group (n_{exp}: +21.92cm; n_{con}: +10.25cm). Regardless of the non-significant outcome, this improved SEBT score is a sign of improvement in dynamic stability for the experimental group. However, it is unknown whether this improvement actually helps runners run faster or prevent potential running-related injuries; a more stable lower extremity should provide better and consistent movement control.

The SEBT score gain in the both groups may also relate to the gain they experienced in Sahrmann core stability test (n_{exp} improved from 1.54 to 2.42; n_{con} improved from 1.75 to 1.94). Since this test has 5 levels, the results showed that the experimental group improved approximately 1 level in average, while the control group stayed at same level. It is apparent that CST improved strength in core muscles, and may also have contributed to improved lower extremity dynamic stability for the experimental group.

5000 meter run

Despite the fact that many sport scientists look for causes or patterns leading to running-related injuries or typical kinetics and kinematics of running, many runners are primarily interested in superior performance. Many runners exert maximal effort at their races. Often they think that they can do better at next one. This also applies to recreational runners who want to run longer distances after some period of training.

Runners are also interested in every possible way to improve running performance such as purchasing lighter shoes and apparel, trying effective and the famous training plan, new running mechanics, and consuming endurance supplements. CST is certainly a possible way for any type of runner to optimize overall running efficiency. That is the reason why it is important to study CST to determine the effect on running performance. 5000 m run was conducted for performance analysis. It is one of the most popular distances for participating in local races (Taunton et al., 2002).

The results showed significant improvement in the experimental group after the training period (the average of 47 sec faster time, and it is 2.7% improvement), while the control group also improved run time by the average of 17 sec (1.0% improvement). This explains that the experimental group showed almost two and half times greater improvement than the control group. CST may certainly be one of the factors improving the running time. Based on the qualitative feedback from the participants in the experimental group, some were aware of body alignment as well as utilizing the core muscles to stabilize the running form.

While all the other tests were done in an indoor laboratory setting, the 5000 m run was timed at local outdoor tracks. Thus, it is important to note that the there were climate differences at the time of the 5000 m run tests. During the pre-training run test, the temperature was the average of 86.08 $\pm$ 2.01° Fahrenheit with average of 64% humidity, as compared to the average of 73.33 $\pm$ 6.61° Fahrenheit and 58% humidity during the post-training run test. Climate change can influence physiological response such as sweat rate and fatigue level. The improvement in the run time for both groups may have been affected by the weather conditions between the two tests. Although the experimental group was significantly heavier in the average of body mass (see Table 1), they improved the average 5000 m run time by 2.7%, as compared to the control group (improved by 1.0%). Even though the weather condition affected both groups equally, the experimental group showed better improvement, which may be the results from performing CST.

Also, this study period fell within the middle of the marathon training period, participants' weekly mileage increased by approximately 10 – 20% from the screening day. The longer distance in total weekly mileage may have influenced their ability to run faster at the post-training 5000 m run test. As mentioned earlier, past studies revealed many critical answers for better running performance. It is certainly a key to control running environment and training as much as possible to identify the effect of a single variable such as CST.

Although any kinetic or kinematic data were not analyzed during the 5000 m run test, some factors influenced the faster running time in both groups and specifically in the experimental group. The investigator further analyzed the time of foot contact during the both pre- and post- training GRF tests, and the results showed that the both groups displayed shorter time of foot contact (which may have contributed to faster stride frequency or stride length). Furthermore, the experimental group averaged .019 sec shorter time of foot contact in the post-training GRF test. The results may have related to the overall faster 5000 m run time, although it is important to note that 5000 m run test was performed at maximum effort while the GRF tests were done at self-selected running pace. Therefore, the relationship between the faster 5000 m run time and the time of foot contact remains unclear.

Lastly, the past studies showed that performing CST showed no significant improvement in athletic performance, this study showed the significant improvement in 5000 m run time by performing CST (Scibek et al., 2001; Stanton et al., 2004). The workload of CST in the present study was four times per week for six weeks as compared to the past study, which was two times per week for six weeks. The higher workload may have contributed to the improvement of the run time.

Feedback from Participants

As mentioned earlier, some participants in the experimental group qualitatively reported that the CST raised the awareness of being in an upright posture in daily living (walking and sitting). Posture was not assessed in this study, but the postural awareness may have influenced the positioning of the upper extremity and mid-section in some participants during the training period and post-training tests. Needless to say, psychological effects played a major role in changing athletic performance. The CST may have caused some participants to pay attention to better posture during the study.

During the screening period, average body weight was higher in the experimental group (see Table 1), and many of them lost body weight during the training period (average -1.94kg). This may be due to the higher volume of training in both running (longer weekly mileage) and CST (sets and repetitions increased every two weeks). It is important to comment that weight loss for some participants many have played a major role in the faster times during post-training test.

Study Limitations

Since running performance can be analyzed as a compound of many factors, there were some limitations in this study.

1. Group difference: As mentioned earlier, the group was not divided based on equality in performance level. Based on the independent T-test, significant differences were shown in baseline body weight and typical running pace (see Table 1). Additionally, even though it was not significant, the control group had a longer average weekly mileage and better score in Sahrmann core stability test score. Lastly, the control group displayed a faster running velocity during the pre and post GRF tests. It is thus, safe to say that the

control group had better runners. These facts probably affected the overall outcome of the study.

2. Running velocity: Even though all participants were instructed to run across the force plate at a similar speed during the pre and post GRF tests, the average running velocity during the post-training GRF test was faster than for the pre-training GRF test, especially in the experimental group (n_{exp}: pre-test = 2.64m/s, post-test = 2.81m/s; n_{con}: pre-test = 2.99m/s, post-test = 3.08m/s). This increase is approximately 6% for the experimental group and 3% for the control group. This may have affected the outcome of the kinetic variables before and after the training period.
3. Weather condition: 5000m run was timed at outdoor tracks. The pre-training run test was taken during September and the post-training run test was taken during November. The dissimilar weather conditions may have been a limitation in this study since cooler weather with less humidity is more comfortable to run long distance.
4. Normal running activity: Since this study was conducted during the marathon training period to attract experienced runners to participate in this study, weekly mileage increased during the course of six weeks in both groups. This may possibly affect running mechanics (as body started to adapt to the longer run), and this factor may have affected GRF test results.

Conclusions

Within the limitations of this study, the following conclusions can be addressed:

- Six weeks of CST did not affect the kinetic variables significantly. Even though the results did not agree with the research hypotheses, the peak impact vGRF did not increase to a dangerous level. The peak active vGRF did not change, while running performance (and velocity) improved. The duration of the hGRF did not show any significant effects from performing CST. If the running velocity was controlled during the GRF tests, these kinetic results may have been different.
- The statistical analyses showed no significant interactions potentially based on the nature of test-retest procedure on SEBT. However, six weeks of CST increased the SEBT score in the experimental group greater than the control group (twice the improvement of the control group).
- Six weeks of CST may have affected the running performance (time improved two and half times the improvement of the control group).
- Even though the Sahrmann core stability test was not statistically measured, the experimental group moved up a level while the control group stayed at same level.
- Considering the comments from the participants in the experimental group, CST can raise the awareness of being in an upright position during running activity and even in daily living.

- Despite the fact that many sport scientists look for causes and patterns leading to running-related injuries or typical kinetics and kinematics of running, runners are primarily interested in superior performance. Running is a sport that many participants including recreational level challenge their maximal effort, and they often think that they can do better at next one. Based on the results of this study, CST is recommended improve core muscular strength, increase lower extremity control, and raise awareness of how to run in a good posture.

Recommendations for Further Study

Based on the results of this study, the following recommendations can be made:

- Lengthen the training duration (up to 1 year) to observe the long-term effects of CST throughout the season. In addition, the volume of the CST can be modified by the certain periodization. Workload can be changed by the season (off, pre, and on). Then analyze how runners would response to the workload.
- Assess kinematics such as postural positioning.
- Matching the physical characteristics would be a key to have more reliable outcome in this study.
- Control running velocity to be similar individually during pre-and post-training tests.

- This type of study can be focused on not only on athletes, but also on the general population, children, sedentary population, and people with pain relating to postural alignment.

REFERENCES

Adrian, J. M., & Cooper, M., J. (1995). Biomechanics of human movement. Dubuque, IA: Brown & Benchmark.

Alison, G. T., Godfey, P., & Robinson, G. (1998). EMG signal amplitude assessment during abdominal bracing and hollowing. *Journal of Electromyography and Kinesiology*, *8,* 51–57.

Anderson, T. (1996). Biomechanics and running economy. *Sports Medicine*, *22*(2)*,* 76–89.

Andrews, J. R., & Fleisig, G. S. (1998). Preventing throwing injuries. *Journal of Orthopaedic and Sports Physical Therapy*, *27*, 187–188.

Baechle, T. R., & Earle, P. W. (Eds.). (2000). *Essential of strength training and conditioning* (2nd ed.). Champaign, IL: Human Kinetics.

Baitch, S. P., Blake, R. L., Finegan, P. L., & Senatore, J. (1991). Biomechanical analysis of running with 25 degree inverted orthotic devices. *Journal of American Podiatric Association*, *81,* 647–652.

Bates, B. T., Ostering, L. R., Mason, B., & James, L. S. (1979). Foot orthotic devices to modify selected aspects of lower extremity mechanics. *American Journal of Sports Medicine*, *7*, 338–342.

Bellchamber, T. L., & Van Den Bogert, A. J. (2000). Contributions of proximal and distal moments to axial tibial rotation during walking and running. *Journal of Biomechanics, 33,* 1397–1403.

Bennell, K., Crossley, K., Wrigley, T., & Nitschke, J. (1999). Test-retest reliability of selected ground reaction force parameters and their symmetry during running. *Journal of Applied Biomechanics, 15,* 330–336.

Boyer, K. A., & Nigg, B. M. (2004). Muscle activity in the leg is tuned in response to impact force characteristics. *Journal of Biomechanics, 37,* 1583–1588.

Brittenham, D., & Brittenham, G. (1997). *Stronger abs and back.* Champaign, IL: Human Kinetics.

