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Effect of Six Weeks of Lower Leg Strength Training on Peak Ground Reaction Forces in Individuals with Medial Tibial Stress Syndrome

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EFFECT OF SIX WEEKS OF LOWER LEG STRENGTH TRAINING ON PEAK GROUND REACTION FORCES IN INDIVIDUALS WITH MEDIAL TIBIAL STRESS SYNDROME

BY

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

I am submitting herewith a thesis written by *Toyin Ajisafe* entitled "*Effect of six weeks of lower leg strength training on peak ground forces in individuals with medial tibial stress syndrome*." 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. Claire Egret, Thesis Committee Chair

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

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Accepted:

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Leisure Sciences

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CHAPTER I

INTRODUCTION

Recurrent pain in the lower leg caused or induced by exercise, is a common problem among athletes (Cetinus, Uzel, Bilgic, Karaoguz & Herdem, 2004). According to literature, there are several etiological factors that can be linked to the onset of recurrent leg pain (Gaeta et al., 2006). Some of the factors may include conditions such as exercise induced compartment syndrome (EICS), periostitis of the tibia, stress fracture, venous diseases, obliterative arterial diseases (OAD), and shin splints (Cetinus et al., 2004; Gaeta et al., 2006). Yates, Allen and Barnes (2003) reported that the three most frequent causes of exercise-induced leg pain are tibial stress fracture (TSF), chronic compartment syndrome, and Medial Tibial Stress Syndrome (MTSS). MTSS has also been referred to as shin splints in some scientific literature (Wilder & Sethi, 2004; Gaeta et al., 2006). Reinking and Hayes (2006) referred to the term "shin splints" as a common lay term, which only describes the anatomic region of the pain but not the specific pathologic changes. Hester (2006) explained how over the years many researchers have proposed more descriptive anatomic alternatives, to describe the condition that was commonly diagnosed as shin splints. Hester (2006) also stated that medial tibial syndrome, posterior tibialis syndrome, soleus syndrome, and tibial periostitis, are some of the descriptive alternatives that have been suggested by researchers. However, since its introduction by Mubarek et al. in 1982, MTSS has been adopted as the terminology of choice by many authors and sports medicine clinicians (Hester, 2006).

Although Magnusson, Westlin, Nyqvist, Gardsell, Seaman, and Karlsson (2001), described MTSS as "a condition of uncertain origin in athletes," they also described the condition as characterized by pain in the postero-medial section of the tibia, which may or may not show increased scintigraphic uptake in a normal radiograph. Madeley, Munteanu, and Bonanno (2006), defined MTSS as an exercise-induced leg pain of the posteriomedial border of the tibia not attributable to compartment syndrome or stress fracture. Pain resulting from MTSS is often very significant to the point that it may interfere with participation in physical activity, especially sports. Personal experience and anecdotal evidence suggest that individuals who experience anterior lower leg pain due to MTSS may find it challenging to sustain their intensity, while participating in physical activity, especially in sports that involve running and jumping. For instance, frequent sprints in soccer as well as the drop landings after headers are potential aggravators of MTSS-related lower leg pain. In light of the knowledge of the potential disruptiveness of antero-medial lower leg pain (Yates et al., 2003), finding a lasting, preventative, non-surgical intervention against its onset would be highly significant, especially to the athletic community and practitioners.

As stated earlier, tibial stress fracture, EICS, and MTSS are some of the most common lower extremity overuse injuries experienced among runners and other athletes (Hester, 2006; Cetinus et al., 2004; Gaeta et al., 2006). Also because symptoms can be quite similar especially in their early stages, the challenge that sometimes presents to both athletes and practitioners is to be able to substantiate adequate evidence to establish differential diagnoses of the respective conditions (Yates et al., 2003; Gaeta et al., 2006; Edwards, Wright & Hartman, 2005; Yoshimitsu, et al., 2004). While having a differential diagnosis is very important to clinicians, it is equally important to make the diagnosis in an early fashion since treatment is approached differently for these injuries (Ruohola et al., 2006). For instance treatment recommendations for a mid-tibial stress fracture may be completely different than the treatment recommendations for MTSS (Ruohola et al., 2006). Therefore, having a patient who perhaps should have been immobilized, continue to put pressure on their fractured tibia may be detrimental to the healing of the bone tissue. This situation may occur in cases where a conclusive differential diagnosis is not being made in a timely manner.

Gaeta et al. (2006) emphasized that a clinician must strive to specifically define a clinical problem in order to be able to administer the appropriate treatment for a patient's condition. Yoshimitsu et al. (2004) also reinforced the exigency of diagnosing the origins of lower leg pain in an early fashion, since leg pain is a potential and significant source of disturbance toward sport participation among many athletes. Generally, practitioners use different diagnostic tools and methods to evaluate the conditions that present in their clients, in order to be able to rule specific conditions as either present absent. Some of the diagnostic tools that are commonly used include different imagery tests, which give pictorial representations of the tissue under investigation, as well as any pathological changes that may have occurred as a result of injury or disease. Ruohola et al. (2006), stressed sensitivity and specificity as important qualities of imagery when used in a diagnostic process.

In 2003, Yates et al. reported that because MTSS is by far the most common of all the conditions that cause exercise-induced leg pain, it is referred to as the "true shin splints." It is however noteworthy, that opinions seem to vary within the scientific community regarding the most accurate name for anterior-medial lower leg pain. Ruohola et al. (2006), referred to exercise-induced lower leg pain as "stress-related anterior lower leg pain" because of their view that the term "shin splints" lacks accuracy due to its inherently broad spectrum of conditions. Although MTSS will be used to refer to a specific diagnosis in the current study, the term "shin splints" will be mentioned whenever reference is made to literature that uses that terminology in reference to non-vascular and non-fracture antero-medial tibial pain. Both of these terminologies have been widely used on a consistent basis in credible scientific literature (Wilder & Sethi, 2004).

The focus of this study was on the condition known as MTSS, also referred to as shin splints in other literature (Wilder & Sethi, 2004; Gaeta et al., 2006). Mubarek et al. (1982) described MTSS as pain experienced during exercise at the medial surface of the distal two thirds of the tibial shaft. Because of its relatively common occurrence especially among athletes, numerous studies have attempted to understand the pathophysiology for MTSS (Yates et al., 2003; Gaeta et al., 2006; Batt, Ugalde, Anderson, & Shelton, 1998). According to the standard nomenclature of the American Medical Association as documented by Slocum in 1967, shin splints were defined as pain and discomfort in the leg from repetitive running on hard surfaces or excessive use of foot flexors. Yoshimitsu et al. (2004) also described shin splints as pain in the medial aspect of the lower leg.

Literature has suggested that there may be a few different causes for the onset of MTSS (Blackburn, 2002). Overpronation of the foot and the ineffective absorption of ground reaction forces (GRFs) during physical activity, have been strongly implicated by some researchers as likely causes of pain associated with MTSS (Blackburn, 2002). A variety of other factors, including the running surface, the level of the athlete's conditioning, increase in activity level, footwear, and abnormal biomechanics have been considered influential in the development of MTSS (Willems, Clercq, & Delbaere, 2006). Other contributory factors are excessive physical activity, inadequate muscle strength and flexibility, muscle imbalance, inappropriate running surface, lower extremity malalignment, and inappropriate footwear (Wilder & Sethi, 2004; Taunton et al., 2002). According to Willems, Clercq, and Delbaere (2006), intrinsic factors that may be associated with exercise related leg pain include physical condition, previous injury, decreased muscle strength, muscle fatigue, inflexibility, malalignment and adverse biomechanics.

In addition to many other theories regarding the cause of MTSS, some authors maintain that it is related to chronic traction on the periosteum at the periosteal-fascial junction (Michael & Holder, 1985; Brukner, 2000). According to these authors two muscles have been implicated in contributing to this traction: the tibialis posterior and the soleus. Despite the apparent inconclusiveness of evidence regarding the etiology of MTSS there appears to be a general consensus among practitioners regarding the appropriate recommendations for its management. Some of the recommendations include cryotherapy, and giving the affected extremity sufficient rest. Generally, the prescribed periods of rest for individuals with shin splints are not as extensive as ones for stress fracture patients. Yoshimitsu et al. (2004) stated that athletes with tibial stress fracture should cease all sports activities for at least 4 to 6 weeks. Also stretching before the onset of any physical activity, especially ones that may involve the generation of considerable impact through the legs, is generally advised. There remains a need to better understand the etiology and treatment of MTSS (Craig, 2008). This study therefore attempted to explore the differences between soleus and tibialis anterior muscle strength, ankle flexibility, and peak vGRF generation in individuals with MTSS, before and after a six weeks of lower leg strength training.

While it remains unclear why, gender seems to play a role in the frequency of cases of MTSS that are seen by clinicians. Research has shown that women are twice as likely to develop MTSS as men, especially if their body mass index (BMI) is less than 21 $kg.m^{-2}$ (Bennett, Reinking, & Pluemer, et al. 2001). The role of gender was not investigated in the current study. Other factors that may be linked to the onset of MTSS include extrinsic factors such as training errors, surface type, and the shoe type. Intrinsic factors include previous running injury history, structural and biomechanical abnormalities, and bone geometry and density Hester (2006). As mentioned earlier certain studies have suggested a relationship between excessive subtalar joint pronation and MTSS (Bennett et al., 2001; Yates & White, 2004). However other studies have been inconclusive regarding any such relationship (Hester, 2006; Cowan et al., 1996). The etiology of MTSS will be covered in full detail under the literature review section for this study.

Statement of the Problem

A lot of research has been done on many conditions that affect the lower extremities including ligamentous and tendinous injuries, as well as structural factors that may affect performance and influence susceptibility to injury. The direction of investigations has also varied presumably, depending on the philosophy of the researchers and the resources at their disposal. While certain studies focus mainly on finding remedies for specific conditions, others attempt to understand the origins of such conditions. Some studies also look at interactions between a number of variables and how they may influence the onset of specific pathology. For instance in 2002, Overturf & Kravitz examined the relationship between strength training, aerobic exercise and a combination of both, on joint flexibility. Other studies have explored running mechanics and the generation of GRFs in athletic populations (Logan, Hunter, Feland, Hopkins, & Parcell, 2006). In the nineties, at least two separate publications hypothesized that adequate functioning of the leg muscles is necessary to absorb biomechanical force as well as to protect bones of the lower extremities from excessive shock during athletic activities (Fyhrie, Milgrom, Hoshaw, et al., 1998; Richie, DeVries, & Endo, 1993). Despite extensive scientific literature on the biomechanics of the lower extremity, no studies have been done to establish any links between lower leg muscle strength, GRFs, and how changes in those variables may influence the intensity pain associated with MTSS during physical activity.

Purpose of the Study

The purpose of this study was to determine the effects of six weeks of lower leg strength training on ankle dorsiflexion ROM, and the generation of peak vGRFs in individuals with MTSS. The specific relationship between lower leg resistance training and soleus muscle strength was also investigated in the current study. Participants' self-reports of pain during regular physical activity were documented and compared pre and post treatment for any significant differences. The obtained data was then used to evaluate whether the six-week treatment, translated into reduced medial tibial pain during physical activity.

Significance of the Study

According to Blackburn (2002), little is known about the etiology of MTSS. As pointed out earlier, practitioners generally recommend a set of different treatment strategies to manage symptoms associated with MTSS. However, there is no evidence that these treatment strategies really work, or at the least present any sort of relief to individuals experiencing pain due MTSS (Thacker, Gilchrist, Stroup, & Kimsey, 2002). Finding a possible link between leg muscle strength, ankle flexibility and ground reaction force attenuation in individuals with MTSS may give further insight into the etiology of MTSS. This insight may in turn reveal new ways of managing and perhaps preventing the onset of shin pain due to MTSS. Discovering a more effective treatment strategy for managing MTSS will certainly be of great help to practitioners including physical therapists, exercise scientists and personal trainers, as well as coaches, athletes and people within military populations.

Limitations of the Study

The limitations that may have influenced the results of this study as recognized by the researcher include the following:

1) Since participants were sent home with the training program and its progressions, it was impossible to know which participants followed their exercise prescription diligently.

2) Although participants were encouraged to maintain their normal levels of physical activity through the duration of the study, differences in type and intensity of activity between participants may have impacted elicitation and experience of pain, during physical activity.

Delimitations

This study was subject to the following delimitations:

1) All participants were recruited locally from Barry University, Miami Shores, Florida.
2) Participants were screened (through self-report) for any significant lower extremity injuries such as severe ankle sprains and stress fractures, within six months prior to the proposed starting date of the study.
3) Age of participants ranged from between 18 - 26 years (23.25 $\pm$ 3.01 years).
4) Participants were physically active individuals whose BMI were within the norm as stipulated by the American College of Sports Medicine: BMI less than or equal to 25 $kg.m^{-2}$, greater than 18.5 $kg.m^{-2}$.
5) All GRF generating tasks (specifically sub-maximal running), were performed non-shod in order to control for the influence of different shoe types during data collection.
6) Participants in the experimental group were all given the same workout regimen over the course of the six-week treatment.

7) Diagnostic tests including the palpation test and medical history examination were performed by the director of the Barry University athletic training staff, who is trained and licensed to make such inferences.

Assumptions of the Study

The following assumptions were made for this study:

1) Participants adhered to their assigned training programs and executed each exercise as described.
2) Strength training exercises would lead to an increase in lower leg muscle strength after six weeks.
3) Participants maintained their regular diets and eating habits through the entire duration of the study.
4) Participants maintained their regular levels of activity during the course of the study.

Research Hypotheses

The research hypotheses for this study included the following:

1) All participants will show higher peak vGRFs when compared to the normal population, prior to the intervention.
2) All participants will show deficits in ankle passive dorsiflexion ROM when compared to recommended averages for the general population.
3) Participants in the experimental group will show greater lower leg muscle strength and increased bilateral ankle passive dorsiflexion ROM by the end of the study.

Definition of terms

Active range of motion (AROM): movement estimation about a joint in the presence of a voluntary contraction within the muscles that surround the joint.

Bone mineral density: bone mass measurement used to determine fracture risk for osteoporosis.

Double support: when both feet are touching the walking surface at the same time.

Endurance: is the ability to maintain or repeat a given force or power output.

Equinus: is a condition in which the upward bending motion of the ankle is limited.

Exercise induced compartment syndrome: condition that causes pain over the anterior leg bone, usually starting after a period of physical activity and is relieved by rest.

Flexibility: available range of motion (ROM) at a specific joint.

Gait cycle: a sequential occurrence of a stance and swing phase for a single limb.

Locomotion: an act or the power of moving from place to place.

Medial tibial stress syndrome (MTSS): refers to pain that is localized in the distal third of the anteromedial border of the tibia, believed to occur from repetitive running or jumping, and persisting at least two weeks.

Overuse injury: refers to debilitating changes to soft tissue as a result of repetitive movement and use which may manifest in the form of pain and swelling.

Passive range of motion (PROM): movement estimation about a joint in the absence of a voluntary contraction within the muscles that surround the joint.

Passive stiffness: the amount of stiffness within a muscle tendon relative to the amount of stiffness in the actual active contractile fibers of a muscle.

Periostitis: painful inflammation of the periostium of the bone due to irritation or ineffective force dissipation.

Pronated foot: refers to foot that displays an excessively low medial longitudinal arch.

Repetition maximum: the amount of weight that a person could only lift once.

Resistance training: any form of training in which effort is performed against a specific opposing force or resistance.

Single support: when only one foot is in ground contact and the contralateral limb is swing phase.

Stance phase: period during which the foot contacts the ground.

Supinated foot: refers to foot that displays an excessively high medial longitudinal arch.

Swing phase: period during which the foot is not in ground contact.

Tibial stress fracture: is pain that is very tender at specific points along the tibia believed to occur as a result of repetitive running or jumping, and persisting for at least two weeks.

CHAPTER II

LITERATURE REVIEW

Given the fact that no studies to our knowledge have examined how strength training may ultimately influence GRF absorption in individuals with MTSS, the purpose of this study was to investigate the effects of a six-week strength-training program on lower leg muscle strength, ankle passive dorsiflexion ROM, and peak vGRF generation in individuals with MTSS. Increase in muscle strength was measured using the ACSM guidelines for the one repetition maximum test. This chapter will discuss the following: (i) occurrence and etiology of MTSS, (ii) effects of stretching on flexibility and injury prevention, (iii) anatomy of the leg, (iv) muscle-tendon compliance, (v) generation and dissipation of ground reaction forces, (vi) imaging, and (vii) effects of strength training on muscles.

Occurrence and Etiology of MTSS

Herring and Nilson (1987) stated that about 50% of all sports injuries are secondary to overuse. Gellman and Burns (1996) also reported that of 10 million Americans who engaged in some type of running on a daily basis, most of them sustained an overuse injury in the lower extremity. This finding is consistent with the findings of Baquie and Brukner (1997); Brody (1980), who reported that not only are the majority of injuries evaluated in running clinics related to overuse, but approximately half of them involve the lower leg (20%), ankle (15%), and foot (15%). Examples of lower extremity overuse injuries include MTSS, shin splints, stress fractures and Achilles tendonitis (Blackburn, 2002). According to research, MTSS accounts for 13.1% of more than 1800 injuries seen in runners and 22% of 385 injuries seen in aerobic dancers (Yates, Allen, & Barnes, 2003). Other articles including a review of literature by Tweed, Avil, Campbell, and Barnes (2008) have reported that MTSS is common among both recreational and competitive athletes (Bennett, Reinking, & Pluemer, 2001). This information is relevant since this study recruited participants who only engage in recreational sports. Literature has also reported that MTSS may account for up to 10-15% of running injuries and about 60% of lower leg pain in athletes (Bates, 1985). Yates and White (2004) documented that MTSS may account for between 13.2% and 17.4% of all running injuries. Table 1 illustrates the details of some of the past research that have been done on shin splints.

Table 1

Incidence Rates of MTSS and Shin Splints in Military and Athletic Populations

Study	Year	Population	Design	Data Collection Technique	Incidence Rates (%)
James et al.	1978	Runners (N=180)	Retrospective	Clinic	13%
Bennell & Crossley	1996	Runners (Male/Female) (n=54)	Retrospective	Interview	13.6%
Bennell & Crossley	1996	Sprinters (Male/Female) (n=27)	Retrospective	Interview	5%
Cowan et al.	1996	Male military trainees (n=294	Prospective	Monitor	4%
Kaufman et al.	1999	Male military trainees (n=449)	Prospective	Monitor	4%

With the incidence of MTSS being as high as up to 10-15% of all running injuries, and about 60% of lower leg pain in athletes (Bates, 1985), numerous research has been done to investigate the etiology of the condition. One theory on the etiology of MTSS is the inflammation of the periostium of the tibia due to repetitive traction forces from muscles of the lower leg, causing pain in the shin. According to Michael and Holder (1985), excessive pronation and gastronemius-soleus muscle tightness may be involved in the origin of MTSS. They suggested that periostitis (inflammation of the periostium) may occur as a result of repeated eccentric contractions of the medial half of the soleus during foot pronation. The same authors also implicated fatigue of the soleus muscle as a possible reason for the poor dissipation or attenuation of traction forces in the leg, which may invariably result in soft tissue injury (in this case the periostitis of the tibial bone). Gastrocnemius-soleus tightness was assessed as muscle length by Reinking and Hayes (2006), which they then measured by the amount of active ankle dorsiflexion participants demonstrated. Burne et al. (2004) linked lack of endurance and/or lack of strength or imbalance between agonist and antagonist lower leg muscles to the development of MTSS. They showed that males who developed MTSS had significantly less lean calf girth compared to males who did not develop the condition. Madeley et al. (2006) found endurance deficits in the ankle joint plantar flexor muscles in athletes with MTSS.

Tweed, Avil, Campbell, and Barnes (2008) described MTSS-related pain as a dull ache to intense pain that is worsened by repetitive weight bearing activities and may be continuous or intermittent. Diagnosis of MTSS is mostly based on clinical history, location of the pain, and palpation of the medial border of the tibia for tenderness (Tweed, Avil, Campbell, & Barnes, 2008). Currently, there are a few prevalent treatment strategies that practitioners recommend to their clients and patients in order to manage MTSS (Thacker, Gilchrist, Stroup, Stroup, & Kimsey, 2002). Some of the reported intervention techniques include the use of shock-absorbent insoles, foam heel pads, heel cord stretching, alternative footwear, and graduated running programs among military recruits. However, according to Thacker et al. (2002), there is no strong support for any of these interventions.

Anatomy of the Leg

According to Moore (1998), the tibia and fibula, the interosseous membrane, and the crural intermuscular septa divide the leg into three crural compartments. The compartments are namely the anterior (extensor compartment), lateral (fibular or peroneal compartment), and the posterior (flexor compartment). The posterior compartment is further divided by the deep transverse fascia of the leg into deep and superficial crural compartments. The names and actions of muscles that make up the respective compartments of the lower leg are listed in Table 2 (Moore, 1998).

