FUNCTIONAL VS ISOKINETIC FATIGUE PROTOCOL: EFFECTS ON TIME TO STABILIZATION, PEAK VERTICAL GROUND REACTION FORCES, AND JOINT KINEMATICS IN JUMP LANDING

BY

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Dynamic stability provides inherent protection against joint injury and several studies have examined the influence of fatigue on neuromuscular control and joint stability. Thus, the purpose of this study was to compare the effects of an isokinetic(IFP) and functional fatigue protocol (FFP) on stabilization time (TTS), ground reaction forces (GRF) and joint angles following a jump landing. Twenty healthy subjects (age=22±1.6 yrs, height=173.84±10.452 cm, mass=67.13±12.426 kg) were assessed for the designated events. Subjects completed three jump landing tasks, requiring a two-legged jump at 50% of their maximum jump height to the center of a force plate 70-cm from the starting position. Immediately following, each subject completed either the FFP or the IFP. Fatigue was considered to have occurred when time to completion of the FFP increased to 150% of the initial time to completion or failure to produce 50% of the initial IFP peak torque. Immediately following fatigue, post testing was performed. TTS was determined as the point where the sequential average of the vertical ground reaction force data points fell within .25 standard deviations from the mean of the initial 3-sec collection period. Two way repeated measures ANOVA revealed no significant differences when comparing isokinetic to functional fatigue values for vertical TTS [$F(1,19)= 3.93$, $p=.538$], medial/lateral TTS[$F(1,19)= .287$, $p=.598$], anterior/posterior TTS [$F(1,19)= .001$, $p=.978$], toe touch GRF [$F(1,19)=.121$, $p=.286$], and heel strike GRF ($F=3.673$, $p=.070$). Also, no significant differences were revealed when comparing the fatigue protocols for ankle Dorsiflexion [$F(1,19)= .06$, $p=.803$], knee flexion [$F(1,19)= .21$, $p=.652$], and knee valgum [$F(1,19)= .79$, $p=.386$].

The results of this investigation suggest that the specific fatigue protocol used did not impair dynamic stability and that future research should focus on fatigue that occurs during athletic competition and the correctness of the measure of time to stabilization.

CHAPTER 1
INTRODUCTION

Athletes at all levels of competition may eventually suffer from an ankle injury. While the exact cause of these injuries is unknown, a vital component of preventing an injury is the athlete's neuromuscular control. Neuromuscular control is dependent on the central nervous system (CNS) to interpret and integrate proprioceptive and kinesthetic information. This information identifies the joint's ability to sense its position in space and to sense motion of the corresponding body segments.[1-3] After receiving this information, the CNS must then control individual muscles and respective joints involved in specific motions to produce safe coordinated movement.[2,4] While all aspects of neuromuscular control are important to athletes in preventing and rehabilitating injuries, postural control has been have been demonstrated to be important.

Athletes who have better postural sway are less likely to suffer ankle injuries in subsequent athletic seasons.[5-7] Postural control is a complex coordination of sensory and biomechanical information and muscular exertion on external forces.[2,8-11] A loss of any of these factors can lead to increased postural sway and a decreased ability to control a body part or the body as a whole during athletic activity.

Time to stabilization is the body's ability to minimize postural sway when transitioning from a dynamic to static state, thus a very functional test.[12,13] As a form of postural control, TTS involves a complex coordinated effort between the sensory and mechanical systems of the body as well as a series of powerful contractions of lower leg musculature and synergistic stabilizers throughout the lower extremity.[10]

It has been suggested that even healthy athletes may suffer lower extremity injuries during an athletic event due to the fatigue of those muscles resulting in a decrease in neuromuscular control.[9,14-16] These studies focused on lower extremity fatigue induced isokinetically. Thus, fatigue could be quantified as a percent of peak torque. Yet, very little research has focused on neuromuscular control following a functional fatiguing protocol.

Statement of the Problem

Many authors have studied the effects of muscular fatigue on postural control by isokinetically fatiguing their subject's lower extremity musculature.[9,16-18] These studies have generally shown an increase in postural sway after muscular fatigue. However, very little research has examined functional fatigue protocols[19,20] of the ankle and their effects on time to stabilization, a more functional test of postural control. Thus, the purpose of this study is to compare and correlate an isokinetic fatigue protocol's effects on TTS, peak vertical ground reaction forces and biomechanical effects (i.e., ankle and knee flexion and knee valgum) during a single-leg-hop stabilization test to those of a functional fatigue protocol, which is similar to actual athletic practice and game situations.

Hypotheses

There have been three hypotheses made for this investigation.

- All subjects performing fatigue protocols (i.e., isokinetic, functional) will have significant increases in time to stabilization, peak vertical ground reaction forces, and stated biomechanical effects as compared to the pretest measure.
- There will be a significant increase in subjects' time to stabilization, peak ground reaction forces, and stated biomechanical effects following the functional fatigue protocol as compared to the isokinetic fatigue protocol.

- There will be a high correlation between peak vertical ground reaction forces and time to stabilization in both the pretest and posttest of both fatigue protocols.

Definition of Terms

The following terminology will be referred to throughout this research study.

These definitions are provided to clarify the exact parameters that were being studied.

- **Functional fatigue protocol:** Related to the muscular exertion of the lower extremity when performing a sports-specific series of agility drills in an effort to establish a reliable application to athletes in competition. The protocol in this experiment incorporates the: SEMO agility drill, plyometric box jumps, two-legged hop sequence, side-to-side bounds, mini-trampoline balance series, and the co-contraction arc drill.

- **Isokinetic fatigue protocol:** Chosen for its inherent objectivity, patient safety, and reproducibility. It is related to the muscular exertion of the lower extremity when performing a series of isokinetic maximal contractions. The protocol for this experiment incorporates continuous maximal concentric contractions of dorsi flexion and plantar flexion at the ankle.[12]

- **Postural control:** A measure of balance or postural stability. It is the amount a body's center of mass moves within or around its base of support.[11,21]

- **Proprioception:** The awareness of postural movement, the changes in equilibrium, and the knowledge of position, weight, and resistance of objects in relation to the body.[1,8]

- **Stability:** The ability to transfer vertical projection of the center of gravity to the supporting base while keeping the knee as still as possible.[12]

- **Stabilometry:** The common means of objectively detecting proprioceptive deficits and quantitatively measuring aspects of proprioception.[22]

- **Time to stabilization:** A valid and reliable technique to measure balance. The method involves landing on a force plate from a dynamic state, and transitioning balance into a static state.[12,13,23]

- **Peak vertical ground reaction force:** The maximum force or heaviness of a landing. Measured in newtons, it accurately depicts how hard or soft an individual landed from a jump. Ground reaction forces are often expressed as the magnitude of the peak vertical force divided by the subject's body weight, or units of body weight.[24]

- **Biomechanical Effects:** The changes that occur in joint angles (i.e., ankle flexion, knee flexion, and knee valgum) from a non-fatigued to a fatigued jump landing.

Assumptions

There are six assumptions made for this research study.

- All subjects were truthful in reporting previous history of lower extremity and head injury and disorders that affect equilibrium.
- All subjects will give a maximal effort during their testing and treatments.
- Results of this study are representative of all individuals with no prior history of lower extremity and head injury and disorders affecting equilibrium.
- That the functional fatigue protocol was an effective method of fatiguing the musculature of the lower leg.
- That the isokinetic and functional fatigue protocols were equivalent in their ability to each fatigue their subjects to the level required, so as not to skew the results.
- That the testing protocol mimics actual athletic activity and is an accurate measure of time to stabilization.

Limitations

There are five limitations identified for this research study.

- Subjects wore different brands of shoes, although all a similar style during the fatigue protocols.
- Subjects were not familiar with the fatigue protocols.
- Subjects were not familiar with the testing procedures.
- Only one type of isokinetic fatigue protocol was used.
- Only one type of functional fatigue protocol was used.

Significance

This study will test an isokinetic fatigue protocol of the lower leg musculature and its effects on time to stabilization and peak vertical ground reaction forces as compared to a functional fatigue protocol of the lower leg musculature. Through the examination of the main effects of the fatigue protocols and the tests performed, a highly positive correlation will be illustrated. More importantly, a significant difference in the main effects and the interaction of the fatigue and tests (i.e., time to stabilization, peak vertical ground reaction forces, biomechanical effects) will strongly suggest that isokinetic fatigue protocols do not mimic functional activity. These results will provide practical, clinical applications, regarding how functional fatigue increase time to stabilization, allowing clinicians to focus on improving postural control in their athletes. However, these results will also benefit researchers indicating that a functional fatigue protocol is a more reliable method of mimicking the fatigue that takes place during athletic activity.