Brown, L. E., Ferrigno, V. A., & Santana, J. C. (2000). *Training for speed, agility, and quickness.* Champaign, IL: Human Kinetics.

Bus, S. A. (2003). Ground reaction forces and kinematics in distance running in older-aged men. *Medicine & Science in Sports & Exercise, 35*(7), 1167–1175.

Clark, M. A. (2001). *Integrated training for the new millennium.* Thousand Oaks, CA: National Academy of Sports Medicine.

Cosio-Lima, L. M., Reynolds, K. L., Winter, C., Paolone, V., & Jones, M. T. (2003). Effects of physioball and conventional floor exercises on early phase adaptations in back and abdominal core stability and balance in women. *Journal of Strength and Conditioning Research, 17*(4), 721–725.

Cote, K. P., Brunet, M. E., & Gansneder, B. M. (2005). Effects of pronated and supinated foot postures on static and dynamic postural stability. *Journal of Athletic Training, 40*(1), 41–46.

DeLeo, A. T., Dierks, T. A., Ferber, R., & McClay-Davis, I. S. (2004). Lower extremity joint coupling during running: a current update. *Clinical Biomechanics, 19,* 983–991.

DeMont, R. G., & Lephart, S. M. (2004). Effect of sex on preactivation of the gastrocnemius and hamstring muscles. *British Journal of Sports Medicine, 38,* 120–124.

Derrick, T. R., Caldwell, G. E., & Hamill, J. (2000). Modeling the stiffness characteristics of the human body while running with various stride length. *Journal of Applied Biomechanics, 16,* 36–51.

Dib, M. Y., Smith, J., Bernhardt, K. A., Kaufman, K. R. & Miles, K. A. (2005). Effect of environmental temperature on shock absorption properties of running shoes. *Clinical Journal of Sports Medicine, 15*(3), 172–176.

Divert, C., Mornieux, G., Baur, H., Mayer, F., & Belli, A. (2005). Mechanical comparison of barefoot and shod running. *International Journal of Sports Medicine, 26*(7), 593–598.

Dixon, S. J., Collop, A. C., & Batt, M. E. (2000). Surface effects on ground reaction forces and lower extremity kinematics in running. *Medicine & Science in Sports & Exercise*, *32*(11), 1919–1926.

Earl, J., (2002). *Relationship among dynamic malalignment, neuromuscular rehabilitation, and patellofemoral pain syndrome*. Unpublished doctoral dissertation, Pennsylvania State University, University Park, Pennsylvania, USA.

Ferber, R., McClay-Davis, I., & Williams, D. S. (2003). Gender differences in lower extremity mechanics during running. *Clinical Biomechanics, 18,* 350–357.

Giladi, M., Milgrom, C., & Stein, M. (1985). The low arch a protective factor in stress fractures. *Orthopedic Reviews, 14*, 709–712.

Gottschall, J. S., & Kram, R. (2005). Ground reaction forces during downhill and uphill running. *Journal of Biomechanics*, *38,* 445–452.

Gribble, P. H. & Hertel, J. (2003). Considerations for normalizing measures of the star excursion balance test. *Measurement in physical education and exercise science, 7*(2), 89–100.

Gribble, P. H., Hertel, J., Denegar, C. R., & Buckley, W. E. (2004). The effects of fatigue and chronic ankle instability on dynamic postural control. *Journal of Athletic Training*, *39*(4), 321–329.

Hamill, J., Bates, B. T., & Holt, K. G. (1992). Timing of lower extremity joint actions during treadmill running. *Medicine & Science in Sports & Exercise*, *24*(7), 807–813.

Hardin, E. C., Van Den Bogert, A. J., & Hamill, J. (2004). Kinematic adaptations during running: effects of footwear, surface, and duration. *Medicine & Science in Sports & Exercise, 36*(5), 838–844.

Heiderscheit, B. C., Hamill, J., & Caldwell, G. E. (2000). Influence of Q-angle on lower-extremity running kinematics. *Journal of Orthopaedic Sports Physical Therapy*, *30*(5), 271–278.

Hertel, J., Miller, S., & Deneger, C. (2000). Intratester and intertester reliability during the Star Excursion Balance Test. *Journal of Sport Rehabilitation*, *9*(2), 104–116.

Hreljac, A. (2004). Impact and overuse injuries in runners. *Medicine & Science in Sports & Exercise*, *36*(5), 845–849.

Hreljac, A., & Stergiou, N. (2000). Phase determination during normal running using kinematic data. *Medical & Biological Engineering & Computing*, *38*(5), 503–506.

Keller, T. S., Weisberger, A. M., Ray, J. L., Hasan, S. S., Shiavi, R. G., Spengler, D. M. (1996). Relationship between vertical ground reaction force and speed during walking, slow jogging, and running. *Clinical Biomechanics*, *11*, 253–259.

Kerdok, A. E., Andrew, A., Biewener, T. A., McMahon, T. A., Weyand, P. G., & Herr, H. M. (2002). Energetics and mechanics of human running on surfaces of different stiffness. *Journal of Applied Physiology*, *92,* 469–478.

Kerr, B. A., Beauchamp, L., Fisher, V., & Neil, R. (1983). Foot strike patterns in distance running. *Biomechanical aspects of sport shoes and playing surfaces*. University of Calgary.

Kinzey, S. J. & Armstrong, C. W. (1998). The reliability of the star-excursion test in assessing dynamic balance. *Journal of Orthopaedic and Sports Physical Therapy, 27*(5), 356–360.

Kurz, M. & Stergiou, N. (2004). Does footwear affect ankle coordination strategies? *Journal of American Podiatry Medical Association*, *94*(1), 53–58.

Leetun, D. H., Ireland, M. L., Wilson, J. D., Ballantyne, B. T., & McClay-Davis, I. (2004). Core stability measures as risk factors for lower extremity injury in athletes. *Medicine and Science in Sports and Exercise, 36*(6), 926–934.

Li, L., & Hamill, J. (2002). Characteristics of the vertical ground reaction force component prior to gait transition. *Research Quarterly for Exercise and Sport*, *73*(3), 229–237.

Lun, V., Meeuwisse, W. H., Stergiou, P., & Stefanyshyn, D. (2004). Relation between running injury & static lower limp alignment in recreational runners. *British Journal of Sports Medicine, 38,* 576–580.

Mann, R. A., & Hagy, J. (1980). Biomechanics of walking, running, and sprinting. *American Journal of Sports Medicine*, *8*(5), 345–350.

Medical College of Wisconsin (1999, May). Health articles: Iliotibial band syndrome. Retrieved February 18, 2005, http://healthlink.mcw.edu/article/926050036.html

Mercer, J. A., Bates, B. T., Dufek, J. F., & Hreljac, A. (2003). Characteristics of shock attenuation during fatigued running. *Journal of Sports Sciences*, *21*, 911 – 919.

Miller, J. (2001). *Biomechanical analysis of the anterior balance reach test*. Unpublished doctoral dissertation, Pennsylvania State University, University Park, Pennsylvania, USA.

Nadler, S. F., Malanga, G. A., Bartoli, L. A., Feinberg, J. H., Prybicien, M., & Deprince, M. (2002). Hip muscle imbalance and low back pain in athletes: influence of core strengthening. *Medicine and Science in Sports and Exercise*, *34*(1), 9–16.

Novacheck, T. F. (1998). The biomechanics of running. *Gait and Posture*, *7*, 77–95.

Oakley, T., & Pratt, D. J. (1988). Skeletal transients during heel and toe strike running and the effectiveness of some materials in their attenuation. *Clinical Biomechanics*, *3*, 159–165.

O’Connor, K. M., & Hamill, J. (2004). The role of selected extrinsic foot muscles during running. *Clinical Biomechanics*, *19*(1), 71–77.

Olmsted, L. C., Carcia, C. R., Hertel, J., & Shultz, S. J. (2002). Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *Journal of Athletic Training*, *37*(4), 501–506.

Ounpuu, S. (1990). The biomechanics of running: a kinematic and kinetic analysis. *American Academy of Orthopaedic Surgeons*, *39*, 305–318.

Pendergrass, T. L., Moore, J. H., & Gerber, J. P. (2003). Postural control after a 2-mile run. *Military Medicine*, *168*(11), 896–903.

Perry, S. D., & Lafortune, M. A. (1995). Influences of inversion/eversion of the foot upon impact loading during locomotion. *Clinical Biomechanics*, *10*(5), 253–257.

Pribut, S., & Richie, D. (2004, October 1). Separating the buzz from the biomechanics: A guide to athletic shoe trends and innovations. *Podiatry Management.* Retrieved January 23, 2005, from http://www.drpribut.com/sports/pributrichie-run-1004.pdf

Robertson, G. E., Caldwell, G. E., Hamill, J., Kamen, G., & Whittlesey, S. N. (2004). *Research methods in biomechanics*. Champaign, IL: Human Kinetics.

Santana, J. C. (2000a). Maximum running speed: Great marketing, limited application. *Strength and Conditioning Journal*, *22*(5), 31–32.

Santana, J. C. (2000b). *The essence of stability ball training companion guide.* Boca Raton, FL: Optimum Performance Systems.

Scibek, J. S., Guskiewicz, K. M., Prentice, W. E., Mays, S., & Davis, J. M. (2001). *The effects of core stabilization training on functional performance in swimming*.

Unpublished master's thesis, University of North Carolina, Chapel Hill, North Carolina, USA.

Smith, L. S., Clarke, T. E., Hamill, C. L., & Santopietro, F. (1986). The effects of soft and semi-rigid orthoses upon rearfoot movement in running. *Podiatric Sports Medicine*, *4*, 227–233.

Stackhouse, C. L., McClay-Davis, I., & Hamill, J. (2004). Orthotic intervention in forefoot and rearfoot strike running pattern. *Clinical Biomechanics*, *19*, 64–70.

Stanton, R., Reaburn, P. R., & Humphries, B. (2004). The effects of short-term swiss ball training on core stability and running economy. *Journal of Strength and Conditioning Research*, *18*(3), 522–528.

Taunton, J. E., Ryan, M. B., Clement, D. B., McKenzie, D. C., Lloyd-Smith, D. R., & Zumbo, B. D. (2002). A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine*, *36*, 95–101.