Table 2

Muscles of the leg and their functions

Muscle	Lower leg compartment	Action
Gastrocnemius	Posterior	Plantarflexes the foot at the ankle, flexes the knee
Soleus	Posterior	Plantarflexes the foot
Popliteus	Posterior	Unlocks the knee from extended position
Tibialis posterior	Posterior	Inverts the foot, plantarflexes the ankle
Flexor digitorum Longus	Posterior	Plantarflexes and inverts the foot, flexes toes 2-5
Flexor hallucis longus	Posterior	Flexes big toe, weak plantarflexion of the ankle and inversion of the foot
Tibialis anterior	Anterior	Inverts the foot and dorsiflexes the ankle
Extensor digitorum longus	Anterior	Extends 2^{nd}-5^{th} toes, dorsi flexes ankle and everts the foot
Extensor hallucis longus	Anterior	Extends the big toe, dorsiflexes the ankle and inverts the foot
Peroneus longus	Lateral	Everts and abducts the foot, weakly plantarflexes the foot
Peroneus brevis	Lateral	Everts and abducts the foot, weakly plantarflexes the foot

According to Moore (1998), the anterior and deep posterior compartments of the leg are commonly associated with shin splints. Blackburn (2002) also stated that the posterior tibialis, anterior tibialis, flexor digitorum longus and soleus are muscles that may be affected by MTSS. Michael and Holder (1985) implicated the eccentric contractions of the medial one half of the soleus during foot pronation, as a possible contributor to the development of periostitis which may lead to MTSS. Specifically, the posterior tibialis and flexor digitorum longus originate in the upper posterior one half of the tibia and insert under the foot on the second to fifth metatarsals. The posterior tibialis also inserts on the navicular and cuneiforms to help support the medial longitudinal arch of the foot (Blackburn, 2002). The anterior tibialis may also help support the arch because it inserts on the medial cuneiform and first metatarsal. The soleus originates on the posterior two thirds of the tibia and fibula and inserts on the calcaneus (Thompson & Floyd, 1994).

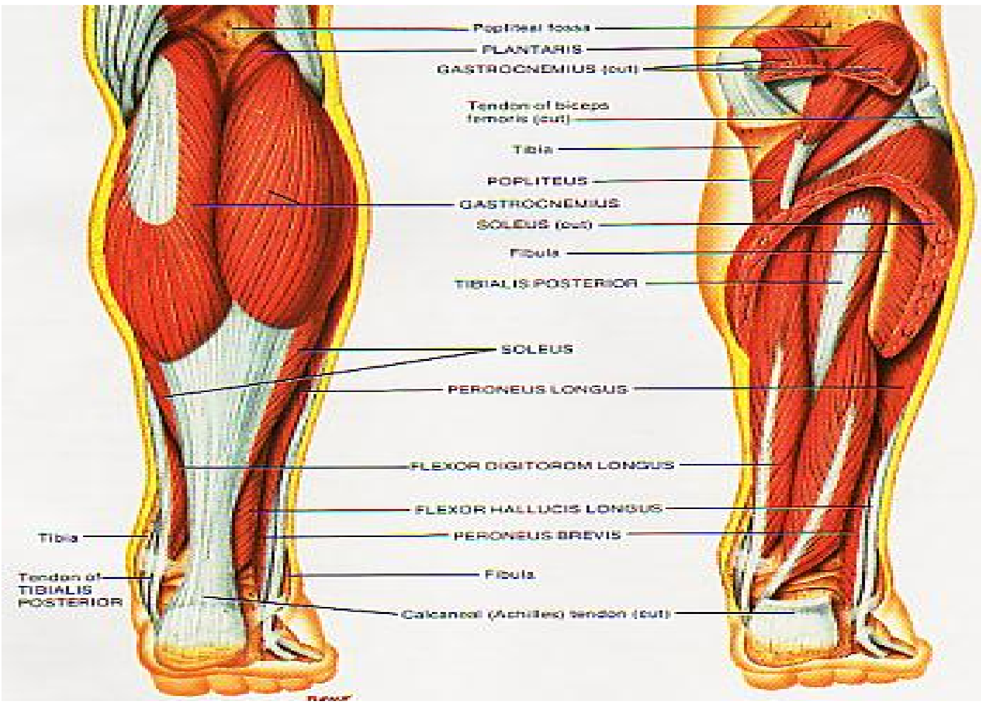

Figure 1 Muscles of the posterior leg compartment.

(http://www.projectswole.com)

Ground Reaction Forces

Generally, faster movements such as running tend to generate greater impact in the extremities during ground contact. In a study by Nilson and Thorstensson (1989), increased speed was accompanied by shorter force periods and larger peak forces. The peak amplitude of the vertical ground reaction forces during walking and running increased with speed to about twice their original values (Nilson & Thorstensson, 1989). The antero-posterior and medio-lateral peak forces also increased about two times their original values. The same authors stated that during the transition from walking to running, the limb support phase becomes shorter while vertical peak forces increase and vertical impulses decrease. Logan, Hunter, Feland, Hopkins, and Parcell (2006), reported that during distance running, ground reaction forces of more than two times a person's body weight are typical. In a 2002 comparative study between barefoot and shod running by De Wit (as cited by Logan et al.), there were significant increased loading rates and greater vertical impact peaks in the barefoot condition. Seegmiller and McCaw (2003) reported that because gymnasts often land with minimal flexion at the hip, knee, and ankle (all mechanisms of force attenuation), they often exhibit higher vertical ground reaction forces than other female recreational athletes, while performing the same drop landing tasks. In congruence with this study, Sands, Schultz, and Newman (1993) found that of 509 new injuries studied among gymnasts, 49.51% occurred in the lower extremity and 15.2% were low back injuries. Repetitive stress syndrome injuries were also the most prevalent type of injuries accounted for.

In a biomechanical study of 13 runners, Mann and Hagy (1980) showed that with increasing speed of gait, the duration of the support phase progressively decreased from

62% for walking, 31% for running, and 22% for sprinting. The saggital plane motion (assessed through the hip, knee, shoulder flexion and extension angles) increased with increasing gait speed as well. The previous study also reported that the posterior calf musculature was active through the first 80% of the stance phase in running, when compared to 15% in walking. These findings demonstrate that a great deal of demand is placed on the lower extremity muscles during movement, depending on the intensity of the task that is being performed. More intense tasks tend to produce greater loads. Seegmiller and McCaw (2003) suggested that repetitive exposure to these high loads is one of the contributing factors to injury, depending on the direction of force application. Figure 2 shows the pattern of GRF generation during ambulation.

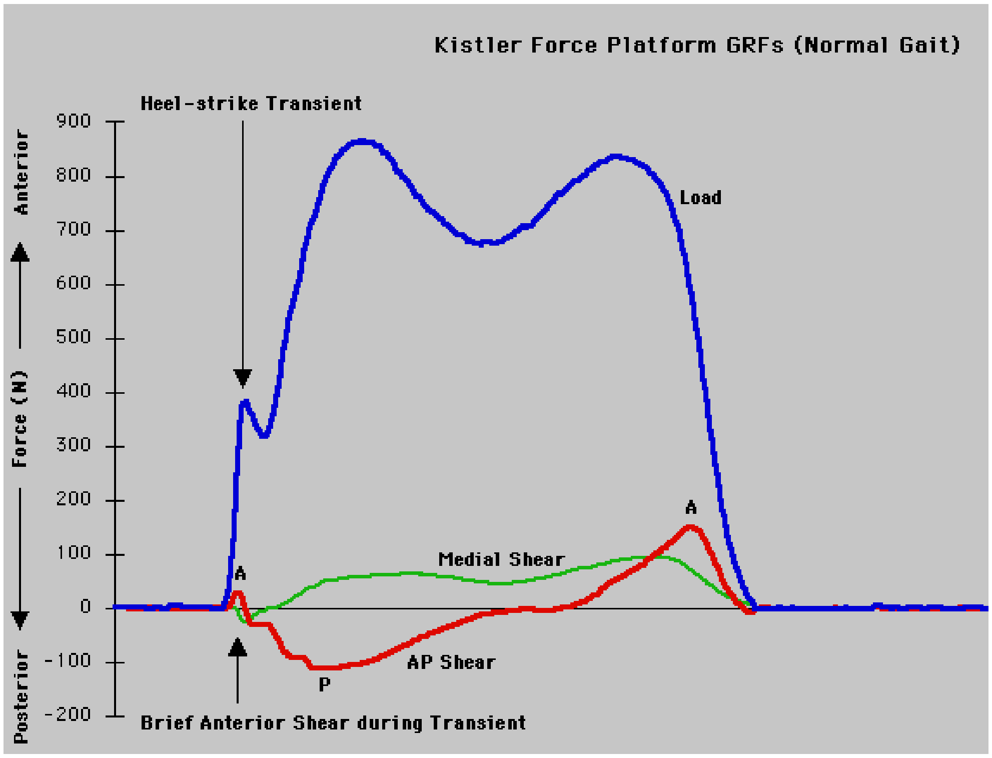

Figure 2 Ground reaction force representation.

(*http://www.smpp.northwestern.edu/~jim/kinesiology/previousMisc.HTM*)

According to Middleton, Sinclair, and Patton (1999), if an individual steps on a force platform, a three dimensional force is applied to the platform. The resultant force or vector can be broken down into three components. GRF components lie in the vertical (Fz), anterior-posterior (Fy), and medial-lateral (Fx) directions. Middleton et al. (1999) suggested that the accuracy expected during a two legged task would be greater than using a single point of application loading technique. Errors are likely to be less than 2mm when the feet are positioned symmetrically about the center of the force platform. As shown in figure 2, the vertical component of GRFs has the greatest magnitude during normal running gait. Anterior-posterior and medial-lateral GRF components remain relatively low during normal gait. The two peaks seen in the gait figure indicate the initial foot contact (passive peak) and the successive push-off on the same foot (active peak) (Nigg, MacIntosh, & Mester, 2000). It is however not clear what the relationship is between MTSS-related pain and the respective force peaks described earlier.

Gait Analysis

With the introduction of the foot scan gait analysis system, scientists have been able to visualize the relative distribution of pressure on the sole of the human feet during movement. Although no relationship has been shown to our knowledge, between pressure distribution and the onset of MTSS, it is however a known fact that pressure causes compression within both biological and non-biological systems. Pressure is a scalar quantity and it is defined as the amount of force applied over a given surface area (Pressure = Force / Area). The implication of this function is that the smaller the surface area over which a certain force is being applied, the greater the resultant pressure.

According to the general principle of injury mechanics, the larger the area of force application the less the likelihood of injury (Whiting & Rugg, 2006). Tying in the principle of pressure together with the dynamics of human gait (both running and walking), an explanation may be apparent for why injury to soft tissue may be more likely during activities such as running and jumping, over others such as walking.

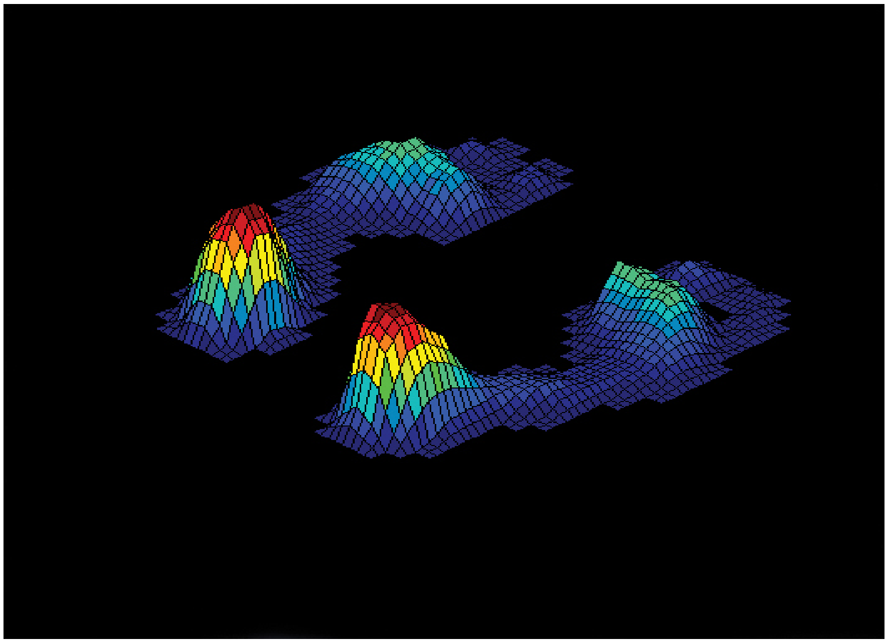

Figure 3 Foot scan image.

(Aetrex Technology & Education, 2008)

The areas highlighted in red in the above figure indicate regions of intense pressure while the yellow areas indicate lower pressure points. The blue regions show the presence minimal pressure (lower than that of the areas in yellow). A closer examination of the foot scan would reveal that the blue areas have the greatest surface area, followed by the areas in yellow, while the portions in red are spread out over the least area. This pattern of corresponding area of force distribution and resultant pressure intensity is consistent with the relationship that was explained earlier between pressure, force, and surface area.

Figure 4 gives a comprehensive analysis of the human gait cycle during normal walking.

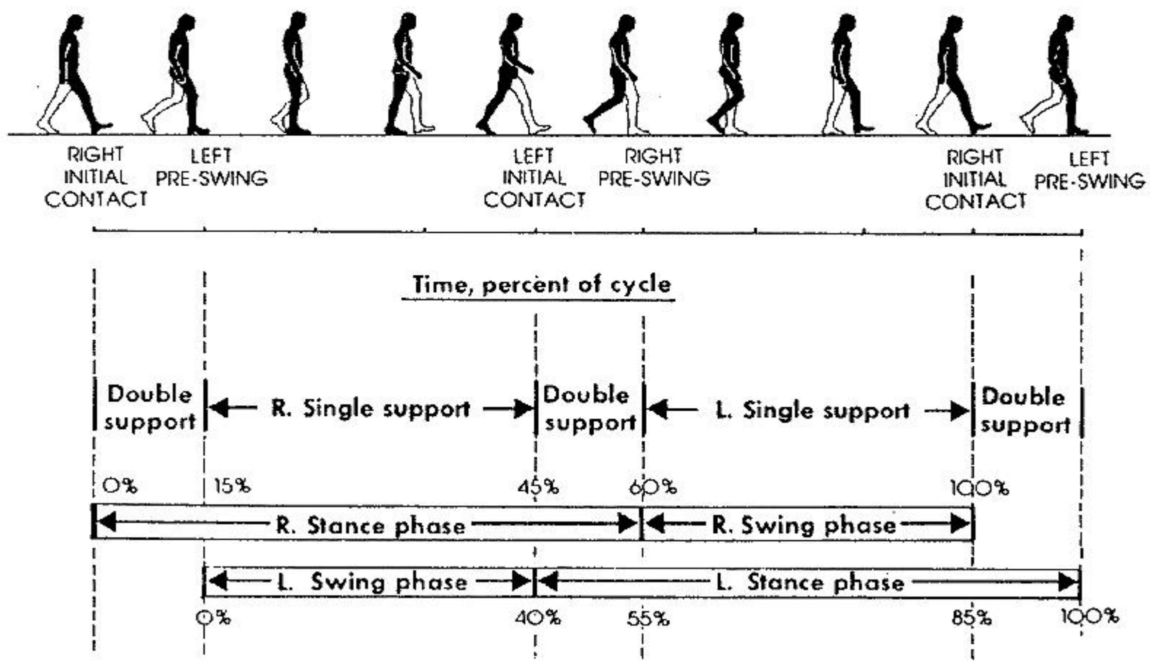

Figure 4 Normal gait cycle in humans.

(*Inman, Ralston, & Todd, 1981*)

About 60% of the human walking gait cycle is spent in the stance phase while the other 40% is spent in the swing phase (Inman, Ralston, & Todd, 1981). However, as walking speed increases, the ratio of time spent in stance versus swing becomes approximately 50:50 (Whiting & Rugg, 2006). Even though less time is spent in the stance phase during increased walking speeds and more so during running, greater ground reaction forces are being generated, while the area of the foot in contact with the ground gets progressively smaller. This may imply that the amount of pressure during foot contact would be much greater, when compared to regular walking. During initial contact, ankle dorsiflexors including tibialis anterior, extensor hallucis longus, extensor digitorum longus and the peroneals, eccentrically control ankle plantar flexion. During midstance ankle plantar flexors including soleus, gastrocnemius, tibialis posterior, flexor digitorum longus, flexor hallucis longus, peroneus longus and peroneus brevis eccentrically control tibial advancement over the foot (Whiting & Rugg, 2006).

Effects of Stretching on Flexibility and Injury Prevention

Opinions tend to vary when it comes to ascertaining the relationship between stretching and the prevention of injury. It was reported that although stretching may be the most common routine advocated by coaches and sports medicine professionals, its recommendation is surrounded by misconceptions and conflicting reports, making it difficult to make any conclusive statements about the relationship between stretching and athletic injuries (Witvrouw, Mahieu, Danneels, & McNair, 2004). More recent studies have shown that stretching may reduce the viscosity of a tendon, thereby increasing the compliance of the tendon unit, which may be beneficial for greater elastic energy storage and release especially in sports that involve high intensities of stretch shortening cycles (Witvrouw et al., 2004).

Whaley, Brubaker, and Otto (2006) defined flexibility as the range of motion around a specific joint or a series of joints. Flexibility can be static or dynamic. Static flexibility is measured passively while an individual is relaxed, while dynamic flexibility is assessed while the individual actively moves a joint through the available range.

Literature has suggested that stretching can increase static flexibility (Whaley et al., 2006). In order to maintain or increase flexibility, it is recommended that stretching exercises be done two to three days per week. A muscle group should be stretched to a position of mild discomfort, and held for 10-30 seconds with a static stretch, and a six second contraction followed by a 10-30 second assisted stretch for peripheral neuromuscular facilitation (PNF) stretching. Stretches should be repeated three to four times for each major muscle group (Whaley et al., 2006).

Closely related to flexibility is the concept of stiffness. Stiffness can be found in muscle fibers, tendons, ligaments or any other extensible biological materials found within the body. McHugh, Connolly, Eston, et al. (1999) found increased evidence of muscle damage after eccentric exercises in participants who had greater passive stiffness. Passive stiffness was also used by Witvrouw, Mahieu, Danneels, and McNair (2004), to refer to the amount of stiffness within a muscle tendon relative to the amount of stiffness in the actual active contractile fibers of a muscle. Hawkins and Bey (1997) also found that in the outer ranges of movement during which tendon stiffness may increase, greater passive forces are generated within the antagonist muscle. These forces could increase the risk of muscle injury (Witvrouw et al., 2004). Although there is a lack of conclusive evidence on the beneficial effects of stretching on injury prevention, stretching may be beneficial for increasing the compliance of the musculo-tendon unit by reducing passive stiffness. Despite inconclusive evidence regarding the role that stretching may play in preventing injury, participants were taken through appropriate lower body stretches prior to data collection sessions, and were instructed to perform a bent knee soleus stretch before executing their lower leg exercises over the course of six weeks.

Effects of strength training on bone density, muscle strength, and muscle endurance

Physical exercise influences bone mass, muscle strength, and coordination in younger as well as in elderly people (Lips & Ooms, 2000). The same study reported that while exercise is important for the attainment of peak bone mass in young people, it may decrease bone loss and increase muscle strength in the elderly. It was also found that the peak strain induced by loading is more important than the total duration of loading. The highest bone mineral densities were seen in weight lifters and squash players while the least gains were observed in swimmers (Heinonen et al., 1995). During a fall, the energy of the falling body is absorbed upon impact with the ground. Energy absorption occurs through a deformation of internal structures of the body, the soft tissue layers as well as the ground itself. In the absence of energy-absorbing padding, much of the energy must be absorbed by the skeleton, which results in high forces on the bone (Lips & Ooms, 2000).

Literature has shown that maximum muscle strength is moderately to strongly related to endurance capabilities and its associated factors (Stone et al., 2006). This study further specified that strength training can increase both high intensity exercise endurance and low intensity exercise endurance, the effect being greater for high intensity exercise endurance. Even though strength training only has minimal effects on VO_2max, literature has suggested that stronger athletes with stronger muscles may be more efficient or economical in their movements, leading to improved endurance capabilities as a result of performing less work to accomplish a certain task (Stone et al., 2006). Aagaard, Simonsen, Andersen, Magnusson, and Dyre-Poulsen (2002), stated that increases in strength are often accompanied by increases in power and rate of force production. The applied implication of increased force development was that it may increase muscle endurance by reducing the relative force (percentage of maximum) applied at similar loads, thus maintaining greater blood flow, and reducing the time of restricted blood flow during muscle contraction. This in turn may reduce limitations to muscle oxygenation and exchange of substrates and metabolites (Aagaard, Simonsen, Andersen, et al., 2002).