CHAPTER 2
REVIEW OF LITERATURE

Introduction

Injuries to the ankle or talocrural joint can occur in any sport because the ankle is the focal point to which total body weight is transmitted to during ambulation.[25] Therefore the talocrural joint is one of the most common areas for injury in the athletic population, specifically the stabilizing ligaments of the joint.[7,22,26-33] Starkey[33] reviewed injury data over a span of ten years for the NBA, and found that the most common site of injury was the ankle joint. Ankle injuries accounted for more than 10% of all injury occurrences, and 11% of time lost due to injuries. Similar observations have been reported elsewhere.[28,29] According to Ekstrand and Tropp[29] approximately 40% of all injuries occur at the ankle joint. Anecdotally, most of these injuries occur at the end of activity when the athlete is fatigued.[16]

Ankle sprains, which affect the stabilizing ligaments, are caused by sudden inversion or eversion forces that overwhelm the ankle's defenses (i.e., proprioception, muscular strength).[25] These forces are often combined with plantar flexion and result in the stretching or tearing of the peroneal muscles and or stabilizing ligaments[3] While relatively minor injuries, ankle sprains can result in a great deal of missed athletic participation. Therefore, measures to prevent the mechanisms of injury need to be studied to reduce or prevent ankle injuries as much as possible.

Several theories have been explored as to the cause of ankle injury. These causes can be broken into extrinsic and intrinsic factors[3,4,30] Extrinsic factors include poor equipment, improper shoes and playing surface. Intrinsic factors include muscular fatigue, excessive pronation and ligament laxity. All these factors taken individually or in combination can lead to ankle injuries. Muscular fatigue of the lower extremity has been one of the focus of recent studies, in an attempt to better understand its direct effect on ankle and how it predisposes the ankle to injury.[9,14-19,34]

Fatigue of the lower leg musculature is controversial as to its importance to increasing postural sway. Motor control of an extremity is dependent on proprioceptive feedback and reflexive and voluntary muscle responses.[9,35] Muscular fatigue could negatively affect proprioception through either deficiencies in the activation of the muscular mechanoreceptors or a decrease in the muscular function. These deficiencies have been credited through a positive correlation between muscular fatigue, quantified as 50% of the initial baseline test, and a decrease in postural control during several studies.[9,16-19] Most of these correlations have used isokinetic fatigue protocols in a non-weight bearing position, and with postural control testing methods and protocols conducted in full-weight bearing positions.

Talocrural Joint

The ankle joint (talocrural joint) is made up of three bones; the tibia, fibula and the talus. The tibia, the weight bearing bone of the lower leg, is affixed to the fibula via several ligaments. The distal aspects of these bones (i.e., medial and lateral malleolus) form the ankle mortise (Figure 2-1), in which the head of the talus sits and rocks in an anterior/posterior direction during ambulation.[3,25,30,36,37]

The articulation of this joint forms a strong preventative measure against medial or eversion ankle sprains because the medial malleolus extends significantly more distally than the lateral malleolus which forms a bony block that limits talar abduction. The anatomical failure of the body to prevent lateral ankle sprains with bony defenses causes the ligaments and musculature of the lower leg to play a vital role in stabilizing the ankle from lateral sprains. The stabilizing ligaments of the ankle joint, which protect the ankle in three distinct areas and from different motions, are the tibiofibular, lateral, and medial. The tibiofibular ligament is the distal and proximal extremes of the interosseous membrane that transverses the entire lower leg, connecting the tibia and fibula.[36,37] The oblique arrangement of the tibiofibular ligaments aid in the distribution of force placed upon the lower leg and stabilizes the ankle from rotation forces during activity.[3,25,30,37] The medial or deltoid ligament (Figure 2-2) is the primary resistance against eversion of the ankle and is the strongest ligament in the talocrural joint.[3,25] The deltoid ligament is actually four ligaments that act as an interconnected fan, increasing its strength and decreasing its incidence of injury. The ligaments of the medial aspect of the ankle originate collectively at the medial malleolus of the tibia and insert individually to the talus, calcaneous, and navicular.[3,4,30,36,37]

The lateral ligaments of the talocrural joint (Figure 2-3) also collectively originate at a common site, the lateral malleolus of the fibula, and insert at the talus and calcaneous. These ligaments, named after their respective insertions are the anterior-talofibular (ATF), the calcaneofibular (CF), and the posterior-talofibular (PTF).

Individually, none of these lateral-stabilizing ligaments are as strong as the deltoid ligament structure.[25] The ATF has the highest incidence of injury in the ankle joint because it is the first ligament to undergo stress when the ankle is inverted and plantarflexed.[11,25] The CF ligament situated vertically is usually only injured during severe grade two ankle sprains, while the PTF ligament is the strongest of the lateral ligaments and is usually uninjured, except in the most severe ankle sprains.[25] Collectively these stabilizing ligaments protect the ankle from inversion forces, while the ATF and PTF also prevent anterior and posterior translation of the talus in their respective directions.[3,11]

Supporting the stabilizing ligaments are the surrounding muscles of the lower leg. These muscles, respective nerves and vascular supply are divided into four main compartments that serve different functions.[3,25,37] The anterior compartment contains the anterior tibialis and toe extensors, which are the primary and secondary dorsiflexors of the foot respectively. The lateral compartment holds the peroneals, which are the main evertors of the foot and prevent excessive inversion during activity. The posterior tibialis and toe flexors make up the deep posterior compartment, which are secondary invertors and plantar flexors of the foot. The final compartment is the superficial posterior that is made up of the gastrocnemius and soleus muscles, the main plantar flexors of the foot and main stabilizers of ankle motion.[3,4,25] While all the muscles mentioned are important, weakness of the peroneals and gastrocnemius/soleus complex would more significantly put an athlete at risk to injury, specifically to inversion ankle sprains.[38,39]

The ankle joint, while stable during daily activities undergoes extreme forces during athletic competition, which places increasing stress at the lateral aspect of the joint. This additional stress is focused on an area that is anatomically weak, increasing the ankle joint's incidence of injury. The intrinsic factor of muscular fatigue on postural control, becomes increasingly important in the body's effort to maintain its center of balance and preventing lateral ankle sprains, in a weak anatomical area.

Figure 2-1. Anterior view of ankle mortaise; tibia(1), fibula(2), talus(3).

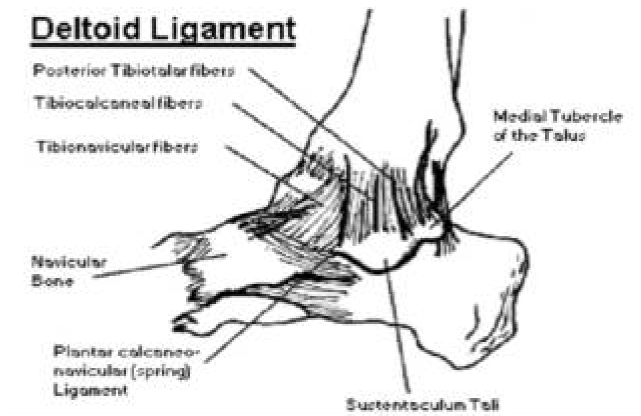

Figure 2-2. Medial or Deltoid ligament of the ankle

Figure 2-3. Lateral ligaments of the ankle.

Time to Stabilization

Time to stabilization, a form of postural sway, is defined as the time that is required to reach stability after landing.[10,22] Increased postural sway is a negative factor that can lead to increased incidence of injury caused by diminished factors of neuromuscular control and or balance.[5,7] Proprioception is defined by Reimann and Lephart[2] as the ability of a joint to determine its position in space; detect movement, kinesthesia, and sense resistance acting on it. The importance of understanding proprioception and kinesthesia during athletic competition is vital to preventing injuries. Without sufficient proprioceptive and kinesthetic awareness, the body would not be able to respond to changes in joint angles, inhibiting the joint's ability to protect itself from extreme motion or forces that would cause damage to soft tissue or bone.

Hoffman and Payne[22] and Johnston et al.[9] attribute the diminished ability to detect motion and joint position sense to a decreased accuracy of afferent input and efferent output or an increase in muscular fatigue. The afferents that are responsible for the response time of muscular activation, to maintain the body's center of balance, are mechanoreceptors[1,9,11,40] These mechanoreceptors are located in the joints and muscles of the body,[1,3,9,11,39,41] and include the joint mechanoreceptors: Ruffini's endings, Pacinian corpuscles and free nerve endings.[1,11,37] The mechanoreceptors interpret the joint's position and detect a passive or active movement of the joint in both closed and open kinetic chains. Muscle mechanoreceptors, such as muscle spindles and Golgi tendon organs located in the muscles and tendons, are responsible for sensing changes in muscle length and tension respectively.[1,8,11,40] Together these receptors relay information to the central nervous system (CNS) regarding changes occurring in and around the joint to help keep the body within its center of balance.[1,4,11,37,40,42,43] A decrease in the efficiency of these mechanoreceptors would increase the latency period of the reacting joint musculature.[2,11,30,35,44]

An increase in reaction time due to malfunctioning mechanoreceptors allows a joint to be dangerously extended beyond normal anatomical ranges of motion. This contortion is accomplished because the surrounding muscles (i.e., gastrocnemius, peroneals) may not fire as quickly and then could not correct the body's center of balance. This inhibiting factor of mechanoreceptor deficiencies can be complicated further by muscular fatigue.