Thomas, J., & Nelson, J. (2001). *Research methods in physical activity* (3rd ed.). Champaign, IL: Human Kinetics.

U. S. National Library of Medicine and the National Institute of Health (2004). Medical Encyclopedia. Retrieved February 18, 2005, from http://www.nlm.nih.gov/medlineplus/encyclopedia.html

Van Gheluwe, B., Kerwin, D., Roosen, P. & Tielemans, R. (1999). The influence of heel fit on rearfoot motion in running shoes. *Journal of Applied Biomechanics*, *15,* 361–372.

Verdejo, R. & Mills, N. J. (2004). Heel-shoe interactions and the durability of EVA foam running-shoe midsole. *Journal of Biomechanics*, *37,* 1379–1386.

Wen, D. Y., Puffer, J. C., & Schmalzried, T. P. (1997). Lower extremity alignment & risk of overuse injuries in runners. *Medicine & Science in Sports & Exercise*, *29*(10), 1291–1298.

White, S. C., Gilchrist, L. A., & Christina, K. A. (2002). Within-day accommodation effects on vertical reaction forces for treadmill running. *Journal of Applied Biomechanics*, *18,* 74–82.

Whiting, W. C., & Zernicke, R. F. (1998). Biomechanics of musculoskeletal injury. Champaign, IL: Human Kinetics.

Wilk, B. R., & Valdez, M. M. (2002). Running shoes wear out before they stop working. *American Journal of Sports Medicine*, *4*(6), 459-460.

Williams, D. S., McClay, I. S., & Manal, K. T. (2000). Lower extremity mechanics in runners with a converted forefoot strike pattern. *Journal of Applied Biomechanics*, *16,* 210–218.

Williams, D. S., McClay, I. S., & Hamill, J. (2001). Arch structure and injury patterns in runners. *Clinical Biomechanics*, *16,* 341–347.

Williams, D. S., McClay, I. S., Sholz, J. P., Hamill, J., & Buchanan, T. S. (2004). High-arched runners exhibit increased leg stiffness compared to low-arched runners. *Gait and Posture*, *19*, 263–269.

APPENDICES

Appendix A

Recruiting Flyers

Study Participants Needed
For Core Training Study for Runners

1) Are you currently injury-free?
2) Do you run at least 15 miles per week?
3) Do you want to strengthen your core muscles to possibly improve your running?

If you answered "*Yes*" to all of the above, you may qualify for an important study assessing the effect of core training to improve running performance!

BARRY UNIVERSITY · MIAMI · 1940 · FLORIDA

Biomechanics Laboratory

Free Biomechanical Analysis

Contact Kimi
(804) 986-7204 or
ksato@mail.barry.edu

Study Participants Needed
For Core Training Study for Runners

1) Are you currently injury-free?
2) Do you run at least 15 miles per week?
3) Do you want to strengthen your core muscles to possibly improve your running?

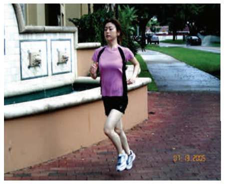
If you answered "*Yes*" to all of the above, you may qualify for an important study assessing the effect of core training to improve running performance!

BARRY UNIVERSITY · MIAMI · 1940 · FLORIDA

Biomechanics Laboratory

Free Biomechanical Analysis

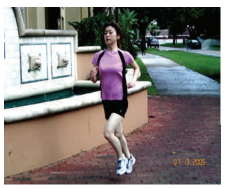
Contact Kimi
(804) 986-7204 or
ksato@mail.barry.edu



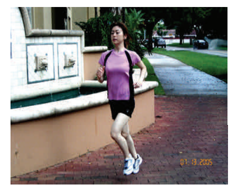
Study Participants Needed
For Core Training Study for Runners
1) Are you currently injury-free?
2) Do you run at least 15 miles per week?
3) Do you want to strengthen your core muscles to possibly improve your running?
If you answered "Yes" to all of the above, you may qualify for an important study assessing the effect of core training to improve running performance!
BARRY UNIVERSITY · MIAMI · 1940 · FLORIDA
Biomechanics Laboratory
Free Biomechanical Analysis
Contact Kimi
(804) 986-7204 or
ksato@mail.barry.edu



Study Participants Needed
For Core Training Study for Runners
1) Are you currently injury-free?
2) Do you run at least 15 miles per week?
3) Do you want to strengthen your core muscles to possibly improve your running?
If you answered "Yes" to all of the above, you may qualify for an important study assessing the effect of core training to improve running performance!
BARRY UNIVERSITY · MIAMI · 1940 · FLORIDA
Biomechanics Laboratory
Free Biomechanical Analysis
Contact Kimi
(804) 986-7204 or
ksato@mail.barry.edu



Study Participants Needed
For Core Training Study for Runners
1) Are you currently injury-free?
2) Do you run at least 15 miles per week?
3) Do you want to strengthen your core muscles to possibly improve your running?
If you answered "Yes" to all of the above, you may qualify for an important study assessing the effect of core training to improve running performance!
BARRY UNIVERSITY · MIAMI · 1940 · FLORIDA
Biomechanics Laboratory
Free Biomechanical Analysis
Contact Kimi
(804) 986-7204 or
ksato@mail.barry.edu



Appendix B

Screening Questionnaires

Screening Questionnaires: Participant #: _______

Height: ________ / ______cm Weight: _________ / _______kg

Sex: Male Female Age: ____________

Do you currently engage in weight training / core strength training as a supplemental workout for your running?

YES NO

If yes, how often? _________time / week

If no, have you ever done weight training or core strength training? YES NO

If yes, how long ago? ____________

What kind of running shoes do you prefer for most of your running?

Brand: __________ Name: ________ (if you know).

Do you consider the shoes as (please circle): motion control stability cushioning?

What is your typical steady running pace? __________min. / mile

What is your typical weekly mileage? __________miles / week

If you have ever experienced or diagnosed following running-related injuries, please circle

IT band syndrome
(side of your thigh near the knee joint)

Piriformis syndrome
(deep inside of your buttocks)

Hip flexor pain

Patellofemoral pain (Runners' knee)

Shin splints

Stress fracture

Plantar fasciitis

Others: _______________

Surgery required for any? Yes No

Sahrmann core stability test:

Level: _______________

Appendix C

Informed Consent Form

Barry University
Informed Consent Form

Does core strength training influence running kinetics,
lower extremity stability, and 5000m performance in runners?

You are invited to participate in a research study being conducted by Kimi Sato, a graduate student in the Department of Sport and Exercise Sciences at Barry University, who is seeking information that will be useful in the field of biomechanics, in particular running biomechanics. The specific aim of the study is to determine whether 6-weeks of core strength training can enhance ground reaction forces, stability of the lower extremity, and overall running performance in runners. We expect 30 participants (15 runners in a control group and 15 runners in an experimental group).

If you decide to participate in this research, you will be asked to be present for approximately 30 minutes of laboratory testing and up to 60 minutes of 5000m run test at pre- and post- treatment tests. In accordance with the study's aim, you will be asked to be involved in the following procedures:

All testing will take place in the Barry University Biomechanics Laboratory in the Health and Sports complex in Miami Shores, and selected accurately measured outdoor tracks in Broward / Miami-Dade counties. You will be asked to wear your running shoes, socks, shorts, and T-shirt or tank top at both testing sites.

First, you will be asked to measure your force during ground contact. You will warm-up for at least one mile on a preset route around the Barry University athletic fields in order to reach your comfort zone of running speed. At the end of the one mile, you will then run into the Biomechanics Laboratory through its main door and continue running across a force plate (a force plate is a device set flush with the floor that allows us to measure your force at contact with the ground). You are encouraged to keep your pace and not focus on or target the force plate. It is possible that you may miss the plate all together. If this occurs, you will be asked to try again running out the second door of the lab and repeating your entrance until an accurate but natural placement by the right foot is achieved. At the completion of this test, you will be asked to warm down for ¼ to ½ mile and return to the laboratory.

Upon a completion of force measurement, then you will be asked to complete the Star Excursion Balance Test (SEBT), a test of stability in a standing position. Prior to the SEBT, you will be asked to have the length of your leg measured. A tape measure will be placed on a point on your hip to a point on your ankle. This measure is necessary in order to determine a ratio that involves your leg length and your total reaching length of your leg during the SEBT. During the SEBT, you will place your left foot on the center of a straight line. Then, you will reach your toes of the leg you are not standing on (right foot) as far as possible to the directions of 0 (straight out in front), 90 (to the side), and 180 (to the back) degree lines while maintaining balance. Then, you will switch to your right foot and follow the same sequence. You will get 2 trials on each foot to reach your toes to the guided directions. You will also be given a demonstration by Kimi Sato in how to perform this test prior to testing.

Within five days of the laboratory testing, you will be asked to meet with Kimi

Sato at a local track to measure your 5000m run time. You will warm-up like you normally do prior to running. Then, you will run 5000m and be timed by Kimi Sato. The accurately measured track is 400m per lap; thus, you will run 12.5 laps to complete a total of 5000m distance. At the completion of this test, you will be asked to warm down for ½ mile.

If you are randomly assigned to the control group, you will not receive the core strength training (CST) protocol, and will be instructed to maintain your already existing training routine and report any alternations to the investigator. If you are selected to be in an experimental group, you will be asked to perform 5 core strength exercises for 4 times per week for 6 weeks. The following five exercises will be visually demonstrated and verbally instructed by Kimi Sato after the pre-treatment testing time: a) Abdominal crunch on stability ball, b) Back extension on stability ball, c) Supine opposite 1-arm / 1-leg raise, d) Hip raise on stability ball, and e) Russian twist on stability ball. You will receive stability ball as it is considered to be a home training. In addition, you will receive a hard copy of exercise instructions including pictures and training log. You will be asked to fill out the training log after each session and you will be also contacted by Kimi Sato at the end of each week to ensure the progress or answer any concern. Each CST session will take approximately 20 to 30 minutes. You are allowed to take 30 to 60 seconds of rest periods will be provided if desired. You will also increase the volume of the session by every two weeks in order to progress your strength level.