Strength training has been found to affect all motor unit types including type I and type II motor units. According to Stone et al. (2006), the use of type I units may be enhanced during certain movements while the use of type II units is reduced (vice versa), for other kinds of movements at. In addition, strength training has been found to increase the number of type IIa fibers, which have high glycolytic and oxidative potential, and are considerably fatigue-resistant (Stone et al., 2006). Fatouros et al. (2002) found results that indicated that resistance training may be able to increase range of motion of a number of joints of inactive older individuals, possibly due to an improvement in muscle strength. There is also some evidence that fatigue resistance can be improved through strength training as a result of prolonged membrane excitation and enhanced ionic regulation (Stone et al., 2006). Lastly, research has shown that appropriate resistance training can modify the lactate threshold (LT) of skeletal muscle, which may make it possible to maintain the LT at higher values during periods of primarily aerobic training in which the anaerobic system is not being taxed (Marcinik, Potts, Schlabach, Will, Dawson, & Hurley, 1991).

Muscle fatigue and ground reaction force attenuation

According to Bennell, Matheson, Meeuwisse, and Brukner (1999), skeletal muscle attenuates and dissipates forces applied to bone. The same authors reported that during running, the foot strikes the ground approximately 500 times per kilometer. With each foot strike generating ground reaction forces that may vary from two to five times the body weight, and up to twelve times the body weight during jumping and drop landing tasks, shock waves traveling through the bone may result in vibrations from 25 to 100 Hertz. However because the shock waves are attenuated considerably by muscles and joint structures, only 54% of total generated force made its way to the medial femoral condyle in a separate study as reported by Brukner et al. (2002). This report also indicated that muscle weakness or fatigue could predispose an individual to an increase or a redistribution of stress to the bone. This theory is consistent with an earlier theory by Michael and Holder (1985) that gastrocnemius-soleus muscle weakness and its lack of endurance may predispose an individual to having MTSS.

In an investigation of the effects of muscle fatigue on lower extremity mechanics during single leg drop landings, Stublar, Usenik, Kamik, and Munih (2007), found that there was no significant change in overall shock attenuation prior to, and after fatigue. This information is important since GRF data will be collected in a non-fatigued state for the current study. However, Brukner, Bennel, and Matheson (2002) found that during a 45-minute run, women who had a history of stress fracture recorded increased ground reaction forces than the control group whose ground reaction forces did not vary during the run. In 1990 while utilizing a biomechanical analysis model, Scott and Winter found that the tibia is subjected to a large forward bending moment as a result of ground reaction forces. However the calf muscles oppose this large bending moment by applying a backward moment as they contract to control the tibia's rotation and the foot's lowering to the ground (Brukner, et al., 2002). The total effect of this moment opposition is a smaller bending moment and a decreased bone strain to the tibia.

CHAPTER III

RESEARCH METHODOLOGY

The purpose of this study was to investigate the effects of six weeks of lower leg strength training on muscle strength, passive ankle dorsiflexion ROM, and peak vGRF generation in individuals with MTSS. The specific aim of this study was to determine how six weeks of soleus and tibialis anterior muscle strength training may influence: (a) lower leg muscle strength, (b) ankle passive dorsifexion ROM, and (c) and non-shod running peak vertical GRFs. Based on the stated aims of the current study, the following methods were employed to conduct the investigation. It was our expectation that obtained results may contribute to further understanding the etiology and possible treatment of the MTSS.

Participants

Ten healthy, physically active individuals were recruited for this study ($n_{control}$ = 5, $n_{experimental}$ = 5). All participants were of college age or older, between 18-26 years of age (age = 23.25 $\pm$ 3.01 years; height = 1.65 $\pm$ 0.12 m; weight = 69.82 $\pm$ 10.75 kg). All the participants had been diagnosed with and experienced MTSS related leg pain for at least 3 months prior to the anticipated date for first set of data collection. Participants were recruited from Barry University, Miami Shores. Recruitment was done by posting and circulating flyers among the different recreational sports teams within the Barry University community. General information about the study was explained to interested volunteers through email, telephone and in person, depending on the medium through which they chose to express their interest to the investigator. Although efforts were made to get as many participants as possible across each gender group, participation in this study was not predetermined by need for uniform gender distribution. The inclusion criteria for participation in this study included the following: (a) prior involvement (moderate to high) in regular physical activity, preferably an aerobic or resistance training regimen (Trappe, Raue, & Tesch, 2004), (b) normal BMI (no greater than 25 $kg.m^{-2}$, and no less than 18.5 $kg.m^{-2}$) for all participants, (c) absence of any lower extremity injuries such as fractures, muscle strain, compartment syndrome and vascular diseases, for at least three months prior to the start of the study, (d) normal blood pressure checked on at least two separate occasions within a month of the study's commencement date , and (e) a low risk score on the administered ACSM risk stratification and physical activity readiness questionnaire (PAR-Q). Screening for these criteria was done in person, over the telephone, or through email, depending on the medium of preference of interested volunteers.

Risks Associated with Exercise

The risks of involvement in this study were no greater than that experienced during participation in a vigorous physical activity such as competitive sports or heavy weight lifting. Muscle strains were a possibility. According to the ACSM handbook (Whaley, Brubaker, & Otto, 2006) exercise only provokes cardiovascular events in individuals with preexisting heart disease (diagnosed or undiagnosed). However the following procedures were used to minimize these risks: All participants were of normal body mass index ((BMI), no greater than 25 $kg.m^{-2}$, no less than 18.5 $kg.m^{-2}$), and had a recent history of involvement (moderate to high) in regular aerobic or resistance training activities. Participants were between the ages of 18-26 years and completed PAR-Q forms as well as a pre-participation screening questionnaire for risk stratification. Only individuals with a low risk were selected to participate in this study.

In addition the investigator also conducted blood pressure screenings for each volunteer. All participants were informed of the early symptoms of Coronary Artery Disease (CAD). This was so participants knew what signs to look out for if they ever experienced any unusual sensations during exercise or other physical exertion. Participants were instructed to notify the investigator of unusual sensations immediately. All weight lifting sessions were conducted one-on-one, and under the direct supervision of the principal investigator who holds certifications through the American Council on Exercise, for personal training, and the Aerobic Fitness Association of America, for group fitness instruction. Exercise sessions were always preceded by stretching and proper warm up. Exercise loads were based on each participant’s one repetition maximum (1RM) scores.

Experimental control

Medical history was thoroughly examined by interviewing each participant and medical diagnostic tools including a palpation test (administered by the head trainer in the Barry University athletic training room) were employed. A visual analog pain scale (see appendix section) was used by participants throughout the entire duration of the study, to record any pain that they may have experienced during the course of their regular physical activity.

Procedures

All participants were asked to report to the Barry University Biomechanics Laboratory on a set day and time. The preliminary data collection (pre-treatment) included a five-minute warm up on a stationary bike in the biomechanics lab, followed by a lower leg stretching protocol. These activities preceded the actual testing sessions. Stretching exercises targeted the anterior, posterior and lateral leg muscles, as well as the quadriceps and hamstrings muscle groups.

Passive ankle dorsiflexion ROM

Passive ankle dorsiflexion ROM was measured by having participants stand upright with both feet at shoulder width, maintaining a distance of about 8 inches from the laboratory wall, placing one foot ahead of the other in a step-stance position. Participants were instructed not to touch the wall unless it was necessary in order to prevent a fall or to prevent loss of balance. Touching the wall during any trial rendered the trial invalid. The knee of the leading leg was held in full extension starting out. Shifting all of their weight onto the leading leg, participants were then asked to lean forward by bending the ipsilateral knee as far forward as they could, while lifting the contralateral foot off the floor (see figures 6 and 7). Figures 6 and 7 illustrate the ankle passive dorsiflexion ROM measurement procedure, without the goniometer in place. The arrows in the figures indicate the coordinates over which the measurements were taken.

The moving arm of the goniometer was aligned with the mid shaft of the tibial bone, and the stationary arm was placed over the base of the fifth metatarsal. Three sets of measurements were taken on each leg, recording the angular displacement between the shank and the vertical. Participants were asked to return their feet to the starting position before each new measurement was taken. The average of all three measurements was recorded as the available dorsiflexion range of motion in the specified ankle. Figure 5 is an adaptation from the study by Bus (2003). It is a representation of the model after which the ankle passive dorsiflexion ROM measurement was patterned, in the current study. The unilateral ankle dorsiflexion stance is representative of the kinematics typically seen during midstance of human locomotion.

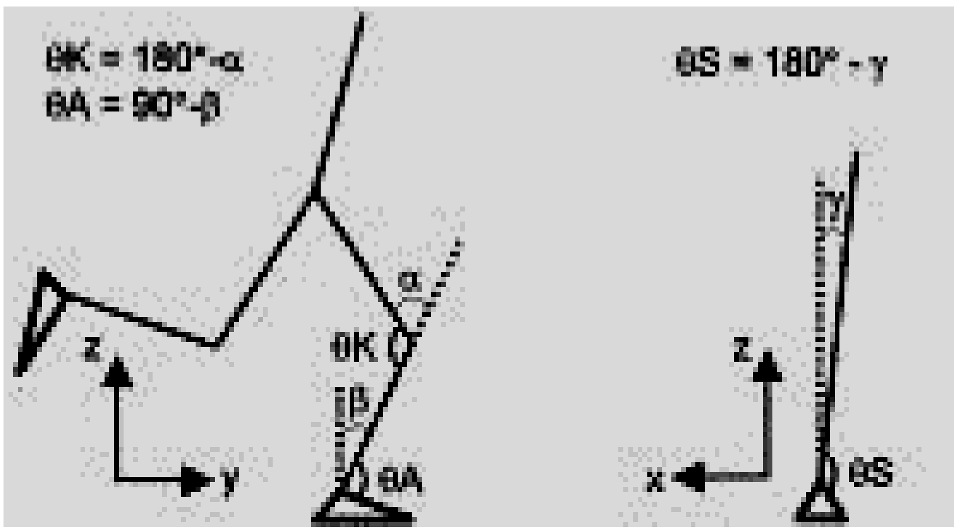

Figure 5 Convention for angular displacements in the sagittal plane (left) of the knee joint ([theta]K) and the ankle joint ([theta]A) and in the frontal plane (right, posterior view) of the subtalar joint ([theta]S) of the right lower extremity (Sicco, 2003).

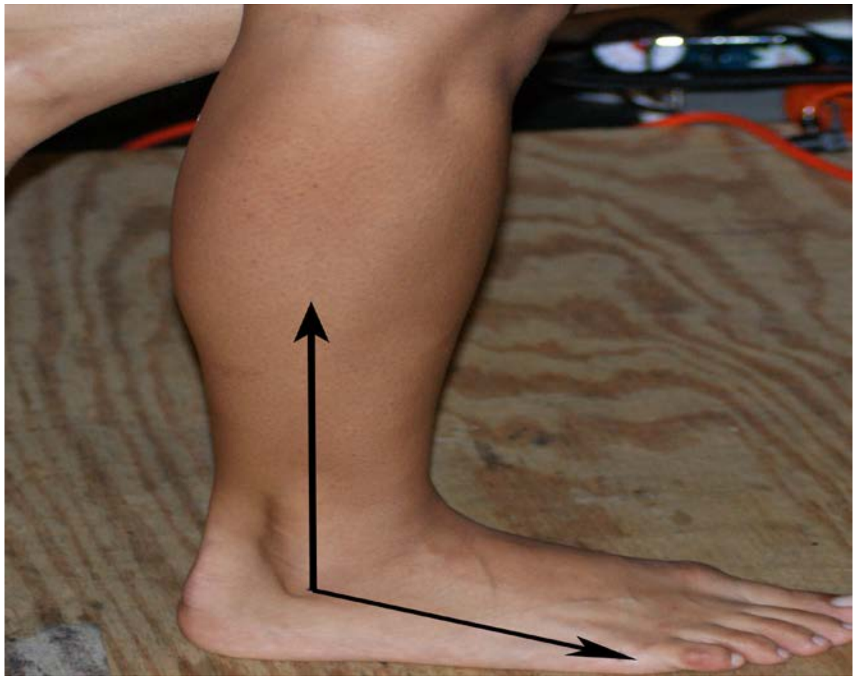

Figure 6 Starting position for ankle DFROM.

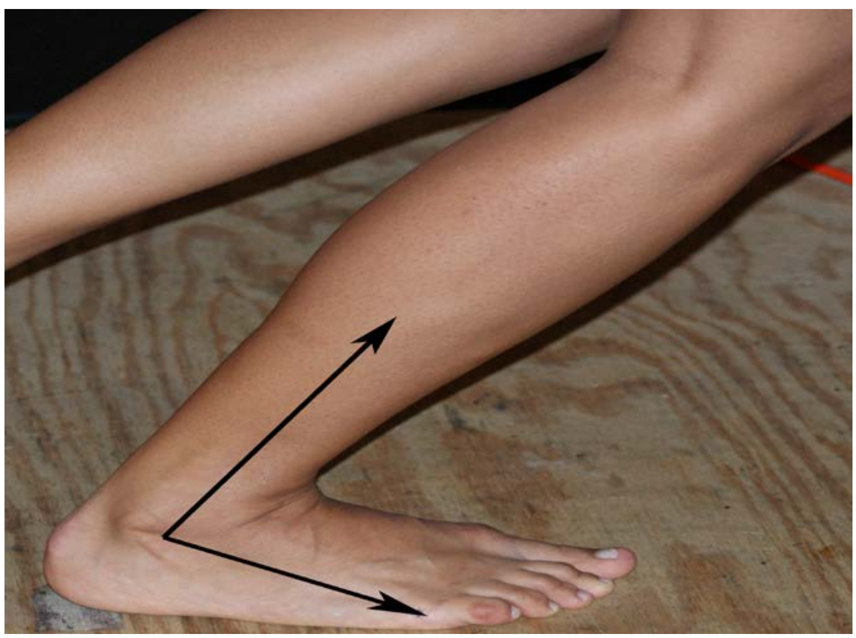

Figure 7 Ending position for ankle DFROM.

Ground Reaction Forces (GRFs)

After the warm up procedure, participants were asked to practice running sub-maximally across an AMTI force plate embedded in the floor of the Biomechanics laboratory. The length of the runway was 6.9 m. It is important to note that this distance was not predetermined, but was based on a qualitative estimation of how much space would be helpful in order for participants to be able to acquire uniform linear velocity before contact was made with the force plate. The desired uniform velocity may in fact not have been achieved during some of the trials. Also the first three runs were timed using a stopwatch in order to set a comfortable level of running velocity for each participant. Subsequent runs were then required to match the set velocity by being within 0.1 seconds of the set time. This was to ensure that running intensity was kept relatively consistent across trials. The average running duration was about 3.2 seconds across both groups.

All participants were instructed to run non-shod. Once participants felt comfortable running across the force plate, three different trials were conducted to assess peak vertical GRFs. Participants were instructed to step onto the force plate with their dominant foot, which was described to them as their kicking foot.

1RM test

Immediately following GRF data collection, participants were taken to the Barry University fitness center, housed in the same building as the Biomechanics Laboratory. Participants then performed 1RM tests for two lower leg exercises (described in the exercise protocol section) included in the training program. The 1RM test was performed as follows: (a) participants were asked to warm up by completing a number of submaximal repetitions, (b) 1RM was determined within four trials with rest periods of 3-5 minutes between trials, (c) an initial weight that was within each participant's perceived capacity was selected (50-70%), (d) resistance was progressively increased by 2.5 - 20kg until participants could not complete the selected repetitions. Participants were encouraged to perform exercise repetitions at a consistent angular speed and ROM, in order to ensure consistency between trials, and (e) the final weight lifted successfully was recorded as the absolute 1RM (Whaley, Brubaker, & Otto, 2006).

Exercise protocol

The following leg exercises were selected based on equipment availability and the muscle groups of interest that they target. Only participants in the experimental group received the training program. Participants were asked to perform three sets of 10-12 repetitions of bilateral seated calf raise and a seated reverse calf raise exercise, three times a week for six weeks. The seated calf raise exercise has been reported to especially isolate the soleus muscle during resistance training (Trappe, Raue, & Tesch, 2004). Participants in the control group did not receive any training program but were asked to maintain their regular fitness lifestyle, and to report any alterations to the investigator. Figures 8, 9, 10 and 11 illustrate the proper procedure for executing both of the assigned exercises.

Figure 8 Seated calf raise exercise (starting position).

Figure 9 Seated calf raise exercise (ending position).

Figure 10 Reverse seated calf raise exercise (starting position).

Figure 11 Reverse seated calf raise exercise (ending position).

The procedure for the seated calf raise is as follows: (a) participants were instructed to sit on a Cybex lower leg machine (see figures 8 and 9), with both of their knees at 90 degrees of flexion (ankles in slight dorsiflexion), (b) select weights were then loaded onto the machine, (c) participants were asked to raise their heels off the foot platform of the machine by plantar flexing at the ankle, moving loaded weights up against gravity, and (d) the heels were lowered back down to the starting position after each lift.

The procedure for the reverse seated calf raise is as follows: (a) participants were instructed to sit on the same Cybex machine (see figures 10 and 11), with both of their knees at 90 degrees of flexion (ankles in maximum plantarflexion, with the distal halves of the feet hanging down freely off of the edge of the machine's foot platform), (b) select weights were loaded onto the machine, (c) participants were then asked to raise their fore-feet by dorsiflexing at the ankle, moving loaded weights vertically up against gravity, and (d) the fore-feet were lowered back down to the starting position after each lift.

Each exercise consisted of three sets of 10-12 repetitions with loads ranging from 60-80% of each participant's 1RM. This load selection was made based on muscle strengthening recommendations by the ACSM (Whaley, Brubaker, & Otto 2006). Trappe, Raue, and Tesch, (2004), had their participants perform four sets of 15 repetitions of calf exercises during their investigation of the soleus muscle protein synthesis response. If participants indicated that their twelfth repetition had become considerably less challenging at any point during the six weeks, they were instructed to increase the amount of training weight by 10 lbs, or until their twelfth repetition became challenging.

Lower leg exercises were performed three times a week by participants in the experimental group (Whaley, Brubaker, & Otto, 2006).

Medial tibial pain

Participants were all provided with a visual analog pain scale (see appendix), and report charts to document any occurrence of medial tibial pain that they may have experienced over a period of six weeks. The six week pain scores were then totaled for each group, and weekly total pain was expressed as a percentage of the total pain.

Instrumentation

A laboratory goniometer was used to measure the passive ROM in the ankle joint. Activity related pain was assessed and documented by each participant over the course of the intervention, using a visual analog pain scale. A 1RM test was administered for both modes of leg exercises, for each participant according to guidelines outlined by Whaley, Brubaker, and Otto (2006). Comparison to standard norms was done also using the same guidelines from the same authors. Because assigned training programs included warm-ups and stretching regimens, participants were not expected to face any additional risks of injury, especially with the initial selection criteria. Seated calf seated raise exercises were performed using a calf raise machine (Cybex International, Inc., Medway, MA). 1RM determinations were achieved by using ACSM guidelines (Whaley, Brubaker, & Otto, 2006). Force readings were taken by means of an AMTI force plate (Advanced Mechanical Technologies, Inc., Watertown, MA). Medial tibial pain was ranked using a visual analog pain scale by PDlabs, Dorset, UK. Force data collection and statistical analysis were done using the Peak Motus software version 8.2 (ViconPeak, Centennial, CO), and the Statistical Package for Social Sciences (SPSS, version 16.0) (SPSS Inc., Chicago, IL), respectively.

Design and analysis

Dependent Variables

The dependent variables in this study were peak vGRFs, soleus muscle length (assessed as passive ankle dorsiflexion ROM), and lower leg muscle strength (measured as 1RM scores). One other dependent variable included the cumulative pain scores that participants reported during their regular physical activity. Pain due to MTSS was defined as a dull ache to intense pain that was exacerbated by repetitive weight bearing activities and may be continuous or intermittent (Tweed, Avil, Campbell, & Barnes, 2008).

Independent Variables

The independent variable was the group difference (experimental group was assigned lower leg exercises and control group was not).

Statistical Analysis

Statistical analysis was done using the SPSS software. Values for both the dependent and independent variables were input and relevant analysis was done for any outliers. Data analysis guidelines were followed, as recommended by Cronk (2006). A mixed MANOVA was calculated to determine any significant effects of lower leg strength training on the following dependent variables: (a) bilateral gastrocnemius-soleus muscle strength, (b) bilateral ankle dorsiflexion ROM, and, (c) peak vGRFs. Significance was defined as $p < 0.05$.