McKinely and Pedotti[10] noted that the subjects with the shortest time to stabilization had all three major muscles of the lower leg (gastrocnemius, soleus, anterior tibialis) contracted prior to landing. This contraction creates greater muscle stiffness, which would allow faster reaction to the landing surface. Subjects with poor time to stabilization scores showed little to no anticipatory control contraction of lower leg musculature as measured by electromyography.[10]

Aniss et al.[45] provided another insight into a decreased time to stabilization score. The study examined the various gains of cutaneomuscular reflexes evident in extensor and flexor muscles of the lower leg. These data indicated that these reflexes are only present when their respective muscles are in contraction. Aniss et al.[45] and McKinely and Pedotti[10] indicated that an association exists between anticipatory or voluntary contraction of the lower leg musculature and a decrease in reaction time for the cutaneomuscular reflexes of the lower leg and time to stabilization, respectively. This would decrease time to stabilization and if fatigue decreases force output in musculature, then pre-landing contraction at the end of an activity might also be decreased and not strong enough to excite the cutaneomuscular reflexes.[45]

Konradsen et al.[39] determined through a clinical experiment that the latency period, response to stimulus, of the peroneals was too long to prevent ligamentous overload in the clinical setting. Kondradsen et al.[39] also concluded that during activity, the ankle joint and respective musculature receives information from the receptors near the ankle and foot, rather than from visual or vestibular information, since those sensory inputs were not denied to the subjects during the experiment. This study supports the data collected by McKinely and Pedotti[10] and Aniss et al.[45] that anticipatory contraction of the lower leg musculature is a prime stabilizing factor of the ankle.

Recent studies have reported positive correlations between muscular fatigue and an increase in postural sway and time to stabilization.[9,16-19] As stated earlier, time to stabilization, an aspect of motor control for the lower extremity, is dependent on proprioceptive and kinesthetic feedback as well as reflexive and voluntary muscle responses.[9] Muscular fatigue would negatively affect this proprioceptive feedback loop through either deficiencies in the activation of the muscular mechanoreceptors or a decrease in the force produced by muscular function. Decreases in activation of mechanoreceptors increase the latency period of the muscle action and prolongs the time to correction and regaining the individual's center of balance.[10,39,45] Muscular fatigue also decreases the force production of a muscle when measured via isokinetic fatigue protocols.[9,14,16-18,46-48] These protocols often indicate a subject is fatigued when peak torque falls below 50% of the initial contraction.[9,16,17,19,20] Thus a delayed firing of the corresponding musculature with a decreased force production may exponentially increase injury risk and incidence.[7,44,45,49]

Because of these data from isokinetic fatigue protocols, there have been several training protocols established to help injured athletes regain proprioception, potentially reducing time to stabilization indirectly. While the protocols vary in specific components, most encompass a single leg balance program, focusing on maintaining the center of gravity within the base of support.[11,49] Common ways of training include maintaining center of balance on a stable surface and progressing to an unstable surface (i.e., a wobble board). These training programs require a significant amount of balance and motor control, while acclimating the muscle to fatigued conditions. Konradson[50] illustrated that proprioceptive training can be 80% effective in reducing the frequency of ankle sprains.

Measurement of Postural Sway

Training protocols can only be effective and measured if there is a baseline to measure postural sway against. Several valid and reliable testing methods are available including the single leg balance, Balance Error Scoring System and Star Excursion test. However, more functional and dynamic measures of time to stabilization can be measured using single-leg-hop stabilization test on force plates. However, according to Reimann[35] there is no relationship between static and dynamic measurements of postural sway.

One possible technique to measure balance is stabilometry[22] often seen in the form of a Biodex stability system (BSS).[21,51] Stabilometry is a technique that utilizes a force plate to measure the displacement of an individual's center of gravity while standing in a static state. While indicating a reliable measure of balance, these data points were also comparable to studies performed using static force plates.[21]

Force plates are more often used to determine stability[12]-center of pressure or ground reaction forces for a single limb stance.[12,13,51] These measurements are obtained though measuring force at three or more points on the platform or the torque around the horizontal axes.[7,13] Time to stabilization is a functional exam of stability by definition, forcing subjects to maintain balance through a transition from a dynamic to a static state.[13] Two common methods for this transition are the step down or hop tests. Respectively, the subject would step down off an elevated platform or hop a set distance with a minimum height requirement, land on the force plate and regain their center of balance.[12,52] Goldie et al.[53] developed a testing protocol that was reliable and minimized lost data due to subject mortality. This protocol also noted that ground reaction forces produced more reliable results than center of pressure scores.[13,51,53]

Ground Reaction Forces

Ground reaction forces (GRF) are a method of measuring balance by measuring the torque around two horizontal and one vertical axes.[13] These forces are indicators of how heavily an athlete lands from a jump, and how well they balance in a stance, making a good measure of the time it takes that athlete to stabilize their body mass within their center of gravity. GRF acting on the body during landings have been associated with injury to the lower limb.[24,26]

Ground reaction forces and center of pressure measures have been used repeatedly in single stance tests of balance and stabilometry. Goldie et al.[13] found that GRF were more reliable indicators of balance and stabilization of the subject than center of pressure measures. Previous studies have also shown the reliability of this measure to be high.

Ground reaction forces are often expressed as the magnitude of the peak vertical force divided by the subject's body weight, or units of body weight.[24]

There are two common appearances of ground reaction forces, that of athletes who land flat footed (Figure 2-4), and that of athletes who land with a toe-heel technique (Figure 2-5).[26] The flatfoot method produces a unimodal, while the toe-heel method produces a bimodal ground reaction force-time history.[26] The more practiced landing technique, the toe-heel, produces to maximum force outputs on the bimodal curve from forefoot and heel contact respectively.[26,54] Recent studies have shown peak vertical GRFs as high a 6.0BW.[26]

However, little research has been done to illustrate the effects of fatigue on GRF, most of the research has focused on style of jump, and landing technique. The effects of fatigue on GRF could be very significant, as joint angles and muscle stiffness at touch down play a major role as to the magnitude of the peak vertical GRF.

Landing from any jump requires the body to produce movements which will further minimize the GRFs and soften the landing.[10,55] According to Dufek and Bates[26], the height of a jump plays a minor role in the magnitude of GRF as compared to knee joint angle at touch down. This theory is backed by studies that show a toe-heel landing as opposed to a flatfoot landing, requires greater joint flexion to decrease GRFs.[24,26]

In an attempt to reduce GRF the body must anticipate the landing and prepare for it by increasing muscle stiffness.[10,55] Activation of the lower extremity musculature, specifically the triceps surae complex will help slow the rate of decent and decrease ground reaction forces on the body. Further reduction of GRFs can be accomplished by allowing the knee and hip to flex more which increases the time of landing providing an attenuation in kinetic energy.[10,24,55] A deficiency in the body's ability to produce anticipatory contractions and eccentrically contract lower extremity musculature in a controlled manner would drastically increase GRF as well as an athlete's time to stabilization.[24] These deficiencies are often caused by fatigue of the lower extremity through participation in athletic events.

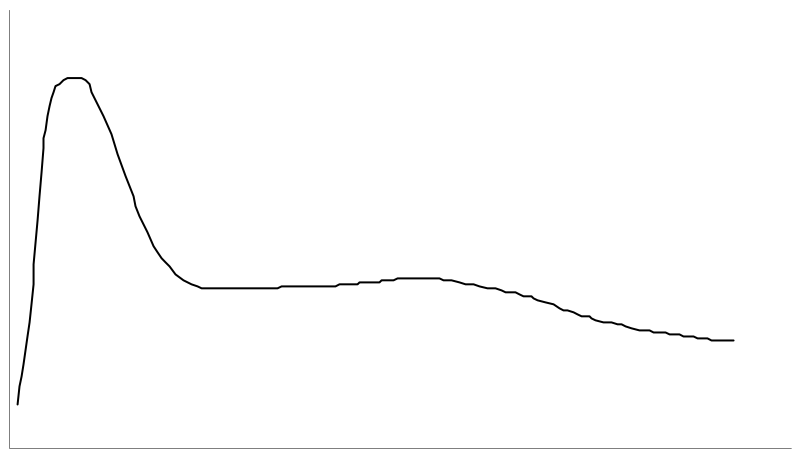

Figure 2-4. Force time history of a flat foot landing.

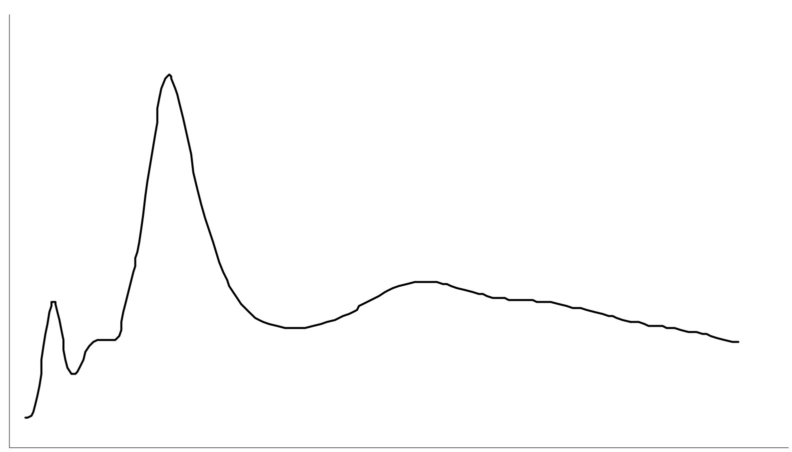

Figure 2-5. Force time history of a toe to heel landing.