After the treatment period, both groups will be asked to report back to Biomechanics Laboratory to repeat the same testing procedures as well as 5000m run time at the same location.

Your participation is voluntary and you may withdraw at any time without prejudice. The testing is under the direction of Kimi Sato and Dr. Monique Butcher Mokha, but other persons may assist with treatment session and data collection.

You may benefit from participating in this study by learning your own stability score which can provide you information in determining your exercise plan. Indirectly, your participation may benefit coaches and sports medicine professionals in determining the relationship of stability and forces at ground contact in runners since high forces have been associated with increased risk for injury in runners.

The risks of participating in this study are minimal and include muscle soreness and injury from performing the running or stability test. To minimize this risk, you will be asked to warm up, including stretching, prior to performance. Additionally, demonstration will accompany all tests, and the preset running route will be examined for any hazards that could lead to injury. There is also the risk of self-consciousness because of being videotaped. To minimize this risk, only Kimi Sato, Dr. Butcher Mokha, and qualified research assistants will have access to the data.

As a research participant, information you provide will be held in confidence to the extent permitted by law. Any published results of the research will refer to group averages only and no names will be used in this study, and data will be kept in a locked file. Your signed consent form will be kept separate from the data. All data and videotapes will be destroyed after five years.

If you have any questions or concerns regarding the study or your participation in the study, you may contact me, Kimi Sato, at (804)986-7204, or my supervisor, Dr.

Monique Butcher Mokha at (305)899-3064, or the Institutional Review Board point of contact, Mrs. Nildy Polanco, at (305) 899-3020. If you are satisfied with the information provided and are willing to participate in this research, please check “yes” and signify your consent by signing this consent form.

Voluntary Consent

I acknowledge that I have been informed of the nature and purposes of this experiment by Kimi Sato and that I have read and understand the information presented above, and that I have received a copy of this form for my records. I give my voluntary consent to participate in this experiment.

_______ Yes, I would like to participate in the study.

_______ No, I do NOT want to participate in the study.

______________________ __________

Signature of Participant Date

______________________ __________

Researcher Date

Name (print): ______________________________

Email: ___________________________

TEL: ______________________________

Appendix D

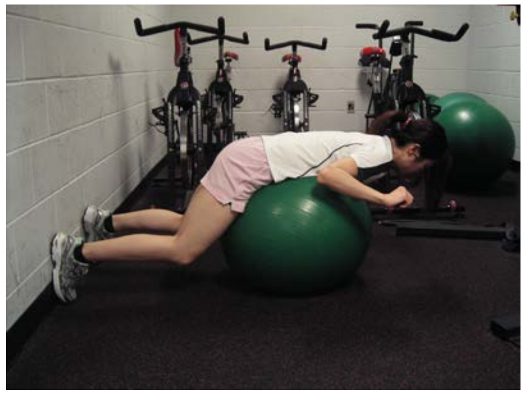
Core Strength Exercises

Abdominal crunch on stability ball

Starting position of abdominal crunch on stability ball

Finishing position of abdominal crunch on stability ball

Back extension on stability ball



Starting position of back extension on stability ball

Finishing position of back extension on stability ball

Supine opposite 1-arm /1-leg raise

Starting position of supine opposite 1-arm/1-leg raise

Finishing position of supine opposite 1-arm/1-leg raise

Hip raise on stability ball

Starting position of hip raise on stability ball

Finishing position of hip raise on stability ball

Russian twist on stability ball

Starting position of Russian twist on stability ball

Finishing position of Russian twist on stability ball

Appendix E

Exercise Instruction and Training Log

Training Instruction:

Before you begin Core Strength Training:

1) 5 -10 minutes of stretching or cardio exercise to warm up your body first.
2) Be sure to read the instruction of each exercise until you totally feel comfortable performing.
3) You may contact me if you feel like you are not performing the exercise in proper way.
   ksato@mail.barry.edu or 804-986-7204.

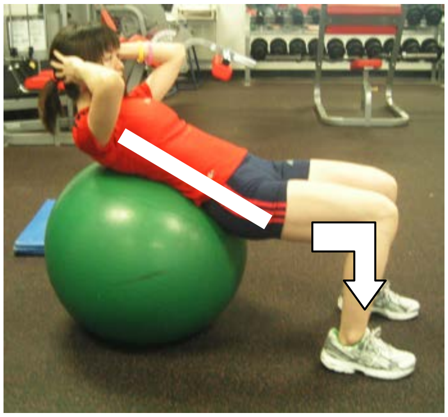
While performing the exercises:

1) Be sure to breath-out during exertion phase and breath-in during downward phase.
2) Relax your neck muscles. No exercises are listed to develop tension in neck area.

After the Core Strength Training session:

1) DO NOT forget to hydrate your body (at least 20 oz of water or sports drink during a session).
2) Cool down by performing light stretching in your abdominal/back area.
3) Fill out the "Training Chart"

1) Abdominal Crunch on Stability Ball



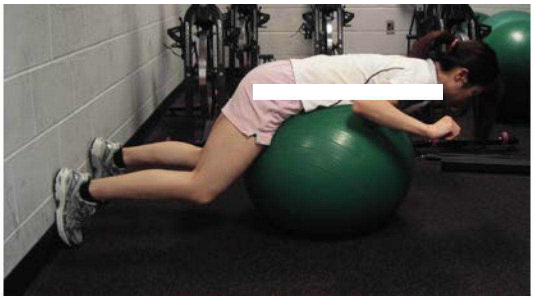
Starting position of abdominal crunch on stability ball

Finishing position of abdominal crunch on stability ball

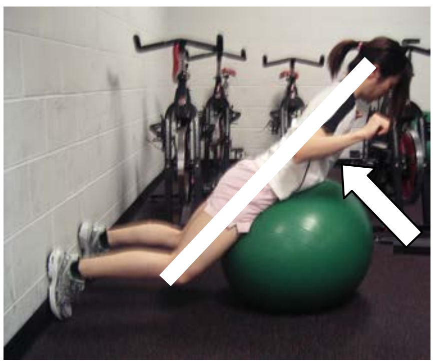
Instruction:

1) Sit on the ball.
2) Walk your way down until your knee is about 90 degree angles.
3) Your back should be on the stability ball (see picture on upper left).
4) Hands are back of your head.
5) Keep your chin in as you come up.
6) Your shoulders and upper back should be off the ball at finishing position (see picture on lower left).
7) Then, return to the starting position as you lower your shoulders.

2) Back Extension on Stability Ball



Starting position of back extension on stability ball



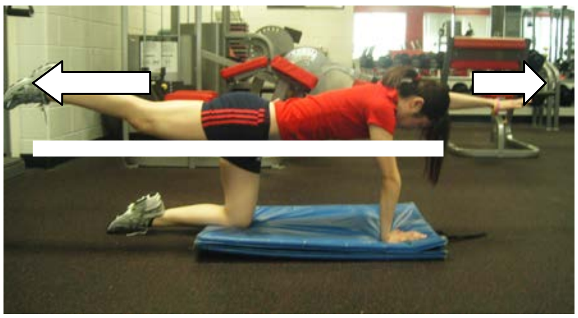
Finishing position of back extension on stability ball

Instruction:

1) Both feet should be against stationary object.
2) Lying on stability ball in supine position (see picture on upper left).
3) Keep your arms on your side.
4) Raise your upper body by squeezing your low back and glutes (see pictures on lower left).
5) Keep your chin in as you come up.
6) Then, return to the starting position as you lower your upper body.

3) Supine Opposite 1-arm/1-leg Raise

Starting position of supine opposite 1-arm/1-leg raise

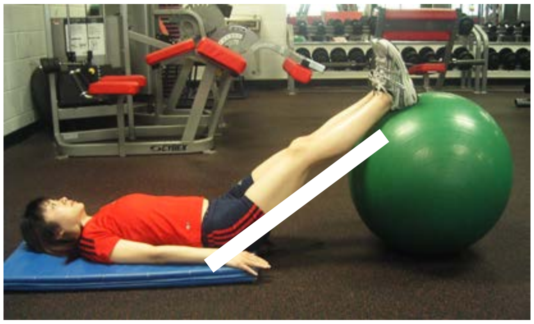


Finishing position of supine opposite 1-arm/1-leg raise

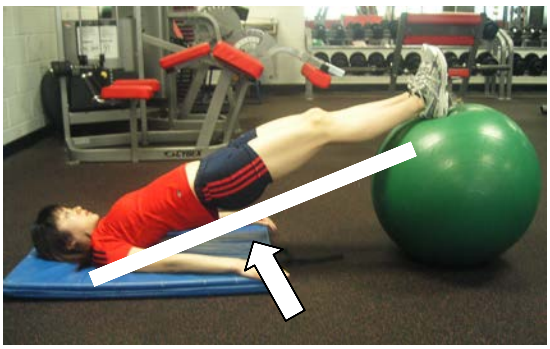
Instruction:

1) Knees and hands are on the floor.
2) Keep your back flat (see picture on upper left).
3) Raise your left arm and right leg at the same time (see picture on lower left).
4) Be sure to keep it static for at least 1 second.
5) Then, return to the starting position.
6) Do opposite in the same sequence.

4) Hip Raise on Stability Ball



Starting position of hip raise on stability ball



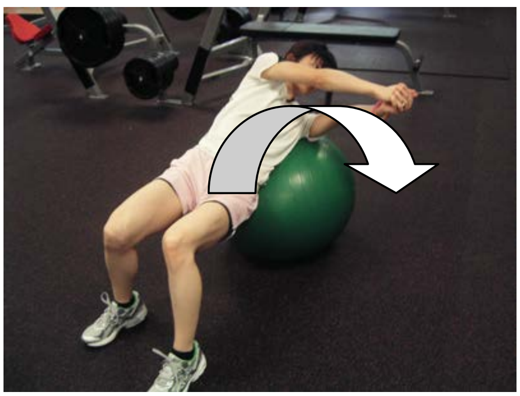
Finishing position of hip raise on stability ball

Instruction:

1) Lying on floor and feet on stability ball.
2) Arms are on your sides (see picture on upper left).
3) Squeeze your glutes and low back to lift your lower body.
4) Be sure to hold for 1 second to balance in the position (see picture on lower left).
5) Then, return to the starting position as you lower your lower body.