CHAPTER IV

RESULTS

The purpose of this study was to determine the effects of six weeks of strength training on lower leg muscle strength and peak vGRF generation, in physically active college-age individuals with MTSS. The specific aim of this study was to determine how six weeks of lower leg strength training may influence: (a) soleus and anterior tibialis muscle strength, (b) passive ankle dorsifexion ROM, and (c) and non-shod running peak vertical GRFs. Based on the stated aims of the current study, the following methods were employed to conduct the investigation. It was our expectation that obtained results may contribute to further understanding the etiology and possible treatment of the MTSS.

Participants

Ten physically active college age individuals volunteered to participate in this study (6 women, 4 men). After initial screening, participants were randomly assigned to one of two groups, i.e experimental and control groups. All ten participants presented for the posttest following six weeks of intervention. The demographic information for the participants is listed in Table 3.

Table 3

Demographic information

	Experimental group n = 5	Control group n = 5
Age (years)	23.50 ± 1.7	23.0 ± 4.24
Height (m)	1.63 ± 0.12	1.67 ± 0.14
Mass (kg)	66.13 ± 10.77	73.52 ± 10.83
Weight (N)	648.0 ± 105.5	720.49 ± 106.1
Average cumulative 6week pain	24.25 ± 4.50	13.5 ± 7.14

Note. All demographic data were self-reported by participants.

Statistical Analysis

A Pearson correlation coefficient was calculated to show the magnitude and direction of any correlations between pretest and posttest scores for all dependent variables. A mixed MANOVA was then calculated to determine any significant effects of the lower leg strength training on the following dependent variables: (a) bilateral soleus muscle strength, (b) bilateral ankle passive dorsiflexion ROM, and, (c) peak vGRFs.

Results

A Pearson correlation coefficient obtained from an initial paired-samples t test showed strong positive correlations between pretest and posttest scores for all dependent variables ($p < .05$) (Table 4). However the paired differences between pretest and posttest scores were not significant ($p > .05$) (see Table 5).

Table 4

Pearson correlation between pretest and posttest dependent variables' scores

Dependent variable	Correlation	Decision
Pretest R dorsiflexion – posttest R dorsiflexion	Strong	Significant
Pretest L dorsiflexion – posttest L dorsiflexion	Strong	Significant
Pretest SCR 1RM – posttest SCR 1RM	Strong	Significant
Pretest RSCR 1RM – posttest RSCR 1RM	Strong	Significant
Pretest Peak vGRFs – posttest peak vGRFs	Strong	Significant

Note. $p < 0.05$ defines a significant difference. R- right, L- left.

Table 5

Pearson correlation and cross interaction between respective dependent variables

Dependent variable	Correlation	Decision
SCR 1RM – RSCR 1RM	Moderate	Significant
SCR 1RM – ankle DF	Weak	Not significant
RSCR 1RM – ankle DF	Moderate	Not significant
SCR 1RM – peak vGRF	Moderate	Significant
RSCR 1RM – peak vGRF	Moderate	Significant

Note. $p < 0.05$ defines a significant difference, $p > 0.05$ shows insignificance. DF- dorsiflexion. All variables are represented as bilateral.

A mixed-design MANOVA showed that lower leg strength training had no significant effect on post-treatment ankle passive dorsiflexion ROM in both extremities ($p > .05$). Also lower leg strength training had no significant effect on bilateral lower leg muscle strength, peak vGRFs, and cumulative pain after six weeks of training (see Table 6).

Table 6

Summary of the statistics on each dependent variable

Dependent variable	Interaction	Main effect: Group
Right ankle dorsiflexion ROM	Not significant	Not significant
Left ankle dorsiflexion ROM	Not significant	Not significant
Seated calf raise 1RM	Not significant	Not significant
Reverse seated calf raise 1RM	Not significant	Not significant
Peak vGRFs	Not significant	Not significant
Cumulative six week pain	Not significant	Not significant

Note. $p < 0.05$ defines a significant difference, $p > 0.05$ shows insignificance.

Bilateral passive ankle dorsiflexion ROM measurement

A mixed-design MANOVA showed that the main effect of group on right passive ankle dorsiflexion ROM was not significant after six weeks ($F(1,6) = 3.7$, $p > .05$). Also the main effect of group on left passive ankle dorsiflexion ROM was significant after six weeks ($F(1,6) = 2.6$), $p > .05$). The differences between pretest and posttest bilateral passive ankle dorsiflexion ROM in the experimental and control groups are indicated in Table 7.

Table 7

Bilateral passive ankle dorsiflexion ROM (degrees) before and after training

	Experimental group mean, n = 5	Control group mean, n = 5
Pre-training (right ankle)	10.07 ± 2.15	8.60 ± 0.29
Post-training (right ankle)	10.70 ± 1.59	8.50 ± 0.31
Difference (pre - post)	+0.63	-0.10
Pre-training (left ankle)	10.40 ± 2.24	9.10 ± 0.46
Post-training (left ankle)	10.85 ± 1.51	9.05 ± 0.40
Difference (pre – post)	+0.45	-0.05

Seated calf raise 1RM values

A mixed-design MANOVA showed that the main effect of group on soleus strength (SCR 1RM) was not significant after six weeks ($F(1,5) = 0.50$, $p > .05$). Also the difference in soleus muscle strength between the experimental and control groups before and after training were not significant ($p > .05$). Soleus muscle strength was not influenced by group differences (see table 8).

Table 8

Soleus muscle strength (SCR 1RM, measured in lbs) before and after training

	Experimental group n = 5	Control group n = 5
Pre-training	116.25 ± 51.05	157.50 ± 66.89
Post-training	138.75 ± 37.50	161.25 ± 60.05
Difference (pre - post)	+22.5	+3.75

Reverse Seated calf raise 1RM values

A mixed-design MANOVA showed that six weeks of lower leg strength training did not have a significant effect on anterior tibialis strength ($F(1,5) = 3.62$, $p > .05$). Although there were differences in antero-lateral lower leg muscle strength between the experimental and control groups before and particularly after training, the differences were not significant ($p > .05$, see Table 9).

Table 9

Anterior tibialis muscle strength (RSCR 1RM, measured in lbs) before and after training

Time	Experimental group n = 5	Control group n = 5
Pre-training	90.0 ± 42.03	91.25 ± 33.0
Post-training	101.25 ± 34.0	92.87 ± 30.68
Difference (pre - post)	+11.25	+1.62

Peak vGRF values

A mixed MANOVA showed that lower leg strength training did not have any significant effect on peak vGRFs after six weeks ($F(1,5) = 0.17$, $p > .05$, see Table 10). In addition to peak vGRFs, Table 10 also shows the respective times to peak, impulses, and loading rates, as observed during this study. Peak vGRFs were normalized to each participant's body weight. There were no significant changes in peak vGRFs after six weeks of training ($p > 0.05$).

Table 10

Peak vGRFs before and after 6 weeks

Group	Peak vGRF (BW)	Time to peak (s)	Impulse (Ns)	Loading rate (N/s)
Experimental (pretest)	9.1	0.1	0.91	91.0
Experimental (posttest)	9.5	0.1	0.95	95.0
Control (pretest)	10.2	0.1	1.02	102
Control (posttest)	10.1	0.1	1.0	100.7

Medial tibial (shin) pain

Participants in the experimental and control groups were asked to document medial tibial pain as experienced over the course of study. Pain was ranked using a ten-point visual analog pain scale (0 = no pain, 10 = worst pain possible, and bed rest is required). Total pain was then calculated over six weeks and total weekly pain was computed as a percentage of the total six-week pain for both groups. Table 11 summarizes the distribution of tibial medial pain over the course of six weeks.

Table 11

Percentage distribution of medial tibial (shin) pain over six weeks

Group	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Experimental (n = 5)	22.7%	20.4%	18.9%	14.2%	11.8%	11.8%
Control (n = 5)	25.5%	19.3%	17.8%	10.0%	11.6%	15.5%

Summary of Results

A mixed MANOVA was calculated to determine any significant effects of lower leg strength training on the following dependent variables: (a) bilateral soleus muscle strength, (b) bilateral passive ankle dorsiflexion ROM, and, (c) peak vGRFs. Lower leg strength training did not have a significant effect on post-treatment passive ankle dorsiflexion ROM (bilateral), indicating that the treatment did not significantly improve ankle dorsiflexion ROM after six weeks. Also lower leg strength training had no significant effect on bilateral lower leg muscle strength and peak vGRFs. There was a progressive decrease in percent cumulative pain over six weeks of treatment in the experimental group.

CHAPTER V

DISCUSSION

Literature has drawn a connection between tight calf muscles and the onset of MTSS (Burne, Khan, & Boudville et al., 2004; Yates & White, 2004). In their respective publications, Clement (1974), and Yates and White (2004) described the dysfunction of lower leg muscles as a lack of endurance and/or lack of strength, or imbalance between agonists and antagonists muscles. The same authors then went on to theorize that muscle dysfunction may be part of the etiology of MTSS. In 2006, Madeley, Munteanu, and Bonanno conducted a case-control study comparing the endurance of the ankle joint plantar flexor muscles in athletes with MTSS, to that of athletes without MTSS. Although the previous study found that athletes with MTSS have endurance deficits of the ankle joint plantar flexor muscles, no studies to our knowledge have been done to investigate any relationship between calf muscle strength (specifically the soleus), and the attenuation of GRFs in individuals with MTSS.

According to Scott and Winter (1990), and Richie, DeVries, and Endo (1993), it is important that the lower leg muscles function optimally in order to be able to efficiently absorb biomechanical force (GRFs), and protect lower limb bones from excessive shock during physical activity. Radin et al. (1982) reported that the implications of insufficient shock absorption could be severe to the point that they may cause overuse injuries. Clement (1974) also suggested that weakness and fatigue of the calf muscles may lead to excessive force being transferred to the tibia, thereby predisposing individuals to MTSS related medial tibial shin pain. In the absence of clear and sufficient evidence regarding the speculative effects of GRF on overuse injuries (specifically MTSS), it was important to explore what the relationship might be, between lower leg muscle strength and GRF absorption in individuals with MTSS.

Summary of findings

All participants in the study were college age (23.25 ± 3.01 years), physically active individuals (engaging in moderate to intense recreational sport or exercise at least twice a week). Participant distribution included five volunteers in the experimental group and five other volunteers in the control group. All participants had been diagnosed with MTSS at least 3 months prior to the commencement of the study. Over the course of six weeks, participants in the experimental group were instructed to follow a biweekly lower extremity strength training program, targeted at increasing the strength of the soleus, tibialis anterior, and the peroneals (longus, brevis, and tertius). Although participants in the control group were not assigned any exercise program, all volunteers were instructed to maintain their regular physical activity levels and eating habits.

The following dependent variables were measured before and after six weeks of intervention: (a) ankle passive dorsiflexion ROM, (b) SCR 1RM, (c) RSCR 1RM, (d) peak vGRFs, and (e) average total medial tibial shin pain. The SCR and RSCR 1RM tests were used to assess soleus and anterior tibialis muscle strength, respectively.

1. The results indicated that lower leg strength training did not have a significant effect on bilateral passive ankle dorsiflexion ROM. This finding did not support our hypothesis that six weeks of lower leg strength training would lead to an increase in bilateral ankle dorsiflexion ROM.
2. Although the groups displayed noticeable differences in pre and post-

treatment values on measures of lower leg strength (the experimental group showing greater differences), the main effect for group was not significant for SCR 1RM, RSCR 1RM, and peak vGRFs.

3. There was a progressive decrease in self-reported medial tibial pain (expressed as a weekly percentage of the total six-week pain score aggregate). Both groups showed an initial decline in pain, but the decline continued past the third week only in the experimental group.

Bilateral passive ankle dorsiflexion ROM

According to the Peak Motus gait analysis tutorial (2004), the saggital plane motion of the ankle during the stance phase of normal gait can be broken down into three sub phases namely the heel rocker, ankle rocker and forefoot rocker. Immediately following the initial heel contact, the ankle typically dorsiflexes 5^{o} as the body's center of mass undergoes forward displacement. This initial ankle dorsiflexion occurs in order to counteract the extension moment acting through the heel, posterior to the ankle. This is the heel rocker (Peak Motus gait analysis tutorial, 2004). As the stance phase progresses into loading response, the resultant vGRF may reach up to 140% of the participants' weight. Peak vGRFs generated during this study (which involved submaximal running), were between nine to ten times each participant's body weight. As expected, peak vGRFs obtained during submaximal running in the current study were higher when compared to normative data for normal walking gait (Peak Motus gait analysis tutorial, 2004). In the second stage of the stance phase (the ankle rocker), vGRFs act anterior to the joint center of the ankle, causing 10^{o} of dorsiflexion about the ankle. The dorsiflexion pattern is then broken by a counteracting plantarflexion moment. The third phase of the stance phase (the forefoot rocker) occurs about the metatarsals as the foot accelerates and propels the body forward prior to toe-off (Peak Motus gait analysis tutorial). Although this sub phase is mostly propelled by an extensor moment arising from the concentric contraction of the plantar flexors, the ankle dorsiflexes a minimum of 5^o to provide foot clearance in the subsequent swing phase.

In a publication on the biomechanics of running, Novacheck (1998), reported that during midstance, the ankle dorsiflexes about 20^o acting as a GRF absorption mechanism in conjunction with knee flexion. The ankle also dorsiflexes about 10^o to ensure foot clearance during the swing phase of running (Novacheck).

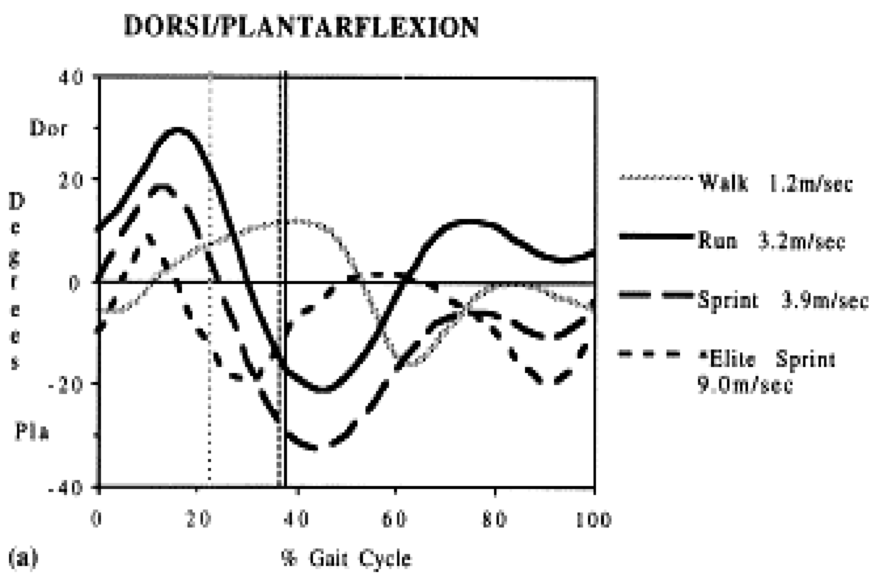

Figure 12 Sagittal ankle motion during walking, running, and sprinting

(Novacheck, T.F., 1998)

It is not clear how sagittal ankle movement (especially dorsiflexion) during specific gait events from the current study may have compared to ones described earlier, since videography and other motion capture equipment were not utilized. However, in place of the temporal, event-specific ROM readings obtainable through video, this study utilized a static passive ankle dorsiflexion ROM measurement, taken in a weight bearing position as shown in figures 5 and 6. While investigating hip and ankle ROM between female ballet dancers and control participants, Bennell et al. (1999) measured passive ankle dorsiflexion ROM in a weight-bearing stance similar to the one in this study. The fundamental design variation between the incumbent study and Bennell et al.'s (1999), is that while participants were not allowed to hold on to the wall in the former, they were instructed to hold on to the wall for support in the latter, during ankle dorsiflexion. Also while the contralateral limb remained in contact with the floor in a manner that is consistent with a lunge in the Bennell et al.'s study (1999), it was held in 90^o of knee flexion and off the floor (similar to the single limb support phase of running), during ipsilateral ankle dorsiflexion in the current study.

These differences in design may explain why the average ankle passive dorsiflexion ROM was drastically different between both studies. Bennell et al. (1999) recorded an average of 31.9^o and 29.2^o of passive ankle dorsiflexion among their experimental and control groups respectively. The mean dorsiflexion angles recorded in the current study were 10.5^o and 11.1^o (pretest and posttest), and 8.0^o and 8.5^o (pretest and posttest), for the experimental and control groups respectively. Cornwall and McPoil (1999) suggested based on past research that between 4^o and 10^o of ankle passive dorsiflexion ROM is required during the stance phase of normal walking gait, pointing out that values less than 10^o may constitute equinus. Cornwall and McPoil found that ankle passive dorsiflexion ROM values between 5^o and 10^o did not result in any significant change in magnitude of frontal plane rear-foot motion (inversion and eversion) during the stance phase of walking. However they found that individuals with limited dorsiflexion ROM showed less time to reinversion values than those with normal passive dorsiflexion ROM, after heel-off occurs. This finding counters prior suggestions that deficits in ankle dorsiflexion ROM is compensated for by excessively pronating the foot during ambulation. The magnitude of the frontal plane rear-foot kinematics was not monitored during ankle passive dorsiflexion ROM assessments in the current study. It is therefore uncertain whether or not participants may have compensated for any dorsiflexion deficits by excessively pronating their feet during the measurements. It is also not clear why the groups had different pretest mean values for ankle passive dorsiflexion ROM, since participants were all individuals who had been diagnosed with MTSS. There is a lack of research that compares ankle passive/active dorsiflexion ROM between normal populations and those with MTSS, and whether or not there might be a link between the duration of MTSS diagnosis and dorsiflexion ROM deficits, when observed. A 2006 study by Reinking reported non-significant differences in active (bent-knee) ankle dorsiflexion ROM between female collegiate athletes who developed ERLP and those who did not.

Although normative data regarding ankle dorsiflexion during human locomotion are available through different publications, they are often specified by velocity. For instance Novacheck (1998) defined walking at 1.2 m/s, running at 3.2 m/s, sprinting at 3.9 m/s in a group of children, and elite sprinters were defined at 0.9m/s. Considering that the running velocity was not measured in this study, assessing the adequacy of the dynamic ankle dorsiflexion angles shown by participants may be challenging. However, when compared to the normal 10^{o} ankle dorsiflexion at midstance during normal adult 1.4 m/s ambulation (Peak Motus gait analysis tutorial), dorsiflexion deficits may be apparent in both groups especially the control group, give the rationale that as the speed of normal gait progresses to that of running and sprinting, the knee, and ankle flexion angles typically increase as the body's center of mass lowers (Novacheck, 1998).

Although the average degree of ankle plantarflexion is greater during sprinting, the degree of ankle dorsiflexion is actually greater during normal running because of the longer duration of the shock absorption period. Despite findings by Fatouros et al. (2002) that resistance training may increase range of motion of a number of joints of inactive older individuals due to an improvement in muscle strength, there was no significant effect of lower leg strength training on passive ankle dorsiflexion ROM in the current study. This finding did not support our hypothesis that lower leg strength training exercises may increase the available passive dorsiflexion ROM at the ankle joint.

Peak vGRFs

In 1999, Nilson and Thorstensson reported that during the transition from walking to running, the limb support phase becomes shorter while vertical peak forces increase and vertical impulses decrease. Logan, Hunter, Feland, Hopkins, and Parcell (2006) found that during distance running, GRFs of more than 2 times a person's body weight (BW) are typical. According to a 2003 study by Bus, peak impact forces were 1.8 times the BW of young (20-35 years old), trained distance runners, running at a controlled speed of 3.3 m/s. In this study, mean impact GRFs (from initial contact) were 3.8 times the average BW in the experimental group (prestest and post test), and 3.5 times the average BW in the control group (prestest and posttest). Given the prior range of typical impact forces by Logan et al. (2006), and Bus (2003), the point can be made that peak impact forces in the current study were excessive, supporting our hypothesis that individuals with MTSS should generate higher GRFs when compared to the general population.