Fatigue Protocols

Fatigue protocols are often used to mimic a subject's loss of power output during an athletic event. Fatigue is defined as an inability to produce an expected force or power output, which negatively affects proprioception through either deficiencies in activation of the muscular mechanoreceptors or a decrease in the muscular function.[15] Traditionally, isokinetic fatigue protocols are used to mimic the fatigue that occurs during an athletic event. These protocols often quantify fatigue at 50% of the initial peak torque generated by the subjects.[9,16-18] The testing protocols of previous research have been conducted at both high and low angular velocities and varying repetitions. The isokinetic fatigue protocol ends traditionally when three consecutive repetitions are below 50% of the initial peak torque, to ensure that fatigue and not lack of effort is indicated by the torque values.[9,16-18]

The purpose of these isokinetic fatigue protocols is to isolate particular muscles and to determine each muscle's role in establishing and controlling time to stabilization. Isokinetic testing provides a fixed speed with a varying resistance to allow for maximal effort throughout a range of motion (ROM).[3,4,56] Using isokinetic machines, the ROM of a joint and the strength of a group of muscles can be assessed. Isokinetic testing provides information such as peak torque, average power and total work done, as well as the subject's fatigue index. Isokinetics allow athletes to perform exercises at a more functional speed than isotonic exercise; a fixed resistance, varying speed exercise.[3,4] The majority of isokinetic testing is done via open kinetic chain (OKC) positioning. An open kinetic chain indicates that the distal extremity, in this case the foot, is not fixed and can move freely without affecting the performed exercise. The counter position is a closed kinetic chain (CKC) which has the distal extremity, hand or foot, attached to the ground or stable platform.[3,20,28,41,47] Open kinetic chain testing is non-weight bearing and therefore, does not account for the stabilizing effects that secondary and synergistic muscles play during closed kinetic chain (CKC) weight-bearing exercises.

Bobbert and van Ingen Schenau[57] compared the mechanical output of the ankle during isokinetic plantar flexion and single-leg jumping. The results indicated that at a given angular velocity of plantar flexion much larger moments were produced during jumping than isokinetic plantar flexion.[57] Bobbert and van Ingen Schenau[57] reasoned that during isokinetic testing the duration of plantar flexion is so short, that the gastrocnemius can not rise to the maximum strength potential and produces a submaximal muscle moment. Also the positioning of isokinetic testing places the muscle fibers of the plantar flexors in an unfavorable area of their force-velocity relationship.[57]

Despite the limitations of isokinetic testing, several studies have indicated a positive correlation between isokinetic peak torque and functional ability. Wilk et al.[48] investigated the relationship between isokinetic knee extension strength and functional testing. The results indicated a positive correlation between isokinetic strength and functional ability. The results from Negrete and Brophy[47] demonstrated the same relationship. While the data indicated a positive correlation, only the Negrete and Brophy[47] results were significant. Similarly, Morgoni et al.[46] compared isokinetic peak torque to maximal ball velocity in young soccer players. These data illustrated a significant and positive correlation between isokinetic peak torque and functional ability.

OKC isokinetic fatigue protocols have also indicated a positive correlation between fatigue and an increase in postural sway. Johnston et al.[#] indicated significant differences in postural sway after conducting isokinetic fatigue protocols. In another study, Vuillerme et al.[15] also indicated significant increases in postural sway after muscle fatigue was induced via an isokinetic protocol.

Regardless of these correlations, a more clinically relevant protocol would be CKC, weight-bearing testing. Recently there have been studies done to investigate close kinetic chain isokinetic testing.[9,20,41,47] These studies have suggested positive correlations between the open and closed kinetic chain isokinetic testing protocols.[20,47] However, it should be noted that most of these protocols compare peak torque to a maximal strength test. Porter et al.[20] conducted a study that illustrated a way to measure standing isokinetic peak torques for dorsiflexion and plantarflexion. In this study, a positive strength correlation was indicated between the non-weight and weight-bearing isokinetic test positions. This could indicate that isokinetic testing is a valid and reliable method of measurement, but no correlations have been noted at this time regarding isokinetic fatigue protocols and functional fatigue protocols.

While several other studies have indicated that a positive correlation between isokinetic strength and functional ability does exist, very little research has been done to determine the validity of isokinetic fatigue protocols. To the best knowledge of the researchers, no study has investigated and compared the effects of an isokinetic fatigue protocol and a functional fatigue protocol on time to stabilization. Functional fatigue protocols may consist of any number of CKC weight-bearing activities that include dynamic movement and require stabilizing effects of the musculature. Sprints[19], toe raises[15] and cutting[34] are just a few examples of functional activities that can be used in a fatigue protocol. Though little research has focused on functional fatigue protocols, several studies have found that postural control has increased significantly with functional fatigue.[12,19]

Conclusion

The ankle joint, supported by stabilizing ligaments and surrounding musculature, is the focal point for the body's weight during ambulation. Due to the significant amount of weight placed upon the joint and the inherent instability of the ankle, the ankle is the most commonly injured body part during athletic competition.[22,24,26,28,33] Ankle sprains, especially lateral, often become chronic injuries due to the incomplete rehabilitation process that does not address the decreased neuromuscular control and the increased time to stabilization resulting from the injury.

Time to stabilization, or the amount of time for the body to regain the center of balance or mass within it's base of support, and can be affected by several factors including injury or a prolonged response time to afferent neural signals caused by muscular fatigue. This increased response time, quantified in time to stabilization, inhibits the already destabilized ankle joint during dynamic movement and increases the chance for injury. To determine the increased response time, subjects must stabilize themselves on a force plate.

The majority of the research investigating the effects of muscular fatigue on postural sway and time to stabilization utilized an isokinetic protocol. Isokinetic protocols are frequently chosen because of the inherent safety to patients, their objectivity, and their reproducibility in testing measures.[15] However, the validity of isokinetic fatigue protocols has not been addressed. To determine if OKC isokinetic fatigue protocols are a true measure of the fatigue experienced during athletic activity, they must be compared to functional fatigue protocols. Any number of CKC weight-bearing activities can be incorporated into a functional fatigue protocol and compared to isokinetic fatigue protocols through the measurement of time to stabilization.

CHAPTER 3
METHODS

Subjects

Twenty subjects were asked to voluntarily participate in this investigation. To be included in this study subjects were between 18 and 30 years of age, and have no prior history of lower extremity or head injury within the past year. Subjects were excluded if they suffered from any disorders that affect neuromuscular control and were moderately trained. (i.e., exercise 2-4 times per week) All subjects were asked to read a description of the study and sign an informed consent form, approved by the university Institutional Review Board (IRB) (Appendix A).

Instrumentation

Medical Eligibility Form

The eligibility form (Appendix B) was designed to determine eligibility for participation in this study. The questionnaire was completed prior to any data collection.

Vertical Jump Station

A Vertec vertical jump device (Sports Imports, Columbus, OH) was used to establish subjects' maximal vertical jump (Figure 3-1). All subjects will stand next to the Vertec device and reach as high as possible. This measure was recorded as the subject's standing height. Subjects will then be asked to jump as high as possible and move the highest vane possible. This height was recorded as the maximal vertical jump height. All vanes are measured off at 1.27 cm increments.

Isokinetic Dynamometer

A Kinetic Communicator (Kin Com) 125 AP (Chattanooga Group, Chattanooga, TN) isokinetic dynamometer integrated with a computer and appropriate software was used to induce isokinetic fatigue of the plantar and dorsi flexors of the ankle (Figure 3-2).

Triaxial Force Plate

A Bertec triaxial force plate as seen in figure 3-3 (Bertec Corporation, Columbus, OH) was used to measure duration of instability from time of impact until pretest values of stability are recorded at a frequency of 600-Hz. The force plate data will undergo an analog to digital conversion and was stored on a PC-type computer using the DATAPAC 2000 (Run Technologies, Laguna Hills, CA) analog data acquisition, processing, and analysis system.

Infrared Timing Device

A Brower infrared timing device (Brower Timing Systems, Salt Lake City, UT) was used to time subjects during the functional fatigue protocol. The device transmitters (Figure 3-4) project an infrared beam at the start and finish line of the functional fatigue protocol area. A subject's time began as they crossed and ended as the subject crossed the finish line. The device was used to determine 150% of initial time for each subject.

Motion Analysis System

Kinematic data was collected using a set of two JVC low speed motion recorder cameras (US JVC Corporation, Fairfield, NJ) as seen in figure 3-5. This system collects all data at 60Hz from two angles, both posterior lateral and anterior lateral for all trials. A motion analysis will allow additional dependent variables of lower extremity joint angles to be measured using Peak Motus motion analysis system (Peak Performance Technologies, Englewood, CO) to digitize all kinematic data.