5) Russian Twist on Stability Ball

Starting position of Russian twist on stability ball



Finishing position of Russian twist on stability ball

Instruction:

1) Sit on the ball.
2) Walk your way down until your knee is about 90 degree angles.
3) Your back should be on the stability ball.
4) Hands are out in front of you.
5) Twist your body without moving your feet (see picture on upper left).
6) Then, twist to the other side while feet are a static position (see picture on lower left).
7) Twist your body side to side.

Training Chart: NAME: ________________________

Week 1 & 2: 2 sets of 10 repetitions

Name of exercises	Week 1 Day 1	Week 1 Day 2	Week 1 Day 3	Week 1 Day 4	Week 2 Day 1	Week 2 Day 2	Week 2 Day 3	Week 2 Day 4
Ab crunch on stability ball								
Back extension on stability ball								
Supine opposite 1-arm/1-leg raise								
Hip raise on stability ball								
Russian twist on stability ball								

Week 3 & 4: 2 sets of 15 repetitions

Name of exercises	Week 3 Day 1	Week 3 Day 2	Week 3 Day 3	Week 3 Day 4	Week 4 Day 1	Week 4 Day 2	Week 4 Day 3	Week 4 Day 4
Ab crunch on stability ball								
Back extension on stability ball								
Supine opposite 1-arm/1-leg raise								
Hip raise on stability ball								
Russian twist on stability ball								

Week 5 & 6: 3 sets of 12 repetitions

Name of exercises	Week 5 Day 1	Week 5 Day 2	Week 5 Day 3	Week 5 Day 4	Week 6 Day 1	Week 6 Day 2	Week 6 Day 3	Week 6 Day 4
Ab crunch on stability ball								
Back extension on stability ball								
Supine opposite 1-arm/1-leg raise								
Hip raise on stability ball								
Russian twist on stability ball								

Instructions:

1) Please fill in the boxes after you performed exercises.
2) The training can be done two or three consecutive days depending on your time availability, but not four consecutive days.
3) If you have any question, please check the “Exercise Instruction” paper or contact me at (804)986-7204 or ksato@mail.barry.edu

Appendix F

Testing Chart

Testing Chart

Pre-training: Body Weight: ________Kg

Post-training: Body Weight: ________Kg

Leg length measurement:

R: __________cm L: __________cm = Total: (R + L / 2) = ____________cm

The results of Star Excursion Balance Test (SEBT):

	0 degree	90 degrees	180 degrees	Total
Pre-training	R_____L_____	R_____L_____	R_____L_____	_____
		_________________% (% = Total SEBT length / Average leg length)		
Post-training	R_____L_____	R_____L_____	R_____L_____	_____
		_________________%		

The results of ground reaction force (GRF) test (Left Foot contact only):

Pre-training Test	Peak vertical impact force _____ Newton = _____BW	Peak vertical active force _____ Newton = _____ BW
	Horizontal breaking force _____ Duration (sec) = _____%	Horizontal propulsive force _____ Duration (sec) = _____ %
Post-training Test	Peak vertical impact force _____ Newton = _____BW	Peak vertical active force _____ Newton = _____ BW
	Horizontal breaking force _____ Duration (sec) = _____%	Horizontal propulsive force _____ Duration (sec) = _____ %

5K run time:

Pre-training (min:sec): ____:____

Post-training (min:sec): ____:____

Appendix G

Manuscript

Journal of Strength and Conditioning Research Format

Does core strength training influence running kinetics,

lower extremity stability, and 5000m performance in runners?

Biomechanics Laboratory
Department of sport and exercise sciences
Barry University
Miami Shores, FL 33161

Kimitake Sato

Monique Mokha

Department of Sport and Exercise Sciences
Barry University
Miami Shores, FL 33161

Corresponding Author:

Kimitake Sato, MS, CSCS, PES
Department of Sport & Exercise Sciences
Barry University
11300 NE 2nd Avenue, Miami Shores, FL 33161
Phone: 804-986-7204
Fax: 305-899-4809
Email: jpnsatok@hotmail.com

Does core strength training influence running kinetics,

lower extremity stability, and 5000m performance in runners?

ABSTRACT

Although strong core muscles are believed to help athletic performance, only few scientific studies have been conducted to identify the effectiveness of core strength training (CST) on improving athletic performance. The aim of this study was to determine the effects of 6-week CST on ground reaction forces (GRFs), stability of the lower extremity, and overall running performance in recreational and competitive runners. After a screening process, 28 healthy adults (age, 36.9$\pm$9.4yrs, height, 168.4$\pm$9.6cm, mass, 70.1$\pm$15.3kg) volunteered and randomly divided into two groups (n=14 in each group). A test-retest design was used to assess the differences between CST (experimental) and no CST (control) on GRF measures, lower extremity stability scores, and running performance. GRF variables were determined by calculating peak impact vertical GRF (vGRF), peak active vGRF, duration of the breaking horizontal GRF (hGRF), and duration of the propulsive hGRF as measured while running across a force plate. Lower extremity stability in three directions (anterior, posterior, lateral) was assessed using the Star Excursion Balance Test (SEBT). Running performance was determined by 5000 meter (m) run times measured on an outdoor track. Six 2 (pre, post) x 2 (CST, control) mixed-design ANOVA was used to determine the influence of CST on each dependent variable, $p<.05$. As 20 participants completed the study (n_{exp}=12 and n_{con}=8), no significant interactions were found for any of the variables except 5000m run, $p>.05$. CST did not significantly influence kinetic variables and lower leg stability.

KEY WORDS: core exercise, stability, running performance,

INTRODUCTION

Core strength training (CST) is widely practiced by professionals with the goals of enhancing core stability and increasing core muscular strength, thereby improving athletic performance. It is believed that in order to improve athletic performance and prevent risk of injury, CST is one of the vital components in the strength and conditioning field. 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. Limited scientific studies have been conducted to determine the effect of CST on lower extremity muscular strength and athletic performance in sport such as running and swimming (1, 2, & 3). Significant improvement in core strength have been documented as a result of CST (1, 2, & 3). However, these same researches failed to find significant changes in the lower extremity strength, mechanics, or performance from CST. This type of research indicates that CST is a useful tool for strengthening core muscles, but the carryover to performance needs further investigation.

In a biomechanical analysis of running, abnormal range of vertical ground reaction forces (vGRFs) and horizontal GRFs (hGRFs) have been associated with the overuse injuries (4, 5, & 6). Aging, lack of joint stability, muscle weakness, harder running surfaces, downhill running, and high arches are found to be indications of increasing impact vGRFs as well (4, 5, 7, 8, & 9).

Insert Figure 1 about here

Adequate stability in the lower extremity may have an important role keeping the vGRF and hGRF within normal range, since poor stability may be linked to injuries in both athletic fields and a daily living. As previous lower extremity injuries such as ankle sprain or overuse injuries often contribute to create muscular imbalance and poor proprioception, proper rehabilitation is needed to regain stability (10).

The purpose of this study was to determine the effects of 6-weeks of CST on ground reaction force, stability of the lower extremity, and overall running performance in recreational and competitive runners. We hypothesized that CST would have the following positive influences; (a) decrease peak impact vGRF, (b) increase peak active vGRF, (c) decrease the amount of time in breaking hGRF, (d) increase the amount of time in propulsive hGRF (e) increase Star Excursion Balance Test (SEBT) scores, and (f) decrease 5000meter (m) run time.

METHODS

Experimental Approach to the Problem

Subjects

Twenty-eight recreational and competitive rear-foot strike runners (10 males, 18 females) volunteered for this study (age, 36.9±9.4yrs, height, 168.4±9.6cm, mass, 70.1±15.3kg). They had no injuries at the time of data collection. They answered specific questions regarding their training strategies, pace, past injury history, and type of footwear used to identify their running background. The participants were then randomly divided to two group; control (n = 14) and experimental (n = 14).

The purpose of screening core stability prior to accepting participants was to eliminate potential participants who already possess a level III, or better score (scale from level I - V); only one participant scored level III thus the potential participant was omitted from the study. The procedure of this test follows that of Stanton et al. (3). Their pilot data exhibited a reliability coefficient of .95 with a standard error of measurement of 7.7% for this test. By assessing the core stability level, 28 qualified participants possessed level I or level II core muscle strength prior to begin the initial test.

Instrumentation

Force plate

An AMTI force plate (Advanced Medical Technologies, Inc., Watertown, MA) was used (sampled at 600 Hz) to measure peak impact vGRF, peak active vGRF, breaking hGRF, and propulsive hGRF. The Peak Motus software (ver. 8.2, ViconPeak, Centennial, CO) was used to reduce the data with Fast Fourier Analysis. The GRFs were normalized mathematically to each participant's BW for peak impact and active vGRFs (Newtons / 9.81m/s^2 / body weight = BW). Duration of breaking hGRF and propulsive hGRF were standardized by percentage (e.g. total foot contact time @ 0.30 seconds = 0.15 seconds of breaking hGRF and 0.15 seconds of propulsive hGRF; thus 50% & 50%).

Star Excursion

The SEBT has been used in the clinical field to measure the functionality of the lower extremity (11, 12, 13, & 14). Olmstead et al. (10) described that the SEBT is an economical, simple, and reliable instrument to measure the dynamic stability of lower body functionality. Kinzey and Armstrong (14) reported a reliability coefficient of .86 after a practice session. Tapes were placed in eight directions bisecting each other at 45 degree angles on the floor of the Laboratory.

Insert Figure 2 about here

According to the methods used by Gribble et al. (13), only 3 out of 8 directions were used in this study to reduce the chance of fatigue during the test. The length of reaches in all 3 directions (0, 90, & 180 degrees) from both feet were added and divided by the leg length (e.g. if a participant scores 20cm in front, 30cm in side, and 30cm in back from both feet is equal to a total of 160cm; divided by the average leg length of 80cm = 200%).

Procedures

GRF Test

All qualified participants reported to the Laboratory and selected outdoor tracks for testing on two occasions: (a) pre-training, and (b) 6 weeks post-training. Tests for running kinetics, lower extremity stability, and running performance were performed identically at both sessions.