In his publication on the biomechanics of running, Novacheck (1998) reported that the ankle plantar flexor moments generated during the push-off phase of running, are larger than those generated during walking, and may range up to 6-8 times the BW. Novacheck (1998) explained that these peak forces which occur in the latter ¾ of the stance phase (midstance), are generated by the contraction of the gastrocnemius-soleus muscle complex during the propulsive phase of running, not the shock of the initial ground contact. Peak vGRFs from the current study were about 9.2 times the individual BW within the experimental group (prestest and post test), and 10 times the individual BW in the control group (prestest and posttest). Comparing the active peak force data from this study to the range stipulated by Novacheck (1998), a reasonable argument can be made that peak vGRFs were excessive as recorded in the current study, once again lending supporting to our hypothesis that individuals with MTSS will generate higher ground forces when compared to the general population. According to Novacheck (1998), certain lower extremity injuries are due to these active muscle forces in midstance, not to the passive impact forces at initial contact. Bus (2003), also commented on the suggested association between both high impact forces and excessive pronation, and lower-extremity injury. While connections have been made between MTSS and deficits in GRFs absorption (Blackburn, 2002), it is not clear which of the phases of GRFs (impact or propulsive) has a greater association to MTSS.

Although differences in soleus and anterior tibialis muscle strength were not statistically significant after six weeks of strength training, a positive significant correlation was found between muscle strength and peak vertical GRFs. Soleus muscle strength was strongly correlated to peak forces while anterior tibialis strength was only moderately correlated. This finding may suggest that there is a relationship between lower leg muscle strength and peak vGRF generation in individuals with MTSS. A vast majority of the studies that have explored GRF generation, its attenuation and its impulses (a function of the time to peak), have utilized drop-landing tests as their fundamental design. This makes it fairly challenging to present a pure juxtaposition of data regarding some of the attributes of peak ground forces (including impulse and loading rate), during submaximal running. Because peak vertical forces did not change significantly after six weeks, our initial expectation that peak vGRFs would reduce among participants in the experimental group was not supported after six weeks. An alternative explanation for the lack of significant change in the amounts of peak vGRFs that were absorbed between the initial and post-treatment trials is the fact that GRFs were measured in a non-fatigued state. Mercer, Bates, Dufek, and Hreljac (2003) concluded that less force was attenuated during fatigued than non-fatigued running despite relatively similar stride lengths. Since deficits in endurance in lower leg muscles (particularly the soleus) have been implicated in the etiology of MTSS, it is possible that any effects of increased muscle strength in improving force attenuation may have been latent since GRF measurements were done in a non-fatigued state. Perhaps measuring and comparing peak vGRFs in a fatigued state may have shown differences in GRF generation especially as it relates to lower leg muscle strength and endurance. Again muscle endurance was not assessed in this study so it remains unclear whether any endurance gains were made in the targeted muscles.

Also considering how GRF time to peak from this study compares to data from past literature. Bates, Dufek, and Davis pointed out in 1992 that there is a general inverse relationship between the magnitude of peak vertical forces and time to peak magnitudes. In a drop-landing study by Seegmiller and McCaw (2003), initial peak vertical force was attained after 10.5 ms and the second peak vertical force was reached after 35.5 ms. Conversely in the current study, initial (impact) peak forces were reached after 40 ms while final active peak forces were reached after 100 ms. Given the differences in mechanics between running and performing a drop-landing, there is a clear and anticipated disparity in how quickly peak forces were reached in Seegmiller and McCaw's study (2003), when compared to this study. During a shod running test of rear foot strikers by Novacheck (1998), passive force peak (2.1 x BW) was attained after 30 ms, while active force peak (3.1 x BW) was reached after about 90 ms. Interestingly the respective peak vertical forces, although less in magnitude, occurred sooner in Novacheck's study when compared to the current study. This observed peak force pattern contradicts the fact that higher peak forces are typically associated with shorter amounts of time to peak. It is important to note that although the focus of this study was on the role of lower leg muscles and the ankle joint, in attenuating peak vGRFs, the knee and the hip joints are involved in ground force management as well. The focus on the lower leg was prompted by the numerous publications that have drawn connections between MTSS and intrinsic lower extremity factors such as muscle strength and endurance, as well as deficits in ankle ROM. Gait pressure was not monitored in this study but given the direct relationship between force and pressure, any changes to peak forces would have impacted foot pressure accordingly. All reference studies pertaining to peak vGRFs were conducted with the participants shod in contrast to this study. This may have caused considerable differences in the force data outcome.

Soleus and anterior tibialis (lower leg) muscle strength

As mentioned earlier, differences in soleus and anterior tibialis muscle strength were not significant after six weeks of training. It is noteworthy however to point out that there were relative differences between the groups on soleus muscle strength (pretest SCR 1RM mean = 116.25 $\pm$ 51.05 (0.79 x mean experimental group BW), 157.50 $\pm$ 66.89 (0.97 x mean control group BW), posttest SCR 1RM mean = 138.75 $\pm$ 37.50 (0.95 x mean experimental group BW), 161.25 $\pm$ 60.05 (0.99 x control group BW)). These scores indicate that the average control group soleus muscle strength was greater than that of the experimental group before training. After six weeks of training however, the gap had narrowed considerably, despite statistically insignificant pretest-posttest differences. Studies have reported that strength training can increase strength and endurance in skeletal muscle (Marcinik et al., 1991; Stone et al., 2006). Although muscle endurance was not measured in the current study, it is possible that muscle endurance may have increased among participants in the experimental group after six weeks. Madeley, Mutnteanu, and Bonnano (2007) found endurance deficits in ankle joint plantar flexors in athletes with MTSS. The authors expressed a lack of clarity on whether endurance deficits were a result or cause of MTSS. In a study by Geertsen, Lundbye-Jensen, and Nielsen (2008), training group participants performed 12 training sessions of explosive dorsiflexion strength training over four weeks at three sessions per week. Electromyographic activity of the anterior tibialis and soleus muscles revealed increases in rate of torque development (RTD) and maximum voluntary contraction (MVC). However due to the lack of significant changes in anterior tibialis and soleus muscle properties, the authors explained increases in RTD and MVC to be a result of increase voluntary drive to muscles. Considering that soleus muscle strength did increase as pointed out earlier, it is possible that six weeks of strength training is not adequate to produce significant measurable changes in muscle strength.

Medial tibial pain

Pain associated with MTSS is typically located in the distal two-thirds of the postero-medial border of the tibia (Magnusson et al., 2001; Mubarek et al., 1982). Metzl and Metzl (2004) explained that in the early stages of MTSS, medial tibial pain occurs at the start of a work out, resolves during the course of the activity, and returns after the activity. They further pointed out that in later stages of MTSS, pain often becomes sharper and persists through the entire duration of the physical activity. In severe cases according to Metzl and Metzl (2004), a person with MTSS may experience pain throughout the entire day including periods of rest, in certain cases. Participants in this study were asked to track their medial tibial pain over six weeks by assigning corresponding pain scores from a visual analog pain scale leaflet. Among the experimental group, medial tibial pain progressively decreased from week one to week six (see Table 11), except for the last two weeks where pain remained at 11 % of the total six-week pain score. Medial tibial pain also decreased among the control group during the first four weeks of the study. However by the fifth week pain scores started to increase from a low of 10.0 % back up to 15.5 % of the total six-week pain. Figure 13 shows the trend of pain scores within the respective groups over a period of six weeks.

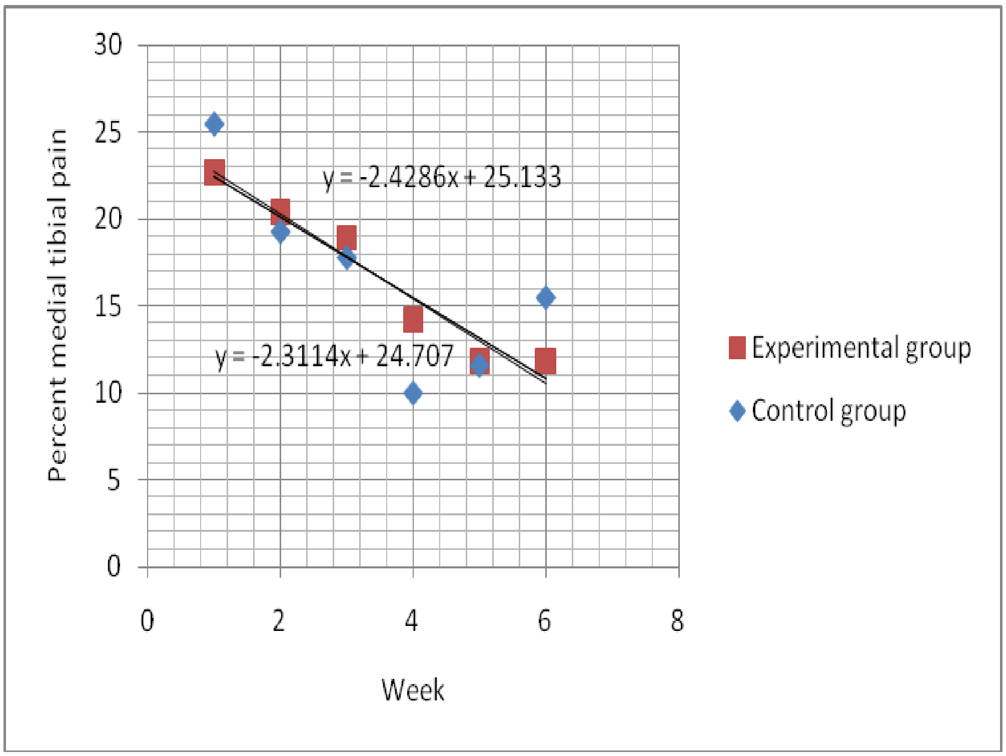

Figure 13 Percentage medial tibial pain

As expected, pain scores decreased among participants in the experimental group, lending support to our pre-intervention hypothesis. The premise of that hypothesis was the anticipation that increases in lower-leg muscle strength and ankle dorsiflexion ROM may produce increased ground reaction force attenuation, thereby reducing medial tibial pain scores among the experimental group. Considering the absence of any statistically significant increase in those outcome measures, it is unclear why there was a consistent decline in pain scores in the experimental group. A possible explanation may be that despite statistical non-significance, there were considerable increases in the average pretest and posttest 1RM scores for soleus and anterior tibialis muscles (see Tables 8 and 9). The change in lower leg muscle strength may have influenced the slight change in peak force value seen in Table 13. But again it remains unclear which phase of peak vGRFs (impact or propulsive) has a stronger correlation to MTSS-related pain. An alternative explanation to the decline in pain among the experimental group is that it may have been a placebo effect of the strength-training program on participants, as they were made aware of study hypotheses as well as the overall study objective. Following up on a placebo effect explanation however, it is difficult to explain why there was an initial decline in medial tibial pain within the control group other than the fact that physical activity level (as a potential medial tibial pain aggravator) may have been reduced during the weeks over which a decline in pain was observed. This explanation may in fact be applicable to both groups since the documentation of physical activity (type, duration, and intensity) was poorly done by participants in both groups, with the exception of a couple.

Lastly there was no documentation of how often participants used pain medication in the current study. It is possible that some of the decline that was seen in medial tibial pain may have been as a result of the effects of pain medication. Not instructing participants to record the use of pain medication may have been a design flaw in this study. Future studies should in fact have all participants should document all usage of any sort of medication while the study lasts.

Feedback from participants

Some of the participants in this study indicated strong enthusiasm and progress with their lower leg exercises. This set of participants verbally reported reduced medial tibial pain and a general sense of increased strength in the lower extremities. A couple of participants were honest and reported low exercise compliance during certain portions of the study, as a result of vacation and changes in job schedule. Overall participants were cooperative and responsive.

Study Limitations

The limitations experienced in this study include the following.

1. Group size: Because the study was conducted during a summer semester, there was a shortage of students available as potential participants. This limited the number of participants that ended up being in each study group. Ideally, about twenty participants should have been recruited for this study. The small size of participants was reflected in the observed statistical power of 0.17, which is considerably less than 0.80, commonly accepted as a standard of adequacy among researchers (Cronk, 2006).
2. Size of the biomechanics lab: The amount of room available for participants to run before making contact with the force plate was minimal. Although the total distance of the runway was about 6.9 meters, participants made foot contact with the force plate at a distance of about 3 meters from the starting

position. This distance may have been limiting as far as allowing participants enough time to build up to what may have been their preferred running speed. Walkway distances of about 6.1 meters have been prominently used in studies that have investigated gait patterns during walking (Cornwall & McPoil, 1999).

3. The non-utilization of a motion-capture system made it impossible to assess the actual running velocity during the trials. Having precise running velocities may have made it easier to make comparisons between this study and other related studies.
4. Due to the non-availability of dual force plate platforms, it was impossible to assess peak forces in both extremities within the same running gait cycle. Since all the participants experienced MTSS related pain bilaterally, it may have been helpful to have drawn parallels between the kinetic data obtained for each lower extremity.
5. Because all the participants were affiliated with Barry University, they had access to the university fitness center. However the leg exercise equipment was only accessible to participants at the university (as far as we knew). Therefore inability to be on the university premises on any certain day would have meant that participants were unable to perform their exercises for the day due to lack of access.
6. The lack of control of running speed may have created room for inconsistencies between running trials, thereby varying the kinetic data that was recorded.

7. Since participants were solely responsible for executing the assigned exercises, the actual level of compliance remains unknown amid poor documentation of all physical activity including the exercises, by many of the participants.

Conclusions

Within the limitations of this study, the following conclusions may be drawn:

- Six weeks of lower leg strength training did not affect significantly, outcome measures of peak vGRFs and bilateral soleus and anterior tibialis muscle strength. This finding did not support the research hypotheses regarding the anticipated relationship between these variables and lower leg resistance training. Although there were changes in soleus and anterior tibialis muscle strength within the experimental group after six weeks of training, the changes were not statistically significant.
- Six weeks of lower leg strength training produced significant changes in passive ankle dorsiflexion ROM among participants in the experimental group. Although passive ankle dorsiflexion ROM did not change the in the reference (control) group, an increase in ROM was observed in the experimental group. The initial research hypothesis was that increases in soleus and anterior tibialis muscle strength will result in increased passive ankle dorsiflexion ROM. Although increases in muscle strength were not statistically significant, this hypothesis was supported by the results.

- Six weeks of lower leg strength training may reduce medial tibial pain due to MTSS. Experimental group participants reported progressively less pain over the course of six weeks of strength training. Although participants in the control group also reported less pain until the third week, self reported pain scores increased throughout the rest of the study. This inconsistency in the pattern of pain in the control group may in fact point to other factors such as reduced level of physical activity, as a possible cause for the initial reduction in pain scores.

Recommendations for further study

Based on the results from this study, the following recommendations can be made for future studies:

- Given the changes that were observed in outcome measures of soleus and anterior tibial muscle strength (although non-significant), extending the period of strength training may produce statistically significant changes in muscle strength.
- An intensive stretching protocol performed at least three times a week should be incorporated alongside resistance training, in the experimental group.
- Using two force platforms may also be helpful in obtaining comparative kinetic data for both lower extremities.
- Motion capture equipment should be used in order to be able to monitor dynamic ankle joint excursions throughout the critical events of running gait, especially during midstance.

- In the absence of a longer laboratory runway, drop-landing tasks from a variety of heights may be considered, since they generate vGRFs which may elicit or contribute to the elicitation of MTSS-related pain.
- Traction forces including antero-posterior and medial-lateral should also be measured and monitored.
- The sample size should be increased to a total of at least 20 participants.
- Efforts should also be made to have gender balance across the groups that are being studied.
- A third group of normal participants (without any history of MTSS) should be incorporated as a control group.
- Running velocity should be set at a fixed value to control for inconsistencies between trials and invariably the kinetic data obtained.
- Participants should be asked to document any usage of pain medication throughout the course of the study.

REFERENCES

Aagaard, P., Simonsen, E.B., Andersen, J.L., Magnusson, P., Dyre-Poulsen, P. (2002). Increased rate of force development and neural drive of human skeletal muscle following resistance training. *Journal of Applied Physiol*ogy, 93: 13: 18-1326.

Baquie, P., & Bruckner, P. (1997). Injuries presenting to an Australian sports medicine centre: a 12 month study. *Clinical Journal of Sports Medicine,* 7: 28-31.

Bates, P. (1985). Shin splints: a literature review. *British Journal of Sports Medicine,* 19: 132-137.

Bates, B.T., Dufek, J.S., & Davis, H.P. (1992). The effect of trial size on statistical power. *Medicine & Science in Sports & Exercise,* 24: 1059–1065.

Batt, M., Ugalde, V., Anderson, M., & Shelton, D. (1998). A prospective controlled study of diagnostic imaging for acute shin splints. *Medicine & Science in Sports & Exercise*, 30: 1564-1571.

Bennell, K.L., & Crossley, K. (1996). Musculoskeletal injuries in track and field: incidence, distribution and risk factors. *Australian Journal of Science and Medicine in Sport* 28: 69-75.

Bennell, K., Khan, K.M., Mathews, B., Gruyter, M.D., Cook, E., Holzer, K., & Wark, J.D. (1999). Hip and ankle range of motion and hip muscle strength in young novice female ballet dancers and controls. *British Journal of Sports Medicine,* 33: 340-346.

Bennell, K., Matheson, G., Meeuwisse, W., & Brukner, P. (1999). Risk factors for stress fractures. *Sports Medicine,* 28: 91-122.

Bennett, J.E., Reinking, M.F., Pluemer, B, et al. (2001). Factors contributing to the development of medial tibial stress syndrome in high school runners. *Journal of Orthopedic Sports & Physical Therapy*, 1: 504-510.

Blackburn, M. (2002). *A prospective design identifying etiological risk factors associated with MTSS and stress fractures in female intercollegiate athletes*. Unpublished master's thesis, East Tennessee State University– Johnson City, Tennessee.

Brody, D.M. (1980). Running injuries. *Clinical Symposium*, 32: 1-36.

Brukner, P. (2000). Exercise-related lower leg pain: bone. *Medicine & Science in Sports & Exercise*, 32: 15-26.

Burne, S.G., Khan, K.M., Boudville, P.B., et al. (2004). Risk factors associated with exerctional medial tibial pain: a 12-month prospective clinical study. *British Journal of Sports Medicine,* 38: 441-445.

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

Cetinus, E., Uzel, M., Bilgic, E., Karaoguz, A., & Herdem, M. (2004). Exercise induced compartment syndrome in a professional footballer. *British Journal of Sports Medicine,* 38: 227-229.

Clement, D.B. (1974). Tibial stress syndrome in athletes. *Journal of Sports Medicine,* 2: 81-85.

Cornwall, M.W. & McPoil, T.G. (1999). Effect of ankle dorsiflexion range of motion on rearfoot motion during walking. *Journal of American Podiatry Medicine Association,* 89: 272-277.

Cowan, D.N., Jones, B.H., Frykman, P.N., Polly, P.W., Harmon, E.A., Rosenstein, M.T. (1996). Lower limb morphology and risk of overuse injury among male infantry trainees. *Medicine & Science in Sports & Exercise,* 28: 945-952.

Craig, D.I. (2008). Medial tibial stress syndrome: evidence-based prevention. *Journal of Athletic Training,* 43: 316–318.

Cronk, B.C. (2006). *How to use SPSS: A step-by-step guide to analysis and interpretation* (4th ed). Glendale: Pyrzac Publishing, pp. 13-89.

Edwards, P.H., Wright, M.L., Hartman, J.F. (2005). A practical approach for the differential diagnosis of chronic leg pain in the athlete. *American Journal of Sports Medicine,* 33: 1241.

Fatouros, I.G. et al. (2002). The effects of strength training, cardiovascular training and their combination on flexibility of inactive older adults. *International Journal of Sports Medicine*, 23: 112-119.

Fyhrie, D.P., Milgrom, C., Hoshaw, S.J., et al. (1998). Effect of fatiguing exercise on longitudinal bone strain as related to stress fracture in humans. *Annals of Biomedical Engineering,* 26: 660-665

Gaeta, M., Minutoli, F., Vinci, S., Salamone, I., D'Andrea, L., Bitto, L. et al. (2006). High-resolution CT grading of tibial stress reactions in distance runners. *American Journal of Roentgenology,* 197: 789-793.

Geertsen, S.S., Lundbye-Jensen, J., Nielsen, J.B. (2008). Increased central facilitation of antagonist reciprocal inhibition at the onset of dorsiflexion following explosive strength training. *Journal of Applied Physiology* 105: 915–922.

Gellman, R., & Burns, S. (1996). Walking aches and running pain- injuries of the foot and ankle. *Primary Care, Clinics in Office Practice,* 23: 263-280.

Hawkins, D., & Bey, M. (1997). Muscle and tendon-length properties and their interactions in vivo. *Journal of Biomechanics*, 30: 63-70.

Herring, S.A., & Nilson, K.L. (1987). Introduction to overuse injuries. *Clinical Sports Medicine,* 6: 225–239.

Hester, J.T. (2006). Conquering medial tibial stress syndrome. *Podiatry Today,* 19: 48-55.

Heinonen, A., Oja, P., Kannus, P., Sievanen, et al. (1995). Bone mineral density in female athletes representing sports with different loading characteristics of the skeleton. *Bone*, 17: 97-203**.**

Inman, V.T., Ralston, H.J., & Todd, F. (1981). *Human walking*. Baltimore: Williams & Wilkins, pp. 128-129.