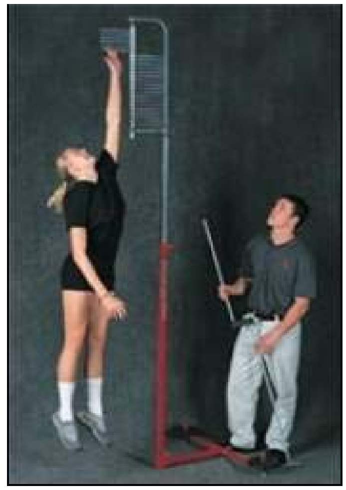

Figure 3-1. Vertec jump station.

Figure 3-2. Isokinetic dynamometer with integrated computer.

Figure 3-3. Bertec triaxial forceplate.

Figure 3-4. Brower infrared timing device as set up for the functional fatigue protocol.

Figure 3-5. JVC low speed motion recorder camera.

Measurements

Time to Stabilization

Subjects will start in a standing position 70 cm from the center of the triaxial force plate. Each subject was required to jump off of both legs and touch a designated marker placed at a position equivalent to 50% of the subject's maximum vertical leap before landing on the force plate[52] The subject is to land on their stance leg (leg used to plant when kicking a ball), stabilize as quickly as possible and balance for 20 seconds on the triaxial force plate. This protocol can be seen in figure 3-6 below moving from right to left.

The average of the three trials were taken as their respective pretest data score. All subjects were instructed to jump with their head up and hands in a position to touch the designated marker. Medial/lateral and anterior/posterior stabilization time was determined using the technique of sequential estimation (Figure 3-7). The technique incorporates an algorithm to calculate a cumulative average of the data points in a series by successively adding in 1 point at a time.[12] This cumulative average was compared against the overall series mean, and the series was considered stable when the sequential average remained within ¼ standard deviation of the overall series mean.[12] The series consists of all data points within the first three seconds of touch down.

Vertical TTS was established as the time when the vertical force component reached and stayed within 5% of the subject's body weight after landing (Figure 3-8).[10] A subject's body weight was established as the average of the variation of the vertical GRF in the final second of the 20-second data collection period.

Ground Reaction Forces

The anteroposterior, mediolateral, and vertical and the ground reaction moments about those axes was collected and analyzed at a frequency of 600Hz. The GRFs measured in Newton's by computer software will accurately depict how hard or soft an individual lands from a jump. These GRF measurements are then quantified as an intensity of the landing, expressed as the magnitude of the peak force divided by the subject's body weight, or units of body weight. Anteroposterior and mediolateral GRF variations were used as part of the TTS calculation. The peak vertical ground reaction force intensity was examined at two points when initial contact with the force plate is made, (F1) forefoot contact and (F2) rearfoot contact within the bimodal curve associated with a toe-heel landing in the force-time history (Figure 3-9).[26]

Motion Analysis

Kinematic data was collected using a set of two JVC motion recorder cameras (US JVC Corporation, Fairfield, NJ). This system collects all data at 60Hz from two angles, both posterior lateral and anterior lateral for all trials (Figure 3-10). Camera 1 was positioned 5.05-m to the posterior lateral side for subjects landing on their right foot or 6.68-m to the posterior lateral side for subjects landing on their left foot, while camera 2 was 5.05-m to the posterior lateral side for subjects landing on their right foot or 6.68-m to the posterior lateral side for subjects landing on their left foot. Both cameras were able to view all reflective markers during each landing task, thus enabling three-dimensional analysis. Reflective markers were placed at the greater trochanter, mid thigh, lateral joint line of the knee, mid shank, lateral malleolus, calcaneous, and head of the fifth metatarsal (Figure 3-11).[57,58] All video data was analyzed using a Peak Motus motion analysis system (Peak Performance Technologies, Englewood, CO). Ankle flexion was seen as the vector angle between the A1-A2 segment (5th metatarsal – calcaneous) and the B1-B2 segment (knee – lateral malleolus). Knee flexion was then measured as the calculated vector between P1-V-P2. With the greater trochanter as P1, the knee as the fulcrum (V) and the lateral malleolus as P2. Knee valgum was determined by the difference of the X coordinates of the greater trochanter and knee in the 3D transformed data. The values were taken at the point just prior to touch down and at all points after touch down. The greatest displacement of the greater trochanter and knee X coordinates after touchdown and at jump height marker were used to find the difference.

Figure 3-6. Jump protocol from right to left. Starting position, mid-jump and finishing position.

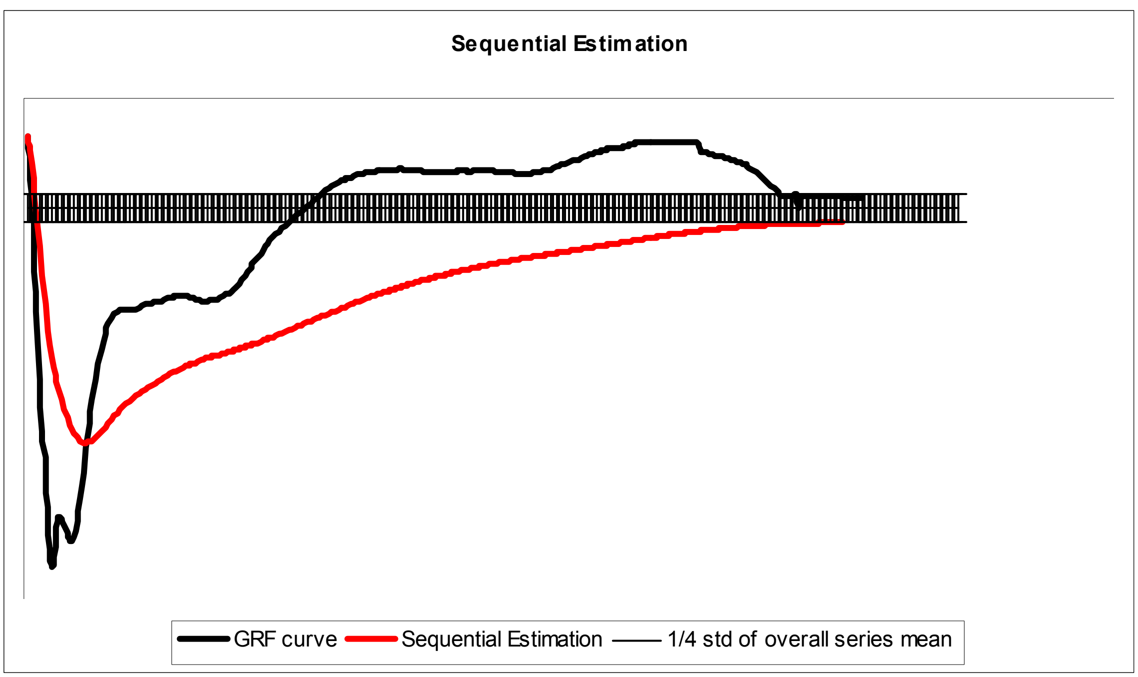

Figure 3-7. Graphical representation of sequential estimation

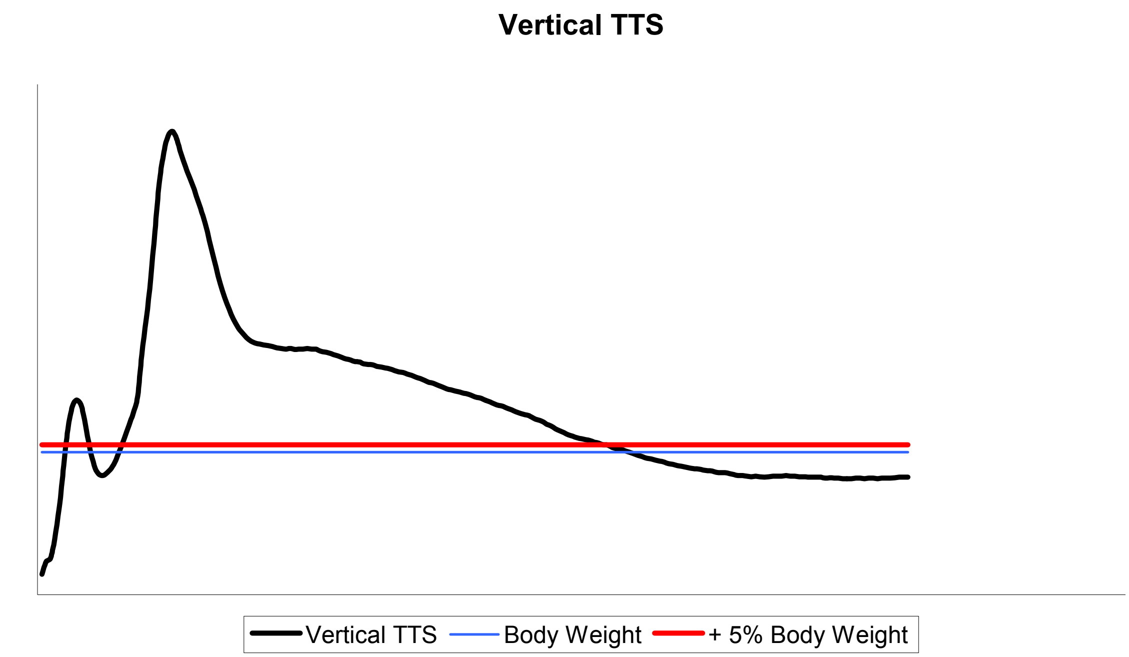

Figure 3-8. Vertical time to stabilization analysis method.