A reflective marker was placed on the lateral part of the left shoe to measure running velocity calculated by Peak Motus software version 8.2 (ViconPeak, Centennial, CO). One camera was positioned on the left side of the force plate perpendicularly to track the reflective marker. Participants were instructed to contact the force plate with their left foot. Bennell, Crossley, Wrigley, and Nitschke (15) showed that the GRFs from left and right foot during running strongly correlated (.73 to .96); thus, only left foot kinetics were measured. They warmed-up by running at self-selected pace outdoor, then returned to the Laboratory to run across the force plate.

Insert Figure 3 about here

This test simulated a real running situation; thus, if the participant reached the force plate with abnormal steps such as shuffling to achieve proper foot placement, the trial was repeated.

SEBT

Prior to the SEBT, the investigator measured all participants' leg length in order to calculate a ratio of a total score of the SEBT and leg length (total length / leg length = score of the SEBT) (12). Leg length was measured from medial malleolus to anterior superior iliac spine (ASIS) of each leg in centimeter (cm) by a tape measure, and the averaged if there is leg length discrepancy. This ensured the accuracy of performance among participants to analyze the level of lower extremity stability. The barefoot condition was required to eliminate extra balance and stability from the shoes during the test (12). First, all participants placed their left foot on the center of a 0 – 180 degree line. Then the participants reached out their toes as far as possible to the direction of 0, 90, and 180 degree lines while maintaining balance. Then, participants switched to their right foot and follow the same sequence. Kinzey and Armstrong's (14) recommended that the instruction and demonstration improved the reliability of the test (from .67

to .87) along with practice sessions prior to the test; thus, adequate amount of practice time was also provided.

In order to maximize the reliability of the measurement, the following detailed instructions were given identically to all participants: (a) placing the foot on the line with medial part of the stable foot while reaching laterally (90 degrees); (b) placing toes of the stable foot aligned on the line for the forward reach (0 degrees); and (c) placing the heel of the stable foot on the line for the backward reach (180 degrees).

Insert Figure 4, 5, & 6 about here

Participants lightly touched the maximum reaching point while being in a static position for at least three seconds to ensure their ability to stabilize their bodies (12). Each participant received two trials in each condition to reach their toes to the guided directions. The length between the toes of the reaching foot and the starting position of the stable foot were measured manually with a tape measure (12).

5000m run test

A 5000m run was done at accurately measured outdoor tracks. Due to the time availability of each participant, the 5000m run was done on a separate day.

However, the 5000m run was performed within seven days of the laboratory testing date (SEBT & GRF test) before and after the training period.
After adequate amount of warm-up including jogging and stretching, 5000m run was timed. The accurately measured track is 400m per lap; thus, all participants ran 12.5 laps to complete a total distance of 5000m. Upon the completion of this trial, the 5000m run time was recorded in minutes and seconds (e.g., 5000m = 19 minutes 43 seconds). In addition, temperature and humidity level were also recorded during all participants' running trials.

Core strength training (CST)

The control group did not receive CST protocol, and were instructed to maintain his/her training routine and report any alterations to the investigator. The experimental group received the CST program that consists of five core-related exercises performed four times per week for six weeks. The following five exercises were visually demonstrated and verbally instructed by the investigator after the pre-training test; (a) abdominal crunch on stability ball to target abdominal muscles, (b) back extension on stability ball to target back extensor muscles, (c) supine opposite 1-arm/1-leg raise to target back/hip extensor muscles, (d) hip raise on stability ball to target back/hip extensor muscles, and (e) Russian twist on stability ball to target abdominal muscles. These exercises were previously used in the past studies to determine the effects of CST (1 & 3). The exercises are relatively well-balanced targeting core muscles (abdominal, hip flexor/extensor, & back extensor muscles). Even though those exercises are relatively novice level according to Stanton et al. (3), some exercises are considered as a challenge for those of who have no experience in CST, but all exercises were fully instructed and demonstrated to ensure the understanding of the proper mechanics after the pre-training laboratory test by the investigator. In addition, the experimental group received a hard copy of exercise instructions including pictures and training log.

Stability balls were provided to the experimental group as the treatment is considered to be a home training. They were instructed to fill out the training log after each session and were also contacted by the investigator at the end of each week to ensure adherence or answer any concerns. The group performed each exercise for two sets of ten repetitions during the first two weeks of the treatment period. Then they performed each exercise for two sets of fifteen repetitions during the third and fourth week. Finally, they performed each exercise for three sets of twelve repetitions during the final two weeks of treatment period. According to Cosio-Lima et al. (1), a total session volume should increase to challenge strength improvement rather than performing the same volume throughout the treatment. Therefore, this study was designed to increase the volume of exercise sessions every two weeks.

Statistical Analysis

All dependent variables were input into Statistical Package for Social Sciences (SPSS) (SPSS Inc. Chicago, IL). Six 2 x 2 (group by time) mixed-design analysis of variance (ANOVA) with repeated measures were performed to determine any significant effect of CST on the dependent variables. Significance was defined as $p < .05$.

RESULTS

CST had no significant influence on lower extremity stability scores measured by the SEBT, or any aspects of the GRF variables (see Table 1). There was a significant interaction in 5000m run time indicating that CST significantly improved running times in the experimental group over six weeks. Although SEBT score was shown significant, the number did improve more in the experimental group over the six weeks of training (+ 11.67 cm better improvement than the control group).

Insert Table 1 about here

Participants

As 28 runners performed pre-training test, 20 participants completed the post-test (n_{con}=8, n_{exp}=12). Demographic information for the 20 participants is shown in Table 2. Based on the independent T-test, weight and average running pace showed difference between the groups (see Table 2).

Insert Table 2 about here

Ground reaction force (GRF) test

Peak impact vGRF

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group (exp, con) by time (pre, post) on peak impact vGRF. No significant interaction was found, ($F(1,18) = 2.05$, $p > .05$). The main effect for training was not significant ($F(1,18) = 0.01$, $p > .05$), and the main effect for the group was not significant ($F(1,18) = 2.31$, $p > .05$). The peak impact vGRF was not influenced by the group or time (see Table 3).

Peak active vGRF

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group by time on peak active vGRF. No significant interaction was found, ($F(1,18) = 0.10$, $p > .05$). The main effect for training was not significant ($F(1,18) = 0.20$, $p > .05$), and the main effect for the group was not significant ($F(1,18) = 1.81$, $p > .05$). The peak active vGRF was not influenced by the group or training (see Table 4).

Duration of the breaking hGRF

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group by time on the duration of the breaking hGRF. No significant interaction was found, ($F(1,18) = .13$, $p > .05$). The main effect for training was not significant ($F(1,18) = 2.82$, $p > .05$). However, the main effect for group was significant ($F(1,18) = 5.16$, *p*<.05). The amount of time in the breaking hGRF was smaller in the experimental group regardless of six weeks of the training time (see Table 5).

Duration of the propulsive hGRF

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group by time on the amount of time in the propulsive hGRF. No significant interaction was found, ($F(1,18) = .16$, $p > .05$). The main effect for training was not significant ($F(1,18) = 2.61$, $p > .05$). However, the main effect for group was significant ($F(1,18) = 5.23$, $p < .05$). The amount of time in the propulsive hGRF was smaller in the control group regardless of six weeks of the training time (see Table 6).

Star excursion balance test (SEBT) scores

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group by time on SEBT scores. No significant interaction was found, ($F(1,18) = 4.02$, $p > .05$). The main effect for training was significant ($F(1,18) = 30.59$, $p < .05$), and the main effect for the group was not significant ($F(1,18) = .23$, $p > .05$). SEBT scores increased in both groups over the 6 weeks (see Table 7).

5000 meter run time

A 2 X 2 mixed-design ANOVA was calculated to examine the effects of group by time on 5000m run time. A significant interaction was found, ($F(1,18)= 56.09$, $p<.05$) (see Table 8).

Insert Tables 4, 5, 6, 7, & 8 about here

DISCUSSION

The purpose of this study was to determine the influence of CST on running kinetics, stability of the lower extremity, and performance in runners. It was expected that CST would positively influence on running kinetics, stability of the lower extremity, and 5000 meter (m) run time.

GRF tests

Peak impact vGRF

Peak impact vGRF is commonly measured variable in the biomechanics of running (5, 6, 7, & 16). If the impact of the initial foot strike is too low (<1.5 BW), this could cause a high loading rate relating to high active vGRF, but if it is too high (> 3.0BW), it could lead to over-use injuries by having high force of heel impact (6, 9, & 16). Normal range is found approximately 1.6 – 2.3BW based on the previous studies with similar running velocities (5 & 16). In this study, the both groups showed the average of relatively in a normal range of peak impact vGRF (n_{exp} = 1.65 & 1.74BW; n_{con} = 1.99 & 1.89BW). Even though the experimental group's number increased, it was not necessarily an excessive increase or range. Therefore, the increase in the experimental group should not be concerned for potential over-use injuries based on the impact force.

The GRF data for both groups were potentially affected by inconsistent running velocity between pre- and post-training GRF tests (n_{exp}: pre-test 2.64m/s, post-test 2.81m/s; n $_{con}$: pre-test 2.99m/s, post-test, 3.08m/s) as one of the limitations of this study. Faster running velocity correlates with higher peak impact vGRF due to the harder initial foot contact (5 & 16). Even though all participants were instructed to run across the force plate at the same speed and as natural as possible (both in pre and post), many participants, especially in the experimental group ran faster at the post-training GRF test.

Peak active vGRF

The peak active vGRF is also a common variable being analyzed in running studies (5, 6, 7, & 16). This variable was chosen to be measured to analyze the force of the push-off during the contact phase. Excessive amount of this force is considered negative effect to runners by putting high pressure to mid- and fore-foot (6 & 16). Suggested range is from 2 to 3BW according to the previous studies in relatively similar running velocity (6, 9, & 16). If this force is too low, it can be interpreted that a runner is not producing enough force to propel forward, but the excessive force would lead to over-use injuries (5 & 16). In this study, the peak active vGRF was within the average range for all participants according to Novacheck (16).