James, S.L., Bates, B.T., & Osternig, L.R. (1978). Injuries to runners. *American Journal of Sports Medicine*, 6: 40-50.

Kaufman, K.R.,, Brodine, S.K., Shaffer, R.A., Johnson, C.W., & Cullison, T.R. (1999). The Effect of Foot Structure and Range of Motion on Musculoskeletal Overuse Injuries. *The American Journal of Sports Medicine* 27: 585-593.

Lips, P., & Ooms, M.E. (2000). Non-pharmacological interventions. *Bailliere's Clinical Endocrinology and Metabolism,* 14: 265-277.

Logan, S., Hunter, I., Feland, B., Hopkins, T., & Parcell, A. (2006). Ground reaction forces between running shoes, racing flats and distance spikes in runners. Unpublished manuscript, Brigham Young University at Utah.

Madeley, L., Munteanu, S., & Bonanno, D. (2006). Endurance of the ankle joint plantar flexor muscles in athletes with medial tibial stress syndrome: A case-control study. *Journal of Science & Medicine in Sport*, 10: 356-362.

Magnusson, H., Westlin, N., Nyqvist, F., Gardsell, P., Seeman, E., & Karlsson, M. (2001). Abnormally Decreased Regional Bone Density in Athletes with Medial Tibial Stress Syndrome. *American Journal of Sports Medicine,* 27: 712-715.

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

Marcinik, E.J., Potts, J., Schlabach, G., Will, S., Dawson, P., Hurley, B.F. (1991). Effects of strength training on lactate threshold and endurance performance. *Medicine & Science in Sports & Exercise*, 23: 739-43.

McHugh, M.P., Connolly, D.A.J., Eston, R.G. et al. (1999). The role of passive muscle stiffness in symptoms of exercise-induced muscle damage. *American Journal of Sports Medicine*, 27: 594-599.

Mercer, J.A,. Bates, B.T., Dufek, J.S., & Hreljac, A. (2003). Characteristics of shock attenuation during fatigued running. Journal of Sports Science, 21: 911-919.

Metzl, J.A., & Metzl, J.D. (2004). Shin pain in an adolescent soccer player: A case-based look at shin splints. *Contemporary Pediatrics.* 21: 36-48.

Michael, R.H., & Holder, L.E. (1985). The soleus syndrome: A cause of medial tibial stress (shin splints). *American Journal of Sports Medicine,* 13: 87-94.

Middleton, J., Sinclair, P., & Patton, R. (1999). Accuracy of centre of pressure measurement using a piezoelectric force platform. *Clinical Biomechanics,* 14: 357-360.

Moore, K.L. (1998). *Clinically oriented anatomy* (3^{rd} ed.). Baltimore: Williams & Wilkins, pp. 443-459.

Mubarek, S.J., Gould, R.N., Lee, Y.F., Schimdt, D.A., & Hargens, A.R. (1982). The medial stress syndrome: a cause of shin splints. *American Journal of Sports Medicine*, 10: 201-205.

Nigg, B.M., MacIntosh, B.R., & Mester, J. (2000). *Biomechanics and biology of movement* (2^{nd} ed.). Champaign: Human Kinetics, pp. 255-256.

Nilson, J., & Thorstensson, A. (1989). Ground reaction forces at different speeds of human walking and running. *Acta Physiologica Scandinavica.*, 136: 217-227.

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

Overturf, R., & Kravitz, L. 2002. Strength training and flexibility. *IDEA Personal Trainer*, 13: 17-19.

Peak Motus Gait Analysis Tutorial. (2004). *Peak performance technologies, Inc. Centenniel*, pp. 6-31.

Radin, J.T. et al. (1982). Shock attenuation and overuse injury. *Journal of Biomechanics*, 15: 487-492.

Richie, D.H., DeVries, H.A., Endo, C.K. (1993). Shin muscle activity and sport surfaces: An electromyographic study. *Journal of American Podiatry Medical Association*, 83: 181-190.

Reinking, M. (2006). Exercise-related leg pain in female collegiate athletes. *American Journal of Sport Medicine*, 20: 1-8.

Reinking, M., & Hayes, A. (2006). Intrinsic factors associated with exercise-related leg pain in collegiate cross country runners. *Clinical Journal of Sports Medicine,* 16: 10-14.

Ruohola, J.P., Kiuru, M.J., & Pihlajamaki, H.K. (2006). Fatigue bone injuries causing anterior lower leg pain. *Clinical Orthopedic and Related Research*, 444: 216–223.

Sands, W.A., Schultz, B.B., & Newman, A.P. (1993). Women's gymnastic injuries: A 5-year study. *American Journal of Sports Medicine*, 21: 271-276.

Scott, S.H., & Winter, D.A. (1990). Internal forces of chronic running injury sites. *Medicine & Science in Sports & Exercise,* 22: 357-369.

Seegmiller, J.G., & McCaw, S.T. (2003). Ground reaction forces among gymnasts and recreational athletes in drop landings. *Journal of Athletic Training,* 38: 311-314.

Slocum, D.B. (1967). The shin splint syndrome: Medical aspects and differential diagnosis. *American Journal of Surgery,* 114: 875-881.

Stone, M.H., & Stone, M.E. et al. (2006). Maximum strength and strength training- a relationship to endurance? *Strength and Conditioning Journal,* 28: 44-53.

Stublar, J., Usenik, P., Kamnik, R., & Munih, M. (2007). *Changes in biomechanics induced by fatigue in single-leg jump and landing*. 11th Mediterranean conference on medical and biomedical engineering and computing, 16: 288-291.

Taunton, J.E., Ryan, M.B., Clement, D.B. et al. (2002). A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine,* 36: 95-101.

Thacker, S.B., Gilchrist, J., Stroup D.F., & Kimsey, C.D. (2002). The prevention of shin splints in sports: a systematic review of literature. *Medical Science in Sports Exercise*, 34: 32-40.

Thompson, C.W., & Floyd, R.T. (1994). *Manual of structural kinesiology* (12th ed.). St. Louis: Mosby-Year Book.

Trappe, T.A., Raue, U., Tesch, P.A. (2004). Human soleus muscle protein synthesis following resistance exercise. *Acta Physiologica Scandinavica*, 182: 189-196.

Tweed, L., Avil, S., Campbell, J., & Barnes, M. (2008). Etiologic factors in the development of medial tibial stress syndrome: A review of the literature. *Journal of the American Podiatric Medical Association* 98: 107-111.

Whaley, M.H., Brubaker, P.H., & Otto, R.M. (2006). *ACSM's guidelines for exercise testing and prescription* (7^{th} ed). Baltimore: Lippincot Williams & Wilkins, pp. 81-82.

Whiting, W.C., & Rugg, S. (2006). Dynatomy: dynamic human movement. Human Kinetics, Champaign , IL.

Wilder, R.P., & Sethi, S. (2004). Overuse injuries: tendinopathies, stress fractures, compartment syndrome and shin splints. *Clinical Sports Medicine*, 23: 55-81.

Willems, T.M., Clercq, D.D., Delbaere, K. (2006). A prospective study of gait related risk factors for exercise-related lower leg pain. *Gait & Posture* 23: 91–98.

Witvrouw, E., Mahieu, N., Danneels, L., & McNair, P. (2004). Stretching and injury prevention: an obscure relationship. *Sports Medicine*, 34: 443-449.

Yates, B., Allen, M., & Barnes, M. (2003)**.** Outcome of surgical treatment of medial tibial stress syndrome. *The Journal of Bone and Joint Surgery,* 85: 1974-1980.

Yates, B., & White, S. (2004). The incidence and risk factors in the development of medial tibial stress syndrome among naval recruits. *American Journal of Sports Medicine,* 32: 772-778.

Yoshimitsu, A., Kazunori, Y., Harukazu, T., Hirokazu, I., & Akio, M. (2004). Magnetic resonance imaging in stress fractures and shin splints. *Clinical Orthopaedics and Related Research,* 421: 260-267.

APPENDICES

Appendix A

Recruiting Flyers

14 PARTICIPANTS NEEDED FOR SHIN SPLINTS STUDY

1) Have been injury-free for the past three months?

2) Do you engage in regular exercise at least twice a week?

3) Have you experienced pain due to shin splints for at least three months?

4) Are you between the ages of 18-26 years old?

* If you answered "yes" to all of the above, you may qualify for a study investigating the effect of lower leg strength training on the absorption of ground forces in individuals with shin splints!

* Contact Toyin
* (701) 610 1517 or ajisafet@bucmail.barry.edu

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Appendix B

Screening Questionnaires

FIGURE 2-2. PAR-Q form.

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition <u>and</u> that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of <u>any other reason</u> why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

<u>Informed Use of the PAR-Q</u>: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ____________________

SIGNATURE ____________________ DATE ____________________

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) ____________________ WITNESS ____________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

continued on other side...

Source: Physical Activity Readiness Questionnaire (PAR-Q) © 2002. Reprinted with permission from the Canadian Society for Exercise Physiology. http://www.csep.ca/forms.asp.

FIGURE 2-1. AHA/ACSM Health/Fitness Facility Preparticipation Screening Questionnaire*

Assess your health status by marking all *true* statements

History

You have had:

_____ a heart attack
_____ heart surgery
_____ cardiac catheterization
_____ coronary angioplasty (PTCA)
_____ pacemaker/implantable cardiac defibrillator/rhythm disturbance
_____ heart valve disease
_____ heart failure
_____ heart transplantation
_____ congenital heart disease

Symptoms

_____ You experience chest discomfort with exertion.
_____ You experience unreasonable breathlessness.
_____ You experience dizziness, fainting, or blackouts.
_____ You take heart medications.

Other health issues

_____ You have diabetes.
_____ You have asthma or other lung disease.
_____ You have burning or cramping sensation in your lower legs when walking short distances.
_____ You have musculoskeletal problems that limit your physical activity.
_____ You have concerns about the safety of exercise.
_____ You take prescription medication(s).
_____ You are pregnant.

If you marked any of these statements in this section, consult your physician or other appropriate health care provider before engaging in exercise. You may need to use a facility with a ***medically qualified staff.***

Cardiovascular risk factors

_____ You are a man older than 45 years.
_____ You are a woman older than 55 years, have had a hysterectomy, or are postmenopausal.
_____ You smoke, or quit smoking within the previous 6 months.
_____ Your blood pressure is >140/90 mm Hg.
_____ You do not know your blood pressure.
_____ You take blood pressure medication.
_____ Your blood cholesterol level is >200 mg/dL.
_____ You do not know your cholesterol level.
_____ You have a close blood relative who had a heart attack or heart surgery before age 55 (father or brother) or age 65 (mother or sister).
_____ You are physically inactive (i.e., you get <30 minutes of physical activity on at least 3 days per week).
_____ You are >20 pounds overweight.

If you marked two or more of the statements in this section you should consult your physician or other appropriate health care provider before engaging in exercise. You might benefit from using a facility with a ***professionally qualified exercise staff***† *to guide your exercise program.*

_____ None of the above

You should be able to exercise safely without consulting your physician or other appropriate health care provider in a self-guided program or almost any facility that meets your exercise program needs.

*Modified from American College of Sports Medicine and American Heart Association. ACSM/AHA Joint Position Statement: Recommendations for cardiovascular screening, staffing, and emergency policies at health/fitness facilities. Med Sci Sports Exerc 1998;1018.

†Professionally qualified exercise staff refers to appropriately trained individuals who possess academic training, practical and clinical knowledge, skills, and abilities commensurate with the credentials defined in Appendix F.

Appendix C

Informed Consent Form

Barry University
Informed Consent Form

Your participation in a research project is requested. The title of the study is The Relationship between Increased Leg Muscle Strength and Ground Reaction Force Attenuation in Individuals with Medial Tibial Stress Syndrome (MTSS). The research is being conducted by Toyin Ajisafe, a student in the Human Performance and Leisure Sciences department at Barry University, and is seeking information that will be useful in the field of Biomechanics and Injury prevention. The aims of the research are to determine how six weeks of leg muscle exercises may influence: (a) leg muscle strength and endurance, (b) ankle flexibility, and (c) the absorption of ground forces during bare foot running.

In accordance with these aims, the following procedures will be employed in the course of this study: (a) all volunteers will be screened for recent fractures, compartment syndrome, and vascular diseases (any of which if present will disqualify from participation in the study), (b) posterior lower leg muscle compartment flexibility will be assessed by measuring ankle dorsiflexion range of motion with the knees bent, (c) ground forces will be recorded for volunteers before and after a six week treatment period, using an AMTI force plate, (d) a maximum strength test (1RM test) will be carried out for two lower leg exercises namely a seated calf raise exercise, and a seated reverse calf raise exercise, and (e) volunteers with MTSS will be assigned a strength training program consisting of stretching and warm-up protocols, and prescribed sets and repetitions of the above exercises. We anticipate the number of participants to be 14 (all previously diagnosed with MTSS).

If you decide to participate in this research, you will be asked to do the following: present to the Barry University Biomechanics Laboratory on a set date and time, for screening and baseline data collection (pre-test). This initial testing session will last about 45 minutes. First you will be asked to perform a five minute warm-up session on a stationary spin bike. You will also perform several lower leg stretches which will target the front, back and side muscles, as well as the thigh muscles.

First your ankle joint flexibility will be measured. You will be asked to stand upright with both feet at shoulder width while maintaining a distance of about 8 inches from the laboratory wall, placing one foot ahead of the other in a step-stance position. You will then be instructed not to touch the wall unless it is necessary in order to prevent a fall or to prevent loss of balance. Touching the wall during any trial rendered the trial invalid. The knee of the leading leg will be held in full extension starting out. Shifting all of your weight onto the leading leg, you will then lean forward by bending the leading knee as far forward as you can, lifting your other foot off the floor. The moving arm of the goniometer will be aligned with the long axis of your leg and the stationary arm will be placed over the base of your small toe. After each measurement is taken you will be asked to return to the starting position to initiate a new measurement. Three sets of measurements will be taken on each leg, recording the angular displacement between the shank and the vertical axis. The average of all three measurements will be recorded as the available dorsiflexion range of motion at the specified ankle.

Next, your ground forces will be measured. You will be asked to practice running barefoot at a self selected speed across an AMTI force plate, embedded in the floor of the Biomechanics laboratory. Once you are judged ready for data collection by the investigator, three different trials will be conducted to assess your ground forces. All participants will be instructed to step onto the force plate with the foot of their dominant (kicking) leg.

Immediately following the measurement of ground forces, you will be taken to the Barry University fitness center, housed in the same building as the Biomechanics Laboratory. You will perform 1RM tests for three exercises including a standing and seated calf raise exercise, as well as a seated reverse calf raise exercise. The 1RM test will be performed as follows: (a) you will warm up by completing a number of submaximal repetitions, (b) 1RM will be determined within four trials with rest periods of 3-5 minutes between trials, (c) an initial weight which will be within your perceived capacity will be selected, (d) resistance will be progressively increased 5.5 to 44 pounds until you cannot complete the selected repetitions. All repetitions will be performed at the same speed of movement and ROM to ensure consistency between trials, and (e) the final weight lifted successfully will be recorded as your absolute 1RM.

The procedure for the seated calf raise exercise is as follows: (a) you will begin by sitting on the Cybex machine (lower leg exercise machine), with both of your knees bent at 90 degrees (feet flat on the floor), (b) select weights will be loaded onto the machine, (c) you will lift your heels by rising up onto the balls of your feet, moving loaded weights vertically against gravity, and (d) you will lower your heels back down to the starting position after each lift.

The procedure for the seated reverse calf raise exercise is as follows: (a) you will begin by sitting on the Cybex machine, with both of your knees bent at 90 degrees (feet flat on the floor), (b) select weights will be loaded onto the machine, (c) you will then raise your toes by bending their foot upwards, moving loaded weights vertically up against gravity, and (d) you will lower your toes back down to the starting position after each lift.

After the completion of the 1RM tests, you may or may not receive a lower leg strength training program depending on which group you have been assigned to. If assigned to the experimental group, you will be expected to perform the strengthening exercises twice a week. You will also perform three sets of between 8-12 repetitions for each exercise. A complete lower leg training session is estimated to last about 20 minutes.

Follow-up data will be collected within three days from the end of the six week training program. You will be asked to present back at the same location as the pre-test. For safety and convenience reasons, you will be asked to dress in work-out clothes, specifically a t-shirt, non-baggy gym shorts, and a pair of gym shoes, during both the initial and final data collection. Each data collection session is estimated to last about 45 minutes (pre-test and post-test). During the six weeks of treatment, participants in the control group will be asked to maintain their normal levels of physical activity and to document any changes. Both groups will also be asked to document other strength training activities that they may engage in during the six week treatment period.

Your consent to be a research participant is strictly voluntary and should you decline to participate or should you choose to drop out at any time during the study, there will be no adverse effects on your standing in the Barry community.

According to the ACSM handbook (Whaley, Brubaker, & Otto, 2006) exercise only provokes cardiovascular events in individuals with preexisting heart disease (diagnosed or undiagnosed). The risks of involvement in this study are no greater than that experienced during participation in a vigorous physical activity such as competitive sports or heavy weight lifting. Muscle strains are a possibility. However the following procedures will be used to minimize these risks: All participants will be of normal body mass index ((BMI), (no greater than 25 $kg.m^{-2}$, no less than 18.5 $kg.m^{-2}$), and will have a recent history of involvement (moderate to high) in regular aerobic or resistance training activities. Participants will be between the ages of 18-26 years and will all complete PAR-Q forms as well as a pre-participation screening questionnaire for risk stratification. Only individuals with low risk will be selected to participate in this study.

The investigator will also conduct blood pressure screenings for each volunteer, who will then be informed of the early symptoms of Coronary Artery Disease (CAD). This is so participants know what signs to look out for if they ever experience any unusual sensations during exercise or other physical exertion. Participants will be instructed to notify the investigator of unusual sensations immediately. All weight lifting sessions will be conducted one-on-one, and under the direct supervision of the principal investigator who holds certifications through the American Council on Exercise, for personal training, and the Aerobic Fitness Association of America, for group fitness instruction. Exercise sessions will always be preceded by stretching and proper warm up. All exercise loads will be based on each participant's 1RM. Although there may not be any direct benefits to you, your participation in this study may contribute to our understanding of the causes and treatment of MTSS.

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 the study. Data will be kept in a locked file in the researcher's office. Data collected during the course of this study will be documented without including participant names. All data will be destroyed after five years from the original date of collection. Your signed consent form will be kept separate from the data.

If you have any questions or concerns regarding the study or your participation in the study, you may contact me, Toyin Ajisafe, at (701) 610-1517, or my supervisor, Dr. Claire Egret, at (305) 899 3064, or the Institutional Review Board point of contact, Mrs. Barbara Cook, at (305) 899-3020. If you are satisfied with the information provided and are willing to participate in this research, please 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 Toyin Ajisafe 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.

______________________ __________

Signature of Participant *Date*

______________________ __________ ______________________ __________

Researcher *Date* *Witness* *Date*

(Witness signature is required only if research involves pregnant women, children, other vulnerable populations, or if more than minimal risk is present.)

Appendix D

Exercise Instruction and Training Log

Training Instructions:

Before attempting the resistance training exercises please observe the following warm up procedure for safety reasons:

1) Select a stationary bike, a treadmill, or an elliptical machine (depending on what you are comfortable with), and warm for 5-10 minutes at a low intensity.
2) Whatever equipment you choose for your warm-up, your intensity should feel like the equivalent of a slow-paced walk starting out then graduating to a medium and finally to a fast-paced walk, progressing after every three minutes.
3) The last minute of your warm-up routine should be spent at the same intensity at which you started out. This is to ensure that your heart rate returns to a fairly low and steady pace as you bring your warm-up session to a close.
4) You may then start your resistance training by first completing about 15 repetitions of the respective exercises without loading any weights onto the equipment.

Breathing technique:

1) As a guide be sure to breathe out during the exertion phase of each exercise, breathing back in during the recovery phase.
2) All other parts of the body should be as relaxed as possible while maintain proper sitting posture, keeping the trunk erect at all times.

Hydration:

1) REMEMBER to drink at least 20 oz of water or a sports drink during the course of your exercise session.
2) REMEMBER to stretch your calf and front leg after exercising.
3) Finally fill out the training log after each session.
4) Please feel free to contact me if you have any questions or concerns regarding your exercises. ajisafet@bucmail.barry.edu or 701-610-1517.

Seated calf raise exercise (starting position).

Seated calf raise exercise (ending position).