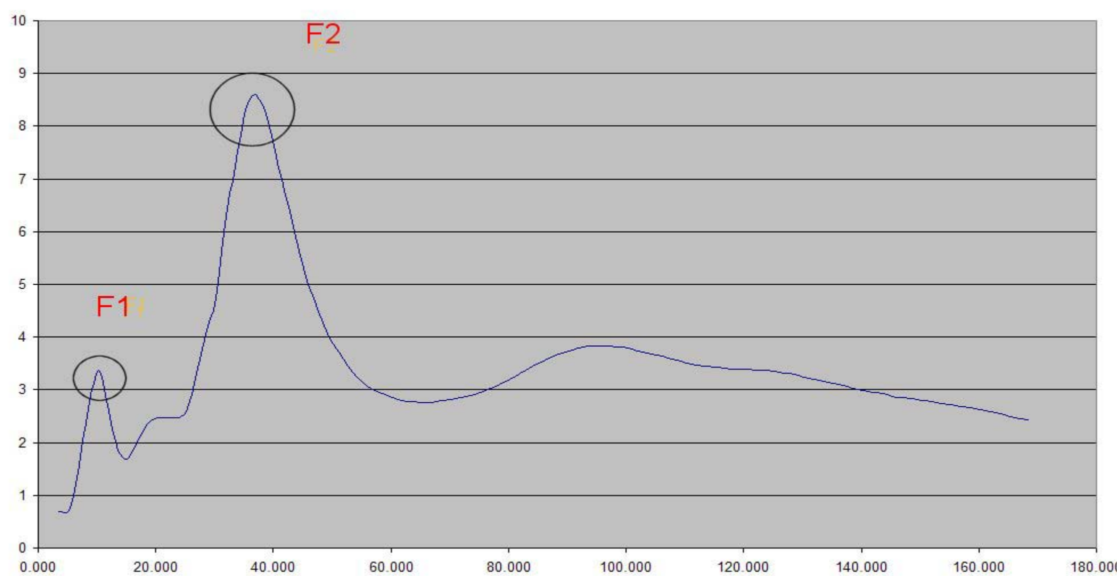

Figure 3-9. Force time history curve with GRF collection points highlighted.

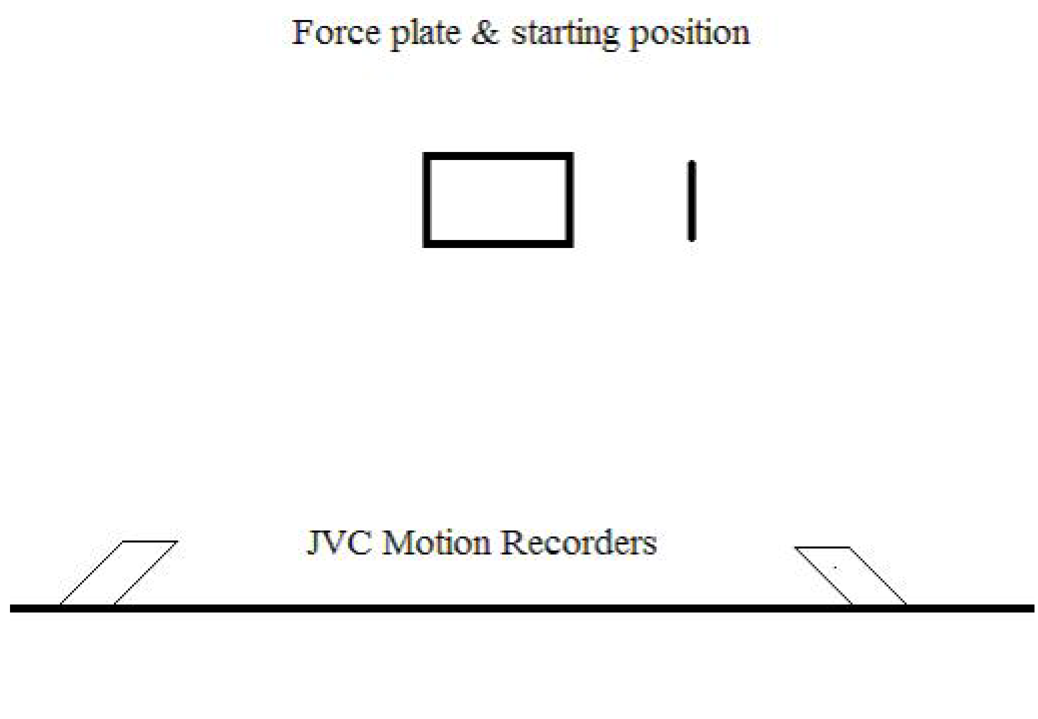

Figure 3-10. Camera setup for motion analysis of joint kinematics.

Figure 3-11. Placement of reflective markers.

Isokinetic Fatigue Protocol

The isokinetic fatigue protocol was administered using the Kincom Isokinetic Dynamometer in the Biomechanics Laboratory (Figure 3-12). Subjects were positioned according to manufacturers specifications for ankle dorsi and plantar flexion (DF and PF). Each subject will perform 3 sub-maximal and 3 maximal repetitions for a warm-up, followed by 1 minute of rest. An initial peak torque value will then be taken using the overlay mode from the 3 maximal repetitions of DF and PF at 120 and 30 degrees per second respectively.[12] The subject will then continue to give a maximal effort with a continuous series of concentric contractions of DF and PF until PF falls below 50% of both the respective peak torque values for a minimum of 3 consecutive repetitions.

Functional Fatigue Protocol

Before the functional fatigue protocol is administered each subject was given instructions and practices and a single maximal effort run of the course for a warm-up, followed by 1 minute of rest. The functional fatigue protocol, will consist of the following:

The SEMO Agility Drill

A series of forward sprints, diagonal back-pedaling, and side stepping within a 12' x 12' area (Figure 3-13). (The subject completed 3 repetitions)

Plyometric Box Jumps

A series of 3 boxes of increasing height, 18" apart (Figure 3-14). The subject must jump onto the first box, stabilize and jump down, immediately jumping back up onto the second box, stabilize and repeat onto the third box. (The subject completed 3 repetitions)

Two-legged Hop Sequence

A series of markers spaced over a ten foot distance, were jumped onto and immediately off of towards the next marker. The subject must jump and land using both feet for each marker (Figure 3-15).[59] (The subject completed 3 repetitions)

Side-to-side Bounds

An area 5' wide in which the athlete must jump sideways from the center marker to the one side back to the center and then to the opposite side (Figure 3-16). (The subject completed 30 repetitions)

Mini-tramp

Subjects must jump onto a mini-tramp, stabilize and jump off onto the floor on the opposite side (Figure 3-17). (The subject completed 30 repetitions)

Co-contraction Arc

Subjects must resist the tension of an elastic cord as the side shuffle around a 180-degree arc (Figure 3-18).[59,60] (The subject completed 10 repetitions)

Fatigue was quantified as the time that it takes for a 150% increase from their maximal effort run through the course. Time to complete the functional fatigue protocol was measured using infrared sensors that indicate the time for the completion of each circuit. Fatigue has been set at 150% to mimic previous studies on the effects of fatigue on time to stabilization in the literature.[19]

Figure 3-12. Subject position for isokinetic fatigue protocol

Figure 3-13. SEMO agility drill.

Figure 3-14. Plyometric box jumps.

Figure 3-15. Two-legged hop sequence

Figure 3-16. Side-to-side bounds.

Figure 3-17. Mini-tramp jumps.

Figure 3-18. Co-contraction arc drill.

Procedure

Each subject will report to the biomechanics laboratory on two separate occasions. On each occasion subjects were pretested for time to stabilization following a single leg landing on a force plate. Each subject will complete either a functional or an isokinetic fatigue protocol immediately following the pre-test. Fatigue protocol completion was randomized counterbalanced. Once fatigue has been induced, each subject was reassessed for time to stabilization following procedures identical to those used during pretesting.

Additionally a motion analysis of each subject's landing technique was conducted for all pre and posttest trials. This analysis, based on the average of the three trials completed, will compare and contrast the average amount of ankle and knee flexion and knee valgum from the two fatigue protocols.

Post testing procedures were initiated 30 seconds following completion of the fatigue protocol. When subjects return on the second occasion the same procedures were followed, however, a different fatigue protocol was used. The ordering of the fatigue protocols were in a randomized counter balanced order with a minimum of one week separating testing sessions.

Data Analysis

The independent variables are the fatigue protocols and test, while the dependent variables will consist of time to stabilization, vertical GRF, and knee and ankle angles. The data was analyzed with two-way analyses of variance (ANOVA) with repeated measures. The two within subject variables will include fatigue protocol (isokinetic vs functional) and time (pre-test vs. post test). The means were compared between all conditions, to determine the main effects of protocol and time. Following the analysis, post hoc testing was conducted using a Tukey's HSD test. A Pearson Product Moment Correlation Coefficient was calculated to determine if a relationship exists between the ground reaction forces, time to stabilization, and knee and ankle angles. An alpha level was set at .05 for all statistical analyses.