The results showed that the peak active vGRF did not change significantly before and after the training period in the both groups (see Table 4). It is questionable to state that CST may have been the major role of this result for the experimental group. The purpose of incorporating CST was to increase core muscle strength to obtain better movement control, especially in the lower extremity to optimize running kinetics. At the same time, the result may be a good indication for the experimental group that their average 5000m run time improved while peak active vGRF did not change. Even though the hypothesis was to increase the push-off force by performing core exercises, CST may have a role on this no change in peak active vGRF, but improved 5000m run time.

The duration of breaking hGRF

When a foot lands in front of the body while running (which often happens at downhill running and faster running velocity), it leads to longer duration and higher force of breaking hGRF because the body becomes stiffer kinematically to accept greater foot impact (5). Reducing the duration of breaking hGRF would help carrying forward momentum. Therefore, it was necessary to determine if CST would positively affect (reducing the duration) this variable. Gottschall and Kram (5) reported that ideal duration of breaking hGRF is approximately 50% or slightly lower, but both groups showed slightly higher percentage of the variable after six weeks (see Table 5). Based on the statistical analysis, there was no significant effect of CST in the experimental group (see Table 1). This may explain that CST has no effect on the duration of breaking hGRF. However, if the running velocity were controlled in the both groups, the results may have been a different outcome.

The duration of propulsive hGRF

This variable is well related to the duration of breaking hGRF since the value was shown in the percentage of the time of the foot contact. Increasing the duration of propulsive hGRF would help runners to carry forward momentum, becoming more economical running in kinesiology term (5 & 16). That is why this variable was measured to see if there is any effect from CST. A past study reported that ideal duration of propulsive hGRF is approximately 50% or slightly longer (5). The both groups slightly decreased the duration of propulsive hGRF after six weeks (n_{exp}: - 3.45%; n_{con}: -1.37%). As mentioned above, the outcome may not show any effect from performing CST. There was no significant effect of CST in the experimental group (see Table 1). It is unclear that how much the CST influence the duration of propulsive hGRF in the experimental group.

Lower Extremity Stability

In this study, stability of level of the lower extremity was measured. Even though there is no evidence of the effectiveness of having good balance and stability to athletic performance, better stability of the lower extremity is believed among health and fitness professionals that it is extremely important to athletic performance as well as a daily living to prevent potential injuries (13). It is necessary to analyze if CST would improve stability level in dynamic movement based on the SEBT. If CST helps improving stability of the lower extremity, CST should be incorporated into training or rehabilitation program. The SEBT scores improved in the both groups because of the possible test-retest effects, which may be the reason why the interaction effects were not significant. However, the experimental group improved the SEBT score better than the control group (n_{exp}: +21.92cm; n_{con}: +10.25cm). Regardless of the non-significant outcome, better SEBT score is a sign of improvement in dynamic stability for the experimental group. Even though it is unknown that this improvement actually helps runners run faster or prevent potential running-related injuries, more stable lower extremity should provide better and consistent movement control.

The SEBT score gain in the experimental group may also relate to the gain that they experienced in Sahrmann core stability test (n_{exp} improved from 1.54 to 2.42; n_{con} improved from 1.75 to 1.94). It is apparent that CST improved strength in the core muscles, and may also have improved lower extremity dynamic stability.

5000 meter run

Many sport scientists seek causes or patterns leading to running-related injuries or typical kinetics and kinematics of running; however, runners are primarily interested in superior performance. Running is a sport that many participants exert maximal effort at races. And they often think that they can do better at next one. This even applies to recreational runners who want to run longer distance after some periods of training. There is no ending in peak performance.

Runners are interested in every possible ways to improve running performance such as purchasing lighter shoes and apparel, trying a famous training plan, changing running mechanics, and taking endurance supplements. CST is certainly a part of the possible ways for any type of runners as supplemental strength training to optimize overall running efficiency. 5000m run was conducted for performance analysis since the distance is one of the most popular distances for participating in local races (9).

The results showed significant improvement in the experimental group after the training period (the average of 47 sec faster time), while the control group also improved run time by the average of 17 sec. CST may certainly be one of the causes to improve the running time, especially in the experimental group. Based on the qualitative feedback from the participants in the experimental group, some were cautious utilizing the core muscles to stabilize the running form.

While all the other tests were done in indoor laboratory setting, 5000m run was timed at outdoor tracks. Thus, it is important to note that the there was climate difference at the time of 5000m run test averaging 86.08 ± 2.01° Fahrenheit with average of 64% humidity at the pre-training 5000m run test, as compared to the average of 73.33 ± 6.61° Fahrenheit with averaging 58% humidity at the post-training 5000m run test. Climate change can influence physiological response such as sweat rate and fatigue level. The improvement of the run time can be well affected by the weather condition between the two tests for both groups. Also, all participants were in the middle of marathon training period during the study, their weekly mileage increased by approximately 10 – 20% since the screening day. Longer distance of total weekly mileage may have influenced their ability to run faster at the post-training 5000m run test. As mentioned earlier, past studies revealed many critical answers for better running performance. It is certainly a key to control running environment and training as much as possible to identify the effect of single variable such as CST.

PRACTICAL APPLICATIONS

CST has been a buzz term in the strength and conditioning, and health and fitness industries. And many physically active people engage in CST as their supplemental workout. Although the limited scientific studies showed that there is no direct relationship between stronger core muscles and better athletic performance, many fitness professionals have strong belief in positive effects of CST.

Despite the fact that may sport scientists seek for causes and pattern leading to running-related injuries or typical kinetics and kinematics of running, runners are primarily interested in superior performance. Running is a sport that many participants including recreational level challenge their maximal effort, and they often think that they can do better at next one. Based on the results of this study, it is recommended performing CST to improve core muscular strength, possibly better lower extremity control, and raise awareness of how to run in a good posture.

CST is a great training tool for those professionals who utilize it in the strength and conditioning field to improve or maintain the strength level in the mid-section of the body. Also, CST has been an effective training tool in the rehabilitation field to recover from previous musculoskeletal injuries to regain muscular strength. The results of this study may not have shown the significant effects of

CST, but as more limitations will be controlled in future studies, the outcome of the data may become what the majority of the people expect. At the same time, the results also can be interpreted that CST may not have to be a primary source of training volume. If strength and conditioning coaches focus on too much of CST, it may negatively influence sport skills due to the lack of specificity training.

This study was relatively a short training period (six weeks) as well as the other studies in the past (1, 2, & 3). A year-around of continuous CST and occasional tests may display the change in the biomechanics characteristics of human performance.

REFERENCES

1. Cosio-Lima, L.M., Reynolds, K.L., Winter, C., Paolone, V., and Jones M.T. Effects of physioball and conventional floor exercises on early phase adaptations in back and abdominal core stability and balance in women. *Journal of Strength and Conditioning Research*,*17*(4):721–5. 2003.

2. Scibek, J.S., Guskiewicz, K.M., Prentice, W.E., Mays, S., and Davis, J.M. The effects of core stabilization training on functional performance in swimming. Unpublished master's thesis, University of North Carolina, Chapel Hill, North Carolina, USA. 2001.

3. Stanton, R., Reaburn, P.R., and Humphries, B. The effects of short-term swiss ball training on core stability and running economy. *Journal of Strength and Conditioning Research*, *18*(3):522–8. 2004.

4. Bus, S.A. Ground reaction forces and kinematics in distance running in older-aged men. *Medicine & Science in Sports & Exercise*, *35*:1167–75. 2003.

5. Gottschall, J.S., and Kram, R. Ground reaction forces during downhill and uphill running. *Journal of Biomechanics*, *38*:445–52. 2005.

6. Hreljac, A. Impact and overuse injuries in runners. *Medicine & Science in Sports & Exercise*, *36*(5):845–9. 2004.

7. Dixon, S.J., Collop, A.C., and Batt, M.E. Surface effects on ground reaction forces and lower extremity kinematics in running. *Medicine & Science in Sports & Exercise*, *32*(11):1919–1926. 2000.

8. Ferber, R., McClay-Davis, I., and Williams, D.S. Gender differences in lower extremity mechanics during running. *Clinical Biomechanics*, *18*:350–357. 2003.

9. Taunton, J.E., Ryan, M.B., Clement, D.B., McKenzie, D.C., Lloyd-Smith, D.R., and Zumbo, B.D. A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine*, *36*:95–101. 2002.

10. Olmsted, L.C., Carcia, C.R., Hertel, J., and Shultz, S.J. Efficacy of the star excursion balance tests in detecting reach deficits in subjects with chronic ankle instability. *Journal of Athletic Training, 37*:501–6. 2002.

11. Cote, K.P., Brunet, M.E., and Gansneder, B.M. Effects of pronated and supinated foot postures on static and dynamic postural stability. *Journal of Athletic Training*, *40*(1):41–46. 2005.

12. Gribble, P.H., and Hertel, J. Considerations for normalizing measures of the star excursion balance test. *Measurement in physical education and exercise science, 7*(2):89–100. 2003.

13. Gribble, P.H., Hertel, J., Denegar, C.R., and Buckley, W.E. The effects of fatigue and chronic ankle instability on dynamic postural control. *Journal of Athletic Training*, *39*(4):321–329. 2004.

14. Kinzey, S.J., and Armstrong, C.W. The reliability of the star-excursion test in assessing dynamic balance. *Journal of Orthopaedic and Sports Physical Therapy*, *27*(5):356–360. 1998.

15. Bennell, K., Crossley, K., Wrigley, T., and Nitschke, J. Test-retest reliability of selected ground reaction force parameters and their symmetry during running. *Journal of Applied Biomechanics*, *15*:330–336. 1999.