Instruction:

1) Sit on the Cybex lower leg machine with both knees bent at 90 degrees (ankles slightly bent upwards).
2) Load select weights onto the machine.
3) Raise your heels while keeping your forefeet on the foot platform of the machine (by plantar flexing at the ankle) moving loaded weights up against gravity.
4) Lower your heels back down to the starting position after each lift.

Reverse seated calf raise exercise (starting position).

Reverse seated calf raise exercise (ending position).

Instruction:

1) Sit on the Cybex lower leg machine with both knees bent at 90 degrees (ankles in maximum plantarflexion, with the distal halves of the feet hanging down freely off of the edge of the machine's foot platform).
2) Load select weights onto the machine.
3) Keeping the heels in contact with floor of the machine, raise both fore-feet up (by dorsiflexing at the ankle), moving loaded weights vertically up against gravity.
4) Lower fore-feet back down to the starting position after each lift.

RESEARCH PARTICIPCANT DAILY EXERCISE LOG

Day/ date	Seated calf raise set/repetitions	Reverse seated calf raise set/repetitions

Experimenter______________________________ Date_________________

Instructions:

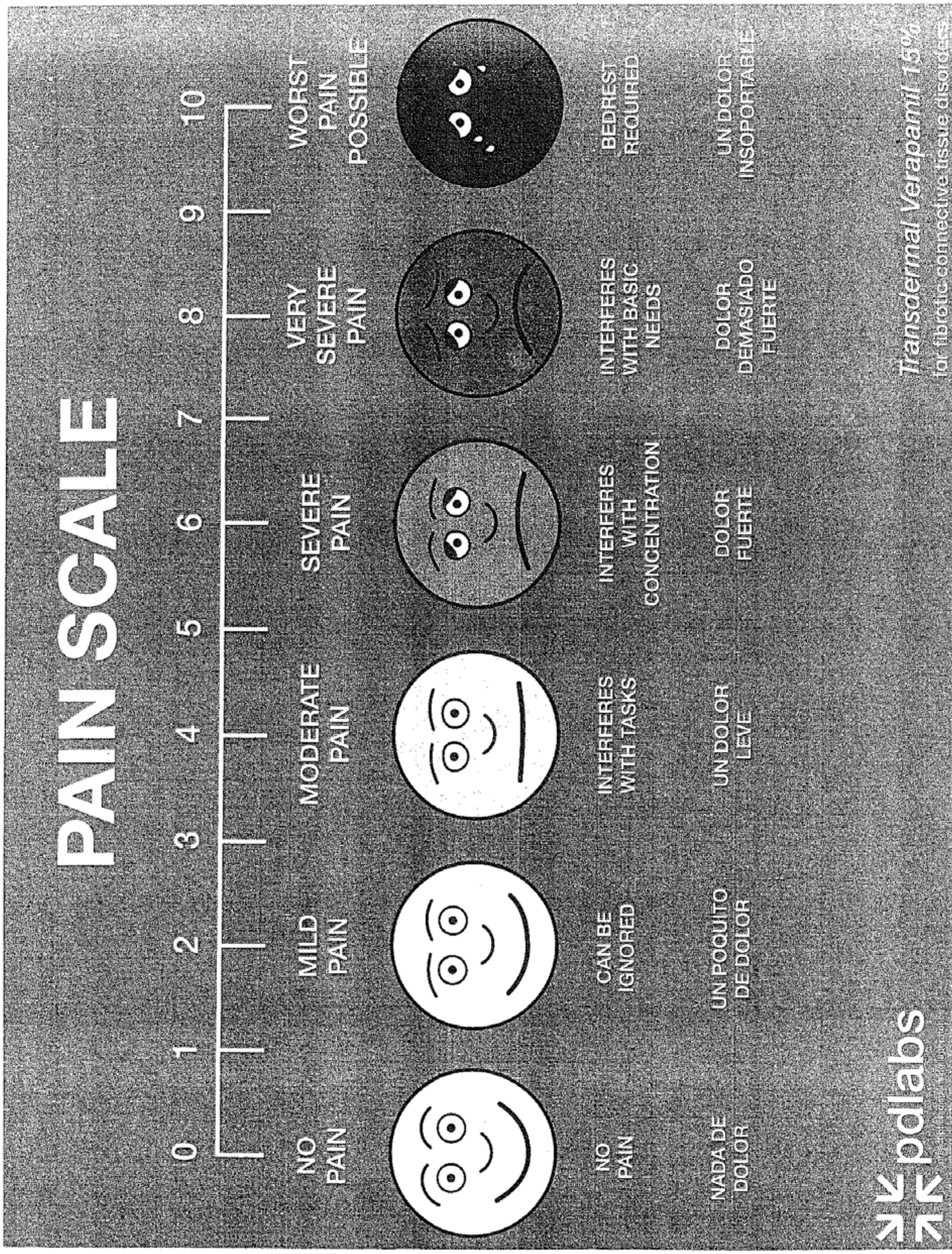
1) Please fill in the boxes after each exercise session.

2) Allow a day of recovery between exercise sessions.

3) You can contact me at ajisafet@bucmail.barry.edu or 701-610-1517 if you have any questions.

Appendix E

Visual analog pain scale


PAIN SCALE
0
1
2
3
4
5
6
7
8
9
10
NO PAIN
MILD PAIN
MODERATE PAIN
SEVERE PAIN
VERY SEVERE PAIN
WORST PAIN POSSIBLE
NO PAIN
CAN BE IGNORED
INTERFERES WITH TASKS
INTERFERES WITH CONCENTRATION
INTERFERES WITH BASIC NEEDS
BEDREST REQUIRED
NADA DE DOLOR
UN POQUITO DE DOLOR
UN DOLOR LEVE
DOLOR FUERTE
DOLOR DEMASIADO FUERTE
UN DOLOR INSOPORTABLE
pdlabs
Transdermal Verapamil 15%
for fibrotic connective tissue disorde

Appendix F

Medial tibial pain documentation

ACTIVITY-RELATED MEDIAL TIBIAL PAIN DOCUMENTATION

Date	Type of activity	Duration of Activity	Pain Scale

Experimenter_________________________ Date__________________

Instructions

1) Please fill in the boxes anytime you experience pain in your shin area.

2) Use the pain scale to assess the intensity of any pain that you may experience.

3) You can contact me at ajisafet@bucmail.barry.edu or 701-610-1517 if you have any questions.

Appendix G

Manuscript

Journal of Strength and Conditioning Research Format

Effect of six weeks of lower leg strength training on peak ground reaction forces in individuals with medial tibial stress syndrome

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Effect of six weeks of lower leg strength training on peak
ground reaction forces in individuals with medial tibial stress syndrome

ABSTRACT

Fifty percent of all sports injuries result from overuse (Herring & Nilson, 1987). Medial tibial stress syndrome (MTSS) may account for between 13.2% and 17.4% of all running injuries (Yates & White, 2004). Burne et al. (2004) proposed a link between lack of endurance, strength or imbalance between agonist and antagonist lower leg muscles, and the onset of MTSS. However no studies have been done to our knowledge to explore the relationship between lower leg strength training and peak vertical ground reaction forces (vGRFs) in individuals with MTSS. The purpose of this study was to determine the effect of six weeks of lower leg strength training on soleus and anterior tibialis muscle strength, peak vGRFs, passive ankle dorsiflexion ROM, and tibial pain in individuals with MTSS. 10 healthy adults (age = 23.25 ± 3.01 years; height = 1.65 ± 0.12 m; weight = 69.82 ± 10.75 kg) with a diagnosis of MTSS volunteered for this study. After initial health screening, participants were randomly assigned to one of two groups. Pretesting was done for soleus and anterior tibialis strength, peak vGRFs, and ankle passive dorsflexion ROM. Experimental group was assigned a six-week exercise program. Posttest was done after six weeks. A mixed-design MANOVA was calculated to determine any significant effect of lower leg strength training on the listed dependent variables. No significant interaction was found for bilateral passive ankle dorsiflexion ROM, soleus and anterior tibialis muscle strength, or peak vGRFs ($p>.05$). There was a decline in pain within both groups. It was therefore concluded that six weeks of lower leg strength training may not be adequate to increase soleus and anterior tibialis strength and significantly impact peak vGRFs.

KEYWORDS: strength training, non-shod running, sub-maximal running.

INTRODUCTION

Recurrent pain in the lower leg caused or induced by exercise, is a common problem among athletes (1). According to literature, there are several etiological factors that can be linked to the onset of recurrent leg pain (2). Some of the factors may include conditions such as exercise induced compartment syndrome (EICS), periostitis of the tibia, stress fracture, venous diseases, obliterative arterial diseases (OAD), and shin splints (1 & 2). It was reported that the three most frequent causes of exercise-induced leg pain are tibial stress fracture (TSF), chronic compartment syndrome, and Medial Tibial Stress Syndrome ((MTSS) (3). MTSS has also been referred to as shin splints in some scientific literature (4 & 2) although one publication referred to the term “shin splints” as a common lay term, which only describes the anatomic region of the pain but not the specific pathologic changes (5). MTSS has been described as pain experienced during exercise at the medial surface of the distal two thirds of the tibial shaft (6).

Literature has suggested that there may be a few different causes for the onset of MTSS (7). Overpronation of the foot and the ineffective absorption of ground reaction forces (GRFs) during physical activity, have been strongly implicated by research as likely causes of pain associated with MTSS (7). A variety of other factors, including the running surface, the level of the athlete’s conditioning, increase in activity level, footwear, and abnormal biomechanics have been considered influential in the development of MTSS (8). Other contributory factors are excessive physical activity, inadequate muscle strength and flexibility, muscle imbalance, inappropriate running surface, lower extremity malalignment, and inappropriate footwear (4 & 9). Some authors maintain that MTSS-related pain may be due to a chronic traction on the periosteum at the periosteal-fascial junction, thus implicating the tibialis posterior and the soleus (10 & 11).

In the nineties two separate publications hypothesized that adequate functioning of the leg muscles is necessary to absorb biomechanical force as well as to protect bones of the lower extremities from excessive shock during athletic activities (12 & 13). However, no studies have been done to our knowledge to determine the effects of lower leg strength training on muscle strength, peak vGRFs, passive ankle dorsiflexion ROM, and how these variables may influence medial tibial pain intensity.

The purpose of this study was to determine the effect of lower leg strength training on muscle strength, peak vGRFs, passive ankle dorsiflexion ROM, and medial tibial pain in individuals with MTSS. We hypothesized that six weeks of lower leg strength training would have the following effects; (a) increase one repetition maximum scores for anterior tibialis and soleus muscles, (b) cause reduced peak vGRFs during submaximal non-shod running, (c) increase passive ankle dorsiflexion ROM, and (d) reduce medial tibial pain.

METHODS

Experimental Approach to the Problem

Subjects

Ten physically active individuals were recruited for this study ($n_{control}$ = 5, $n_{experimental}$ = 5). All participants were of college age or older, between 18-26 years of age (age = 23.25 $\pm$ 3.01 years; height = 1.65 $\pm$ 0.12 m; weight = 69.82 $\pm$ 10.75 kg). All participants had been diagnosed with, and experienced MTSS related leg pain for at least 3 months prior to the anticipated date for first set of data collection. Participants were recruited from Barry University, Miami Shores.

The inclusion criteria for participation in this study included the following: (a) prior involvement (moderate to high) in regular physical activity, preferably an aerobic or resistance training regimen (Trappe, Raue, & Tesch, 2004), (b) normal BMI (no greater than 25 $kg.m^{-2}$, and no less than 18.5 $kg.m^{-2}$) for all participants, (c) absence of any lower extremity injuries such as fractures, muscle strain, compartment syndrome and vascular diseases, for at least three months prior to the start of the study, (d) normal blood pressure checked on at least two separate occasions within a month of the study's commencement date , and (e) a low risk score on the administered ACSM risk stratification and physical activity readiness questionnaire (PAR-Q). Only low risk participants were selected for participation in the study.

Instrumentation

Force Plate

Force readings were taken using an AMTI force plate (Advanced Medical Technologies, Inc., Watertown, MA). Peak vertical GRFs were normalized mathematically to each participant's body weight (Force (N) / 9.81m/s2 / body weight).

A laboratory goniometer was used to measure the passive ROM in the ankle joint. Activity related pain was assessed and documented by each participant over the course of the intervention, using a visual analog pain scale. 1RM tests were administered for both modes of leg exercises, for each participant according to ACSM (62). Because assigned training programs included warm-ups and stretching regimens, participants were not expected to face any additional risks of injury, especially with the initial selection criteria. Seated calf seated raise exercises were performed using a calf raise machine (Cybex International, Inc., Medway, MA). Medial tibial pain was ranked using a visual analog pain scale by pdlabs, Dorset, UK. Software for data collection and analysis included peakmotus and SPSS statistical analysis software by Microsoft Corporation.

Procedures

Passive ankle dorsiflexion ROM

All qualified participants were asked to report to the Barry University Biomechanics Laboratory on a set day and time for pre-testing. During pretest, participants were taken through a five-minute warm-up on a stationary bike in the biomechanics lab, followed by a lower leg stretching protocol.

Passive ankle dorsiflexion ROM was measured by having participants stand upright with both feet at shoulder width apart, maintaining a distance of about 8 inches from the laboratory wall, placing one foot ahead of the other in a step-stance position. The knee of the leading leg was held in full extension starting out. The moving arm of the goniometer was aligned with the mid shaft of the tibial bone, and the stationary arm was placed over the base of the fifth metatarsal. Shifting all of their weight unto the leading leg, participants were then asked to lean forward by bending the ipsilateral knee as far forward as they could, while lifting the contralateral foot off the floor. Tibial shaft displacement was tracked by the moving arm of the goniometer.

Three sets of measurement were taken on each leg, measuring the angular displacement between the shank and the vertical. Participants were asked to return their feet to the starting position before each new measurement was taken. The average of all three measurements was recorded as the available dorsiflexion range of motion in the specified ankle.

Ground Reaction Forces (GRFs)

After warming up, participants were asked to practice running non-shod at a sub maximal speed across an AMTI force plate embedded in the floor of the Biomechanics laboratory. The first three runs were timed using a stopwatch in order to set a consistent level of running intensity for across participants. Subsequent runs were then required to match the set intensity by being within 0.1 seconds of the set time. This was to ensure that running intensity was kept relatively consistent across trials. The average running duration was about 3.2 seconds across both groups. All participants were instructed to run non-shod. Once participants felt comfortable running across the force plate, three different trials were conducted to assess peak vertical GRFs. Participants were instructed to step on the force plate with their dominant foot, which was described to them as their kicking foot.

1RM test

Immediately following GRF data collection, participants were taken to the Barry University fitness center, housed in the same building as the Biomechanics Laboratory. Participants performed 1RM tests for two lower leg exercises (described in the exercise protocol section) included in the training program. The 1RM test was performed as follows: (a) participants were asked to warm up by completing a number of submaximal repetitions, (b) 1RM was determined within four trials with rest periods of 3-5mintues between trials, (c) an initial weight that was within each participant's perceived capacity was selected (50-70%), (d) resistance was progressively increased 2.5 to 20kg until participants could not complete the selected repetitions. All repetitions were performed at the same speed of movement and ROM, to ensure consistency between trials, and (e) the final weight lifted successfully was recorded as the absolute 1RM (62).

Exercise protocol

Only participants in the experimental group received the training program. Participants were asked to perform three sets of 10-12 repetitions of bilateral seated calf raise and a seated reverse calf raise exercise, three times a week for six weeks. The seated calf raise exercise has been reported to especially isolate the soleus muscle during resistance training (58). Participants in the control group did not receive any training program but were asked to maintain their regular fitness lifestyle, and to report any alterations to the investigator.

The procedure for the seated calf raise is as follows: (a) participants were instructed to sit on a cybex lower leg machine (see figures 8 & 9), with both of their knees at 90 degrees of flexion (ankles in slight dorsiflexion), (b) select weights were then loaded onto the machine, (c) participants were asked to raise their heels off the foot platform of the machine by plantar flexing at the ankle, moving loaded weights up against gravity, and (d) the heels were lowered back down to the starting position after each lift.

The procedure for the seated reverse calf raise is as follows: (a) participants were instructed to sit on the same cybex machine (see figures 10 & 11), with both of their knees at 90 degrees of flexion (ankles in maximum plantarflexion, with the distal halves of the feet hanging freely off of the edge of the machine’s foot platform), (b) select weights were loaded onto the machine, (c) participants were then asked to raise their fore-feet by dorsiflexing at the ankle, moving loaded weights vertically up against gravity, and (d) the fore-feet were lowered back down to the starting position after each lift. Each exercise consisted of three sets of eight to twelve repetitions with a load ranging between 60-80% of each participant's 1RM. Participants were asked to document their perceived level of difficulty for each exercise, for purposes of progression, as monitored and implemented by the primary investigator. If participants indicated that the twelfth repetition had become considerably less challenging at any point during the six weeks, they were instructed to increase the amount of training weight by 10 lbs, or until their twelfth repetition became challenging. Lower leg exercises were performed three times a week by participants in the experimental group (64).

Insert figures 1, 2, 3 & 4 about here

Medial tibial pain

Participants were all provided with a visual analog pain scale and report charts to document any occurrence of medial tibial pain that they may have experienced over a period of six weeks. The six week pain scores were then totaled for each group, and weekly total pain was expressed as a percentage of the total pain.

Statistical Analysis

Statistical analysis was done using the Microsoft Statistical Package for Social Sciences (SPSS) (SPSS Inc. Chicago, IL). Values for both the dependent and independent variables were input and all relevant descriptives were extrapolated and documented. A between-within MANOVA was calculated to show any significant effect of lower leg strength training on the dependent variables. Significance was defined as $p < 0.05$.

RESULTS

Lower leg strength training did not have a significant effect on bilateral passive ankle dorsiflexion ROM, bilateral lower leg muscle strength, and peak vGRFs after six weeks. There was a reduction in percentage medial tibial pain over the course of the study in both groups.

Insert Table 1 about here

Participants

Ten physically active college age individuals volunteered to participate in this study (6 women, 4 men). After initial screening, participants were randomly assigned to one of two groups, i.e experimental and control groups. All ten participants presented for the posttest following six weeks of intervention. The demographic information for the participants is listed in Table 3.

Insert table 2 about here

Bilateral passive ankle dorsiflexion ROM measurement

A mixed-design MANOVA showed that the main effect of training on bilateral passive ankle dorsiflexion ROM was not significant after six weeks (Right ankle - $F(1,5) = 16.89$, $p > .05$, Left ankle - $F(1,5) = 7.65$), $p < .05$) (see Table 3).

Seated calf raise 1RM values

A mixed-design MANOVA showed that the main effect of training on soleus strength (SCR 1RM) was not significant after six weeks ($F(1,5) = 0.50$, $p > .05$). Also the difference in soleus muscle strength between the experimental and control groups before and after training were not significant ($p > .05$). Soleus muscle strength was not influenced by group differences (see Table 4).

Reverse Seated calf raise 1RM values

A mixed-design MANOVA showed that the main effect of strength training on anterior-lateral leg muscle strength was not significant after six weeks ($F(1,5) = 3.62$, $p > .05$). Although there were considerable differences in antero-lateral lower leg muscle strength between the experimental and control groups before, and particularly after training, the differences were not significant ($p > .05$). Tibialis anterior muscle strength (measured as RSCR 1RM) was not significantly influenced by group differences (see Table 5).

Peak vGRF values

A mixed-design MANOVA showed that lower leg strength training did not have any significant effect on peak vGRFs after six weeks ($F(1,5) = 0.17$, $p > .05$, see Table 6). In addition to peak vGRFs, Table 10 also shows the respective times to peak, impulses, and loading rates, as observed during this study. Peak vGRFs were normalized to each participant's body weight. There were no significant changes in peak vGRFs after six weeks of training ($p > 0.05$).

Medial tibial (shin) pain

Participants in the experimental and control groups were asked to document medial tibial pain as experienced over the course of study. Pain was ranked using a ten-point visual analog pain scale (0 = no pain, 10 = worst pain possible, bed rest required). Total pain was then calculated over six weeks and total weekly pain was computed as a percentage of the total six-week pain for both groups. Table 7 summarizes the distribution of tibial medial pain over the course of six weeks

Insert Tables 3, 4, 5, 6, & 7 about here

DISCUSSION

The purpose of this study was to investigate the effect of lower leg strength training on peak vertical GRFs in individuals with MTSS, before and after a six-weeks. The specific aim of this study was to determine how six weeks of lower leg strength training may influence: (a) soleus and anterior tibialis muscle strength, (b) ankle dorsifexion ROM, and (c) and non-shod running peak vertical GRFs.