CHAPTER 4
RESULTS

Introduction

The purpose of this study was to compare the effects of isokinetic and functional fatigue on TTS, peak vertical ground reaction forces and joint angles during a single-leg jump landing. The isokinetic fatigue protocol was adapted from those commonly reported in the literature while the functional fatigue protocol was developed to simulate actual athletic practice and game situations. The independent variables included the fatigue protocol (isokinetic vs functional) and time (pre- vs post-exercise). The dependent measures included vertical, medial/lateral, anterior/posterior time to stabilization scores, peak vertical ground reaction forces (toe strike, heel strike), maximum ankle, and knee flexion, and maximum knee valgum. Data were analyzed to identify differences among any of these measures and are presented according to the dependent measure that they represent. Raw data and ANOVA tables are found in Appendices D and E.

Subjects

Twenty healthy subjects free from lower extremity injury, CNS injury and disorders that affect neuromuscular control over the past six months. All subjects read a description of the study and signed an informed consent form, approved by the university Institutional Review Board (IRB) (Appendix A). Subject's averaged 22±1.6 years of age, were 173.84±10.452 cm in height, and 67.13±12.426 kg in weight.

Time to Stabilization

Vertical

The group means and standard deviations for vertical TTS can be found in Table 4-1. The times ranged from 206.71- to 385.63-ms during pre-testing and from 200.60- to 1175.59-ms during post testing. No significant protocol [F(1,19)=4.96, p=.490] or time [F(1,19)=.000, p=.986] main effects were observed. Likewise, no significant protocol by time interaction [F(1,19)= 3.93, p=.538] was observed for vertical TTS.

Table 4-1. Vertical TTS as determined by vertical GRF-Fz (mean ±SD)

Fatigue Protocol	Pre-exercise (ms)	Post exercise (ms)	Combined Protocol (ms)
Isokinetic	290.42 ±42.21	286.15 ±47.88	288.29±44.06
Functional	278.03 ±52.95	281.85 ±62.85	279.577±58.26
Combined Time	284.23±47.68	283.64±56.12	

Medial/Lateral

The group means and standard deviations for medial/lateral TTS can be found in Table 4-2. The times ranged from 53.34- to 2232.11-ms during pre-testing and from 997.98- to 2219.33-ms during post testing. No significant protocol [F(1,19)=.388, p=.541] or time [F(1,19)=.434, p=.518] main effects were observed. Likewise, no significant protocol by time interaction [F(1,19)= .287, p=.598] was observed for medial/lateral TTS.

Table 4-2. Medial/Lateral TTS as determined by GRF-Mx (mean ±SD)

Fatigue Protocol	Pre-exercise (ms)	Post exercise (ms)	Combined Protocol (ms)
Isokinetic	676.57 ±615.78	350.90 ±445.51	1491.137±493.49
Functional	523.29±464.95	533.66 ±594.12	911.31±694.01
Combined Time	912.69±710.89	1489.76±470.58	

Anterior/Posterior

The group means and standard deviations for anterior/posterior TTS can be found in Table 4-3. Times ranged from 796.27- to 2136.538-ms during pre-testing and from 11.67- to 2053.19-ms during post testing. Significant protocol [F(1,19)=8.93, p=.009] and time [F(1,19)=7.72, p=.012] main effects were observed for anterior/posterior TTS. A significantly greater TTS was observed during the pre-test time session (1559.35 ±344.74 ms) as compared to post-test session (1322.92 ±427.01 ms) and the functional protocol session (1320.92 ±417.94 ms) TTS was significantly shorter than the isokinetic protocol session (1440.20 ±475.24 ms). However, these significant main effects were not associated with a significant protocol by time interaction [F(1,19)= .001, p=.978].

Table 4-3. Anterior/Posterior TTS as determined by GRF-My (mean ±SD)

Fatigue Protocol	Pre-exercise (ms)	Post exercise (ms)	Combined Protocol (ms)
Isokinetic	1444.40±323.38	1201.43±470.59	1320.92±417.94
Functional	1678.97±335.21	1201.43±470.59	1440.20±475.24#
Combined Time	1559.35±344.74	1201.43±476.59*	

* Significantly > Pre-exercise, p<.05
# Significantly > Isokinetic, p<.05

Ground Reaction Forces

The group means and standard deviations for peak vertical ground reaction forces can be found in Table 4-4 and 4-5. The ground reaction forces were analyzed at two different points in the ground reaction curve, at toe strike (F1) and at the heel strike (F2). The F1 ground reaction force scores ranged from 389.054- to 1768.49-N, while the F2 ground reaction force scores ranged from 1308.20- to 3748.18-N.

A significant time main effect [F(1,19)=8.64, p=.008] was observed for the ground reaction force at heel strike, as the post test (2772.57 ±590.10 N) ground reaction force was significantly greater than the pre-test (2651.78 ±588.50 N). However, this was not observed at toe strike, as the time main effect was not significant [F(1,19)=1.44, p=.246]. Significant protocol main effects were not observed for either heel strike [F(1,19)=.80, p=.383] or toe strike [F(1,19)=.46, p=.507]. Likewise, significant protocol by time interactions were not observed for heel strike [F(1,19)=.37, p=.070] or toe strike [F(1,19)=.121, p=.286].

Table 4-4. Toe Strike-F1 as determined by GRF-Fz (mean ±SD)

Fatigue Protocol	Pre-exercise (Newtons)	Post exercise (Newtons)	Combined Protocol (N)
Isokinetic	1149.402±234.523	1178.551±166.41	1163.58±207.59
Functional	1103.671±321.225	1137.197±280.255	1120.43±305.05
Combined Time	1125.95±286.96	1156.79±273.41	

Table 4-5. Heel Strike-F2 as determined by GRF-Fz (mean ±SD)

Fatigue Protocol	Pre-exercise (Newtons)	Post exercise (Newtons)	Combined Protocol (N)
Isokinetic	2572.752±572.042	2783.463±623.38	1987.38±957.44
Functional	2730.814±579.321	2761.685±538.683	2746.25±566.71
Combined Time	1960.38±919.45	2772.57±590.10*	

* Significantly > Pre-exercise, p<.05

Joints Kinematics

In this study three aspects of joint kinematics were measured during the dynamic stability protocol. These measurements included a maximum ankle and knee flexion during the jump landing and the maximal knee valgum that occurred as a result of that landing.

Dorsiflexion

The group means and standard deviations can be found in Table 4-6. The maximum ankle flexion scores ranged from 53.42º to 91.40º at pre-test and from 55.76º to 94.44º at post test. No significant protocol [F(1,19)=.94, p=.344] or time [F(1,19)=.02, p=.905] main effects were observed. Likewise, no significant protocol by time interaction [F(1,19)= .06, p=.803] was observed for maximum ankle flexion.

Table 4-6. Ankle Flexion (mean ±SD)

Fatigue Protocol	Pre-exercise (degrees)	Post exercise (degrees)	Combined Protocol (degrees)
Isokinetic	71.9±10.2	71.7±9.5	72.6±9.2
Functional	69.3±7.8	69.3±8.9	69.8±8.1
Combined Time	71.2±8.7	71.2±8.8	

Knee Flexion

The group means and standard deviations can be found in Table 4-7. The maximum ankle flexion scores ranged from 111.11º to 145.94º at pre-test and from 114.00º to 143.11º at post test. No significant protocol [F(1,19)=.67, p=.425] or time [F(1,19)=.58, p=.456] main effects were observed. Likewise, no significant protocol by time interaction [F(1,19)= .21, p=.652] was observed for maximum knee flexion.

Table 4-7. Knee Flexion (mean ±SD)

Fatigue Protocol	Pre-exercise (degrees)	Post exercise (degrees)	Combine Protocol (degrees)
Isokinetic	129.7±9.3	128.8±8.0	129.8±8.9
Functional	128.3±9.3	128.0±7.5	128.2±8.6
Combined Time	129.3±9.3	128.7±7.7	

Knee Valgum

The group means and standard deviations can be found in Table 4-8. The maximum knee valgum scores ranged from -.009cm to .09cm at pre-test and from -.008cm to .084cm at post test. No significant protocol [F(1,19)=.07, p=.796] or time

[F(1,19)=.12, p=.737] main effects were observed. Likewise, no significant protocol by time interaction [F(1,19)= .79, p=.386] was observed for maximum knee valgum.