16. Novacheck, T. F. The biomechanics of running. *Gait and Posture*, *7*: 77–95. 1998.

Figure Legends

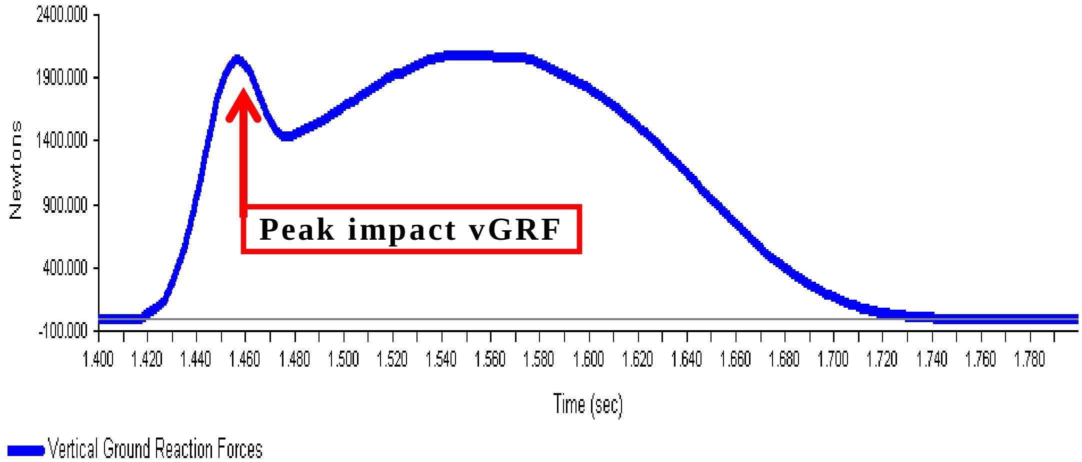


Figure 7. High peak impact vertical ground reaction force.

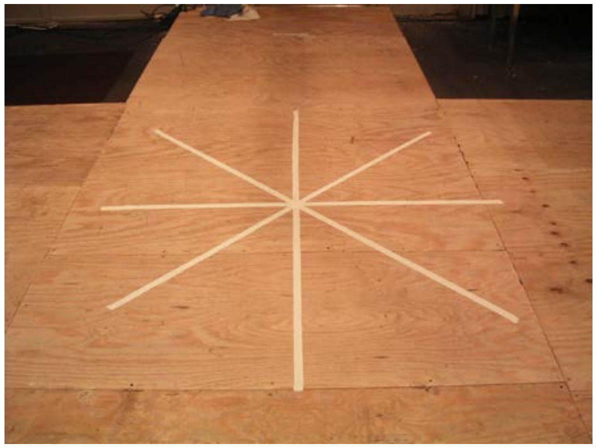


Figure 8. The layout of the Star Excursion Balance Test.

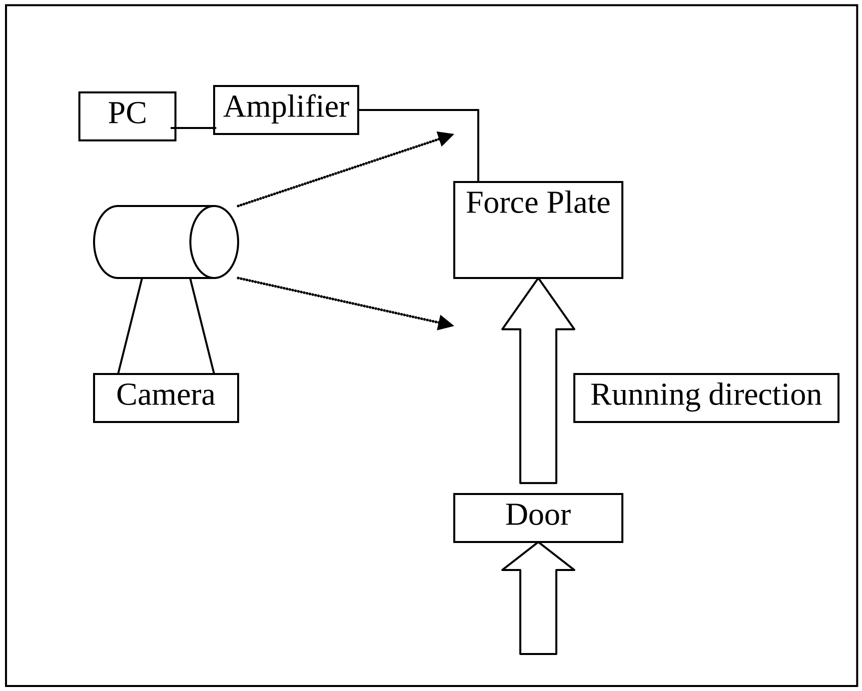


Figure 9. The layout of Laboratory.

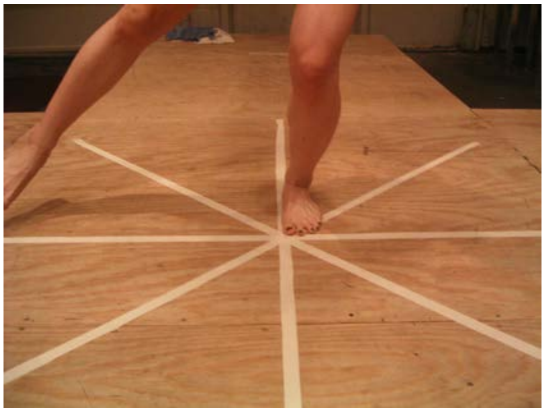


Figure 10. Stable foot (left) position for lateral reach.

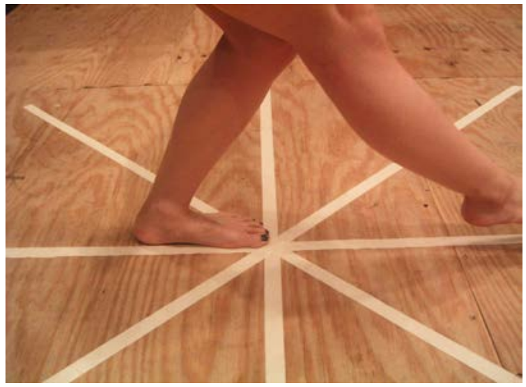


Figure 5. Stable foot (left) position for frontal reach.

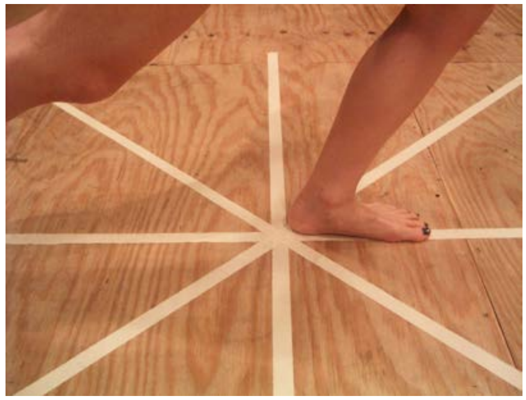


Figure 6. Stable foot (left) position for back reach

Table Legends

Table 1: Summary of the statistics on each variable

Table 2: Demographic information

Table 3: Peak impact vGRF for each group before and after training time (BW)

Table 4: Peak active vGRF for each group before and after training time (BW)

Table 5: Duration of breaking hGRF for each group before and after training time (% as duration during a foot contact)

Table 6: Duration of propulsive hGRF for each group before and after training time (% as duration during foot contact)

Table 7: SEBT scores for each group before and after training time (% as a ratio of total reaching length / leg length)

Table 8: 5000m run time for each group before and after training time (min:sec)

Table 1. Summary of the statistics on each variable.

	Interaction	Main effect: time	Main effect: group
Peak impact vGRF	NS	NS	NS
Peak active vGRF	NS	NS	NS
Time in the breaking hGRF	NS	NS	*
Time in the propulsive hGRF	NS	NS	*
SEBT	NS	*	NS
5000 m run time	*		

Note. ***** denote significant difference, $p < .05$. NS denote not significant, $p > .05$.

Table 2. Demographic information.

	Experimental group N = 12	Control group n = 8
Age (yrs)	37.75 ± 10.63	39.25 ± 10.81
Height (m)	1.67 ± 0.10	1.67 ± 0.84
Weight (kg) *****	75.95 ± 16.89	63.03 ± 12.02
Average running pace ***** (min:sec)	10:45 ± 1:11	9:26 ± 0:47
Average weekly mileage (miles)	20.75 ± 6.66	23.75 ± 6.41
Sahrmann Core Stability Test (level)	1.54 ± 0.40	1.75 ± 0.38

Table 3. Peak impact vGRF for each group before and after time (BW).

	Experimental group n = 12	Control group n = 8
Pre-training	1.65 ± 0.38 BW	1.99 ± 0.38 BW
Post-training	1.74 ± 0.46 BW	1.89 ± 0.24 BW
Difference (pre - post)	+ 0.09	- 0.10

Table 4. Peak active vGRF for each group before and after time (BW).

	Experimental group n = 12	Control group n = 8
Pre-training	2.30 ± .36 BW	2.49 ± .26 BW
Post-training	2.31 ± .42 BW	2.52 ± .24 BW
Difference (pre - post)	+ 0.01	+ 0.03

Table 5. Duration of breaking hGRF for each group before and after time (% as time of foot contact).

	Experimental group n = 12	Control group n = 8
Pre-training	47.30 ± 5.91 %	53.11 ± 4.77 %
Post-training	49.33 ± 6.81 %	54.48 ± 4.76 %
Difference (pre - post)	+ 2.03	+ 1.37

Table 6. Duration of propulsive hGRF for each group before and after time (% as time of foot contact).

	Experimental group n = 12	Control group n = 8
Pre-training	52.70 ± 5.92 %	46.89 ± 4.77 %
Post-training	49.25 ± 6.70 %	45.52 ± 4.57 %
Difference (pre - post)	- 3.45	- 1.37

Table 7. SEBT scores for each group before and after time
(% as a ratio of total reaching length / leg length).

	Experimental group n = 12	Control group n = 8
Pre-training	198.75 ± 26.70 %	199.13 ± 26.34 %
Post-training	220.67 ± 26.90 %	209.38 ± 26.89 %
Difference (pre - post)	+ 21.92	+ 10.25

Table 8. 5000 m run time for each group before and after time (min:sec).

	Experimental group n = 12	Control group n = 8
Pre-training	29:29 ± 2:38 (min:sec)	26:30 ± 1:59 (min:sec)
Post-training	28:42 ± 2:23 (min:sec)	26:13 ± 1:54 (min:sec)
Difference (pre - post)	- 0:47 (2.7% improvement)	- 0:17 (1.0% improvement)