Bilateral ankle passive dorsiflexion ROM

In a publication on the biomechanics of running, it was reported that the ankle dorsiflexes about 20^{o} during midstance, acting as a GRF absorption mechanism in conjunction with knee flexion (14). It is not clear how sagittal ankle movement (especially dorsiflexion) during specific gait events from the current study may have compared to ones described earlier, since videography and other motion capture equipment were not utilized. However in place of the temporal, event-specific ROM readings obtainable through video, this study utilized static passive ankle dorsiflexion ROM measurements which were taken in a weight bearing position as shown earlier. While investigating hip and ankle ROM between female ballet dancers and control participants, researchers measured passive ankle ROM in a weight bearing stance similar to the one in this study (15). The fundamental design variation between the incumbent study and the former is that while participants were not allowed to hold on to the wall in the current study, they were instructed to hold on to the wall for support in the other, during ankle dorsiflexion. Also while the contralateral limb remained in contact with the floor in the study with ballet dancers (consistent with a lunge), it was held in 90^o of knee flexion and off the floor (similar to the single limb support phase of running), during ipsilateral ankle dorsiflexion in the current study. These differences in design may explain why the average ankle passive dorsiflexion ROM was drastically different between both studies.

A previous recorded an average of 31.9^o and 29.2^o of passive ankle dorsiflexion among its experimental and control groups respectively (15). The mean dorsiflexion angles recorded in the current study are 10.5^o and 11.1^o (pretest and posttest), and 8.0^o and 8.5^o (pretest and posttest), for the experimental and control groups respectively. It has been suggested that between 4^o and 10^o of ankle passive dorsiflexion ROM is required during the stance phase of normal walking gait, pointing out that values less than 10^o may constitute equines (16). The same authors found that ankle passive dorsiflexion ROM values between 5^o and 10^o did not result in any significant change in magnitude of frontal plane rear-foot motion (inversion and eversion) during the stance phase of walking. However they found that individuals with limited dorsiflexion ROM showed less time to reinversion values than those with normal passive dorsiflexion ROM, after heel-off occurs. This finding counters prior suggestions that deficits in ankle dorsiflexion ROM is compensated for by excessively pronating the foot during ambulation. The magnitude of the frontal plane rear-foot kinematics was not monitored during ankle passive dorsiflexion ROM assessments in the current study. It is therefore uncertain whether or not participants may have compensated for any dorsiflexion deficits by excessively pronating their feet during the measurements. It is also not clear why the groups had different pretest mean values for ankle passive dorsiflexion ROM, since participants were all individuals who had been diagnosed with MTSS.

There is a lack of research that compares ankle passive/active dorsiflexion ROM between normal populations and those with MTSS, and whether or not there might be a link between the duration of MTSS diagnosis and dorsiflexion ROM deficits, when observed. A study reported non-significant differences in active (bent-knee) ankle dorsiflexion ROM between female collegiate athletes who developed ERLP and those who did not (17). Although the average degree of ankle plantarflexion is greater during sprinting, the relative degree of ankle dorsiflexion is actually greater during normal running because of the longer duration of the shock absorption period. Despite findings by Fatouros et al. (2002) that resistance training may increase range of motion of a number of joints of inactive older individuals due to an improvement in muscle strength, there was no significant effect of lower leg strength training on passive ankle dorsiflexion ROM in the current study. This finding did not support our hypothesis that lower leg strength training exercises may increase the available passive dorsiflexion ROM at the ankle joint.

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Peak vertical ground reaction forces (GRFs)

Research has shown that during the transition from walking to running, the limb support phase becomes shorter while vertical peak forces increase and vertical impulses decrease (18). Also during distance running, GRFs of more than 2 times a person’s body weight (BW) are said to be typical (19). Other studies have recorded peak impact forces of 1.8 times the body weight of young trained distance runners, running at a controlled speed of 3.3 m/s (20). In this study, mean impact GRFs (from initial contact) were 3.8 times the average BW in the experimental group (prestest and post test), and 3.5 times the average BW in the control group (prestest and posttest). Given the suggested range of typical impact forces, a point can be made that peak impact forces in the current study were excessive, supporting our hypothesis that individuals with MTSS should generate higher GRFs when compared to the general population.

In a publication on the biomechanics of running, it was reported that the ankle plantar flexor moments generated during the push-off phase of running, are larger than those generated during walking, and may range up to 6-8 times the BW (14). The same author explained that these peak forces which occur in the latter ¾ of the stance phase (midstance), are generated by the contraction of the gastroc-soleus muscle complex during the propulsive phase of running, not the shock of the initial ground contact. In this study, mean active peak vertical GRFs were 9.2 times the average BW in the experimental group (prestest and post test), and 10 times the average BW in the control group (prestest and posttest). Comparing the active peak force data from this study to the range given in the prior study, a reasonable argument can be made that active peak vertical forces were excessive as recorded in the current study, once again lending supporting to our hypothesis that individuals with MTSS should generate higher GRFs when compared to the general population.

Although differences in soleus and anterior tibialis muscle strength were not statistically significant after six weeks of strength training, a positive significant correlation was found between soleus and anterior tibialis muscle strength, and peak vertical GRFs. Soleus muscle strength was strongly correlated to peak forces while anterior tibialis strength was only moderately correlated. This suggests that there may in fact be a relationship between these variables depending on how strong the correlations were. A vast majority of the studies that have explored GRF generation, its attenuation and its impulses (a function of the time to peak), have utilized drop-landing tests as their fundamental design. This makes it fairly challenging to present a pure juxtaposition of data regarding some of the attributes of peak ground forces during submaximal running, such as impulse and loading rate. Because peak vertical forces did not change significantly after six weeks, our initial expectation that GRF attenuation would increase among participants in the experimental group was not supported after six weeks. During a shod running test of rear foot strikers, passive force peak (2.1 x BW) was attained after 30 ms, while active force peak (3.1 x BW) was reached after about 90 ms (14). Interestingly the respective peak vertical forces although less in magnitude, occurred sooner in the earlier study when compared to the current study. This observed peak force pattern contradicts the fact that higher peak forces are typically associated with shorter amounts of time to peak. It is important to note that although the focus of this study was on the role of lower leg muscles and the ankle joint, in attenuating peak vGRFs, the knee and the hip joints are involved in ground force management as well. The focus on the lower leg was prompted by the numerous publications that have drawn connections between MTSS and intrinsic lower extremity factors such as muscle strength and endurance, as well as deficits in ankle ROM. Gait pressure was not monitored in this study but given the direct relationship between force and pressure, any changes to peak forces would have impacted foot pressure accordingly. All reference studies pertaining to peak vGRFs were conducted shod in contrast to this study, which may have caused considerable differences in the force outcome.

Soleus and anterior tibialis muscle strength

As mentioned earlier, differences in soleus and anterior tibialis muscle strength were not significant after six weeks of training. It is noteworthy however to point out that there were relative differences between the groups on soleus muscle strength (pretest SCR 1RM mean = 116.25 $\pm$ 51.05 (0.79 x mean experimental group BW), 157.50 $\pm$ 66.89 (0.97 x mean control group BW), posttest SCR 1RM mean = 138.75 $\pm$ 37.50 (0.95 x mean experimental group BW), 161.25 $\pm$ 60.05 (0.99 x control group BW)). These scores indicate that the average control group soleus muscle strength was greater than that of the experimental group before training. After six weeks of training however, the gap had narrowed considerably, despite statistically insignificant pretest-posttest differences. Studies have reported that strength training can increase strength and endurance in skeletal muscle (21). Although muscle endurance was not measured in the current study, it is possible that muscle endurance may have increased among participants in the experimental group after six weeks. In a 2006 study, endurance deficits were found in ankle joint plantar flexors in athletes with MTSS (22). The authors expressed a lack of clarity on whether endurance deficits were a result or cause of MTSS. In a previous study (23), training group participants performed 12 training sessions of explosive dorsiflexion strength training over four weeks at three sessions per week. Electromyograpic activity of the anterior tibialis and soleus muscles revealed increases in rate of torque development (RTD) and maximum voluntary contraction (MVC). However due to the lack of significant changes in anterior tibialis and soleus muscle properties, the authors explained increases in RTD and MVC to be a result of increase voluntary drive to muscles. Considering that soleus muscle strength did increase as pointed out earlier, it is possible that six weeks of strength training is not adequate to produce significant measurable changes in muscle strength.

Medial tibial pain

Pain associated with MTSS is typically located in the distal two-third of the postero-medial border of the tibia (24 & 6). It has also been shown that in the early stages of MTSS, medial tibial pain occurs at the start of a work out, resolves during the course of the activity, and returns after the activity (25). However, in the later stages MTSS-related pain often becomes sharper and persists through the entire duration of the physical activity (25). In severe cases of MTSS a person may experience pain throughout the entire day including periods of rest, in certain cases (25). Participants in this study were asked to track their medial tibial pain over six weeks by assigning corresponding pain scores from a visual analog pain scale leaflet. Among the experimental group, medial tibial pain progressively decreased from week one to week six (see Table 11), except for the last two weeks where pain remained at 11 % of the total six-week pain score. Medial tibial pain also decreased among the control group during the first four weeks of the study. However by the fifth week pain scores started to increase from a low of 10.0 % back up to 15.5 % of the total six-week pain.

As expected pain scores were reduced among participants in the experimental group, lending support to our pre-intervention hypothesis. The premise of that hypothesis was the anticipation that increases in lower-leg muscle strength and ankle dorsiflexion ROM may produce increased ground reaction force attenuation, thereby reducing medial tibial pain scores among the experimental group. Considering the absence of any statistically significant increase in those outcome measures, it is unclear why there was a consistent decline in pain scores in the experimental group. A possible explanation may be that despite statistical non-significance, there were considerable increases in the average pretest and posttest 1RM scores for soleus and anterior tibialis muscles (see tables 8 & 9). The change in lower leg muscle strength may have influenced the slight change in impact force value seen in table 13. But again it remains unclear which phase of peak vGRFs (impact or propulsive) has a stronger correlation to MTSS-related pain. An alternative explanation to the decline in pain among the experimental group is that it may have been a placebo effect of the strength-training program on participants, as they were made aware of study hypotheses as well as the overall study objective. Given this explanation it remains unknown why there was an initial decline in medial tibial pain among the control group, other than the fact that physical activity level as a potential medial tibial pain aggravator, may have reduced during the weeks over which a decline in pain was observed. This explanation may in fact be applicable to both groups since the documentation of physical activity (type, duration, and intensity) was poorly done by participants in both groups, with the exception of a couple.

PRACTICAL APPLICATIONS

MTSS is a common lower extremity injury experienced by many athletes. It is interesting however, that given its history and high rate of occurrence, there are still so many divergent opinions regarding its true etiology. One of the leading theories as to the cause of MTSS is the presence of tightness, weakness and perhaps a lack of endurance within the soleus muscle. Other theories include an imbalance between the posterior calf muscles and the anterior leg muscles (mainly the soleus and anterior tibialis).

Given the invasiveness of some of the existing treatment strategies and recommendations (which often involve prolonged periods of rest from participation in physical activity), it is important to explore strength and endurance training strategies as viable alternatives in addressing the root causes of MTSS. Resistance or strength training is widely applied in a variety of professional settings including performance sports and physical rehabilitation. Because of its proven effectiveness, strength training is generally used to achieve a number of different goals ranging from increasing skeletal muscle strength to simply improving muscle endurance.

Although the results from this did not significantly support the hypotheses that six weeks of strength training would increase ankle dorsiflexion ROM, thereby increasing the absorption of peak vGRFs in individuals with MTSS, MTSS related pain decreased after six weeks. This finding suggests that strength training may be introduced as part of the rehabilitation or maybe preventative measures in people with MTSS. Perhaps increasing the number of lower leg exercise sessions per week and the duration of the training period (more than six weeks) may reveal significant changes in the other parameters that were measured in the current study.

REFERENCES

1. Cetinus, E., Uzel, M., Bilgic, E., Karaoguz, A., and Herdem, M. Exercise induced compartment syndrome in a professional footballer. *British Journal of Sports Medicine,* 38: 227-229. 2004.

2. Gaeta, M., Minutoli, F., Vinci, S., Salamone, I., D'Andrea, L., Bitto, L. et al. High-resolution CT grading of tibial stress reactions in distance runners. *American Journal of Roentgenology*, 197: 789-793. 2006.

3. Yates, B., Allen, M., and Barnes, M**.** Outcome of surgical treatment of medial tibial stress syndrome. *The Journal of Bone and Joint Surgery,* 85: 1974-1980. 2003.

4. Wilder, R.P., and Sethi, S. Overuse injuries: tendinopathies, stress fractures, compartment syndrome and shin splints. *Clinical Sports Medicine*, 23: 55-81. 2004.

5. Reinking, M., & Hayes, A. Intrinsic factors associated with exercise-related leg pain in collegiate cross country runners. *Clinical Journal of Sports Medicine,* 16: 10-14. 2006.

6. Mubarek, S.J., Gould, R.N., Lee, Y.F., Schimdt, D.A., and Hargens, A.R. The medial stress syndrome: a cause of shin splints. *American Journal of Sports Medicine*, 10: 201-205. 1982.

7. Blackburn, M. *A prospective design identifying etiological risk factors associated with MTSS and stress fractures in female intercollegiate athletes*. Unpublished master's thesis, East Tennessee State University– Johnson City, Tennessee. 2002.

8. Willems, T.M., Clercq, D.D., and Delbaere, K. A prospective study of gait related risk factors for exercise-related lower leg pain. *Gait & Posture* 23: 91–98. 2006.

9. Taunton, J.E., Ryan, M.B., Clement, D.B. et al. A retrospective case-control analysis of 2002 running injuries. *British Journal of Sports Medicine,* 36: 95-101. 2002.

10. Michael, R.H., and Holder, L.E. The soleus syndrome: A cause of medial tibial stress (shin splints). *American Journal of Sports Medicine,* 13: 87-94. 1985.

11. Brukner, P. Exercise-related lower leg pain: bone. *Medicine & Science in Sports & Exercise*, 32: 15-26. 2000.

12. Fyhrie, D.P., Milgrom, C., Hoshaw, S.J., et al. Effect of fatiguing exercise on longitudinal bone strain as related to stress fracture in humans. *Annals of Biomedical Engineering,* 26: 660-665. 1998.

13. Richie, D.H., DeVries, H.A., and Endo, C.K. Shin muscle activity and sport surfaces: An electromyographic study. *Journal of American Podiatry Medical Association,* 83: 181-190. 1993.

14. Novacheck, T. The biomechanics of running. *Gait and Posture,* 7: 77-95. 1998.

15. Bennell, K., Khan, K.M., Mathews, B., Gruyter, M.D., Cook, E., Holzer, K., and Wark, J.D. Hip and ankle range of motion and hip muscle strength in young novice female ballet dancers and controls. *British Journal of Sports Medicine,* 33: 340-346. 1999.

16. Cornwall, M.W. and McPoil, T.G. Effect of ankle dorsiflexion range of motion on rearfoot motion during walking. *Journal of American Podiatry Medicine Association*, 89: 272-277. 1999.

17. Reinking, M. Exercise-related leg pain in female collegiate athletes. *American Journal of Sport Medicine,* 20: 1-8. 2006.

18. Nilson, J., and Thorstensson, A. Ground reaction forces at different speeds of

human walking and running. *Acta Physiologica Scandinavica.,* 136: 217-227. 1989.

19. Logan, S., Hunter, I., Feland, B., Hopkins, T., and Parcell, A. Ground reaction forces between running shoes, racing flats and distance spikes in runners. Unpublished manuscript, Brigham Young University at Utah. 2006.
20. Bus, S.A. Ground reaction forces and kinematics in distance running in older-aged men. *Medicine & Science in Sports & Exercise*, 35: 1167-1175. 2003.
21. Marcinik, E.J., Potts, J., Schlabach, G., Will, S., Dawson, P., and Hurley, B.F. Effects of strength training on lactate threshold and endurance performance. *Medicine & Science in Sports & Exercise,* 23: 739-43. 1991.
22. Madeley, L., Munteanu, S., and Bonanno, D. Endurance of the ankle joint plantar flexor muscles in athletes with medial tibial stress syndrome: A case-control study. *Journal of Science & Medicine in Sport,* 10: 356-362. 2006.
23. Geertsen, S.S., Lundbye-Jensen, J., and Nielsen, J.B. Increased central facilitation of antagonist reciprocal inhibition at the onset of dorsiflexion following explosive strength training. *Journal of Applied Physiology* 105: 915–922. 2008.
24. Magnusson, H., Westlin, N., Nyqvist, F., Gardsell, P., Seeman, E., and Karlsson, M. Abnormally Decreased Regional Bone Density in Athletes with Medial Tibial Stress Syndrome. *American Journal of Sports Medicine,* 27: 712-715. 2001.
25. Metzl, J.A., and Metzl, J.D. Shin pain in an adolescent soccer player: A case-based look at shin splints. *Contemporary Pediatrics.* 21: 36-48. 2004.

Figure Legends

Figure 1: Seated calf raise exercise (starting position)

Figure 2: Seated calf raise exercise (ending position)

Figure 3: Reverse seated calf raise exercise (starting position)

Figure 4: Reverse seated calf raise exercise (ending position)

Figure 1. Seated calf raise exercise (starting position).

Figure 2. Seated calf raise exercise (ending position).

Figure 3. Seated reverse calf raise exercise (starting position).

Figure 4. Seated reverse calf raise exercise (ending position).

Table Legends

Table 1: Summary of the statistics on each dependent variable.

Table 2: Demographic information.

Table 3: Bilateral passive ankle dorsiflexion ROM (degrees) before and after training.

Table 4: Soleus muscle strength (SCR 1RM, in lbs) before and after training.

Table 5: Anterior tibialis muscle strength (RSCR 1RM, in lbs) before and after training.

Table 6: Peak vGRFs before and after 6 weeks (scaled to group average body weight).

Table 7: Percentage distribution of medial tibial (shin) pain over six weeks.

Table 1. Summary of the statistics on each dependent variable.

Dependent variable	Interaction	Main effect: Group
Right ankle dorsiflexion ROM	Not significant	Not Significant
Left ankle dorsiflexion ROM	Not significant	Not Significant
Seated calf raise 1RM	Not significant	Not significant
Reverse seated calf raise 1RM	Not significant	Not significant
Peak vGRFs	Not significant	Not significant
Cumulative six week pain	Not significant	Not significant

Note. $P < 0.05$ defines a significant difference, $p > 0.05$ shows insignificance.

Table 2. Demographic information.

	Experimental group n = 5	Control group n = 5
Age (years)	23.50 ± 1.7	23.0 ± 4.24
Height (m)	1.63 ± 0.12	1.67 ± 0.14
Weight (kg)	66.13 ± 10.77	73.52 ± 10.83
Weight (N)	648.0 ± 105.5	720.49 ± 106.1
Average number of total 6week physical activity	12.25 ± 10.40	11.50 ± 11.23
Average cumulative 6week pain	24.25 ± 4.50	13.5 ± 7.14

Note. All demographic data were self-reported by participants.

Table 3. Bilateral passive ankle dorsiflexion ROM (degrees) before and after training.

	Experimental group n = 5	Control group n = 5
Pre-training (right ankle)	10.07 ± 2.15	8.60 ± 0.29
Post-training (right ankle)	10.70 ± 1.59	8.50 ± 0.31
Difference (pre - post)	+0.63	-0.10
Pre-training (left ankle)	10.40 ± 2.24	9.10 ± 0.46
Post-training (left ankle)	10.85 ± 1.51	9.05 ± 0.40
Difference (pre – post)	+0.45	-0.05

Table 4. Soleus muscle strength (SCR 1RM, in lbs) before and after training.

	Experimental group n = 5	Control group n = 5
Pre-training	116.25 ± 51.05	157.50 ± 66.89
Post-training	138.75 ± 37.50	161.25 ± 60.05
Difference (pre - post)	+22.5	+3.75

Table 5. Anterior tibialis muscle strength (RSCR 1RM, in lbs) before and after training.

Time	Experimental group n = 5	Control group n = 5
Pre-training	90.0 ± 42.03	91.25 ± 33.0
Post-training	101.25 ± 34.0	92.87 ± 30.68
Difference (pre - post)	+11.25	+1.62

Table 6. Peak vGRFs before and after 6 weeks (scaled to group average body weight).

Group	Active GRF (BW)	Time to peak (s)	Impulse (Ns)	Loading rate (N/s)
Experimental (pretest)	9.1	0.1	0.91	91.0
Experimental (posttest)	9.5	0.1	0.95	95.0
Control (pretest)	10.2	0.1	1.02	102
Control (posttest)	10.1	0.1	1.0	100.7

Table 7. Percentage distribution of medial tibial (shin) pain over six weeks

Group	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
Experimental (n = 5)	22.7%	20.4%	18.9%	14.2%	11.8%	11.8%
Control (n = 5)	25.5%	19.3%	17.8%	10.0%	11.6%	15.5%