Table 4-8. Knee Valgum (mean ±SD)

Fatigue Protocol	Pre-exercise (M)	Post exercise (M)	Combined Protocol (M)
Isokinetic	0.03±0.03	0.03±0.03	0.03±0.02
Functional	0.03±0.02	0.03±0.02	0.03±0.02
Combined Time	0.03±0.02	0.03±0.02	

Correlational Analysis

A Pearson product moment correlation was run on the pretest measures of all dependent variables, to determine if interdependence existed between the dependent variables. Through the analysis several significant correlations were noted. Vertical time to stabilization had significant correlations to GRF-F1 (r=.534, p<.001), maximum ankle flexion (r=-.445, p=.004), and maximum knee flexion (r=-.667, p<.001). The other TTS measures, medial/lateral, and anterior/posterior only had a significant correlation with GRF-F2 (r=-.775, p=.001) and (r=.401, p=.011). In addition to the significant correlation that GRF-F1 had with vertical TTS, a significant correlation was also noted with maximal knee flexion (r=-.385, p=.015). Maximal ankle flexion also had an additional significant correlation with maximal knee flexion (r=.533, p=.001). There were no significant correlations found for knee valgum scores. A complete table of the Pearson product moment correlation coefficients can be seen in Table 4-9.

Table 4-9. Pearson Product Moment Correlation (r and significance)

Pearson product moment correlation coefficients									
		Vertical	Med/Lat	Ant/Pos	GRF-F1	GRF-F2	Ankle	Knee	Valgum
Vertical	r Sig.	1	.173 .284	.145 .373	.534* .001	.158 .336	-.445* .004	-.667* .004	-.208 .198
Med/Lat	r Sig.	.173 .284	1	-.267 .095	.116 .483	-.775* .001	.182 .262	.011 .946	-.027 .866
Ant/Pos	r Sig	.145 .373	-.267 .095	1	.128 .438	.401* .011	-.179 .268	-.309 .053	.131 .420
GRF-F1	r Sig	.534* .001	.116 .483	.128 .438	1	.222 .175	-.230 .159	-.385* .015	-.137 .405
GRF-F2	r Sig	.158 .336	-.775* .001	.401* .011	.222 .175	1	-.201 .221	-.297 .066	-.104 .528
Ankle	r Sig	-.445* .004	.182 .262	-.179 .268	-.230 .159	-.201 .221	1	.533* .001	.077 .637
Knee	r Sig	-.667* .004	.011 .946	-.309 .053	-.385* .015	-.297 .066	.533* .001	1	-.031 .852
Valgum	r Sig	-.208 .198	-.027 .866	.131 .420	-.137 .405	-.104 .528	.077 .637	-.031 .852	1
* Correlation is significant at the .05 level (2-tailed)									

CHAPTER 5
DISCUSSION

The purpose of this study was to compare the effects of isokinetically and functionally induced fatigue on time to stabilization (TTS), peak vertical ground reaction forces and joint kinematics (i.e., ankle and knee flexion and knee valgum) during a single-leg landing stabilization test. Three hypotheses were examined and are discussed below. The first hypothesis stated that there would be significant increases in time to stabilization, peak vertical ground reaction forces, and joint kinematics in the post test measures as compared to the pretest measures. The second hypothesis stated that a greater change in the dependent variables would be noted following functional fatigue as compared to isokinetic fatigue. The results of this study failed to support either of these hypotheses. The third hypothesis stated that there would be a high correlation between peak vertical ground reaction forces and time to stabilization when assessed in an unfatigued state. In general, there was a low to moderate relationship to support the third hypothesis.

Fatigue

The primary purpose of this study was do determine if functionally induced fatigue would have a greater effect on TTS and joint kinematics as compared to isokinetically induced fatigue. However, no differences were observed when comparing the two fatigue protocols. It is difficult to make comparisons between the two types of exercise, as neither protocol had an effect on these variables. This conflicts with the results of previous studies assessing the influence of fatigue on neuromuscular control.[9,16,17,19]

Johnston et al.[9] and Douex et al.[19] reported that both isokinetic and functional fatigue protocols respectively, significantly increased postural sway as subjects stood on an unstable platform. Likewise, Yaggie and McGregor[16] and Joyce et al.[17] induced fatigue in the dorsi and plantar flexors using an isokinetic protocol and observed a significant increase in postural sway during a unilateral balance task. Yaggie and McGregor[16] observed this difference with an eccentric/concentric mode at 60º per second while additionally running the protocol on inversion/eversion motions. Joyce et al.[17] utilized the same isokinetic fatigue protocol that was used in this study, but conducted that protocol in a prone position. It is important to note that none of the above studies used TTS as a measure of neuromuscular control or stability. Thus, it is difficult to make comparisons with our study. It is possible that we might have observed changes has similar testing protocols been used.

It is possible that the isokinetic and functional exercise protocols used in the present investigation did not sufficiently fatigue the musculature of the lower leg. If they had been sufficient, differences in TTS, GRF, or joint kinematics would be expected. No one definition of fatigue exists in the literature, as fatigue can occur at numerous points in the neuromuscular pathway. For the present investigation, isokinetic fatigue was defined as the point at which a subject could not produce 50% of their respective plantar and dorsiflexion peak torque at the respective speeds of 30º and 120º per second in a concentric/concentric mode. This specific protocol has been used previously, by Johnston et al.[9] and Joyce et al.[17] who as stated earlier determined that isokinetic fatigue protocols effect postural sway. The increased postural sway observed in those studies suggests that the lower leg musculature was sufficiently fatigued. Thus, changes in our dependent measures would be expected as well. These isokinetic protocols directly fatigue the plantar flexors, which are the main stabilizing muscles for balancing over an extended period of time.[3,4,25] However, during the time to stabilization, the single leg-hop protocol vertical TTS scores averaged less than .05-sec, while the medial/lateral and anterior/posterior scores were typically less than 3-sec. When landing from a forward jump, momentum brings the center of gravity forward over the stationary foot. Thus, dorsiflexion occurs at the ankle or anterior sway. When this occurs, the plantar flexors are stimulated via the stretch reflex to return the body to a stable position. The triceps surae muscle group, reported as the main stabilizers for balance, would then play a vital role in the initial phase of landing that the single leg hop protocol reproduces. If this theory is correct, then an isokinetic fatigue protocol should have an effect on TTS scores and reinforces the assumption that the isokinetic fatigue protocol used was not sufficient to fatigue the lower leg musculature.

Douex et al.[19] used a functional protocol, fatiguing the subject anaerobically through a series of 40-yard sprints. We defined functional fatigue as the point at which a subject could not complete the exercise protocol in less than 150% of their initial time. Muscular fatigue induced in similarly in isokinetic protocols have been shown to last up to 90 seconds post fatigue.[11] While the functional fatigue protocol has not been used previously in the literature, there were anecdotal reports of delayed onset muscle soreness following testing. Unlike the isokinetic protocol, this type of exercise involved knee, hip, and upper extremity musculature. This protocol was designed to incorporate, various aspects of athletic competition, including agility, quick explosive movements, muscular endurance, and aerobic capacity. Agility and balance in the two leg hop sequence and agility drill. Quick explosive movements in the plyometric box jump. Muscular endurance and aerobic capacity of the lower extremity musculature and the cardiopulmonary system were respectively stressed through the series of side-to-side bounds, mini-tramp jumps and co-contraction arcs. Aerobic capacity was also incorporated in the overall time to completion of the fatigue protocol. On average time to complete one circuit was approximately 5 minutes, with most subjects performing 3-4 circuits before fatigue. It is possible that the increases in time to perform the protocol were due to reduced effort as opposed to actual fatigue. However, it is possible that our functional fatigue protocol was not comprehensive enough to fatigue the lower extremity musculature or not specific enough to fatigue the necessary lower extremity musculature to indicate a difference in TTS scores. Similarly, the opposite could be true, the functional fatigue protocol could have been too effective. Decreasing the subjects neuromuscular control to a level where they could not complete the jump protocol until after fatigue had decreased.

Jump Landing Protocol

Several jump-landing protocols have been used in previous studies to measure postural sway. Forward and lateral step down tests as well as single leg hop tests have all indicated significant effects of fatigue on stabilization time[12,18,52]. It is possible that our failure to observe changes following fatigue was due to trial mortality and difficulty during the performance of the jump landing tests. It could be reasoned that the jump protocol may be too difficult or not specific enough to determine differences between healthy subjects.

Few studies have used TTS as a measure of stability or neuromuscular control; however, only one of these studies has examined the effects of fatigue. Previous studies have compared healthy and injured subjects[12,52]. The results from these studies suggest that subjects with functionally unstable ankles[52] and subjects with ACL deficiencies[12] experience longer times to stabilization than healthy subjects. Maggio et al.[18] examined the effects of evertor muscle fatigue on dynamic stabilization time. In that study, healthy and functionally unstable ankles were assessed during a forward and lateral step down test protocol. The results indicated a significant difference in FUA subjects, but no difference in healthy subjects. We only used healthy subjects in the present investigation. Thus, our results are in agreement with those involving the healthy subjects assessed in the above-mentioned study.

Due to the trial mortality and the subjects' inability to land in a balanced state, a greater variation in the time to stabilization scores was seen. These variations would directly effect the medial/lateral and anterior/posterior TTS scores as the subjects tried to regain balance after landing. Concurrent with the results of Maggio et al.[18], data from this study illustrate a performance improvement in time to stabilization scores post fatigue in healthy subjects. Also noted were the high scores on both TTS measures during the functional fatigue protocol, despite the lack of significance found. These variations in landing as a result of the complicated landing task may also indirectly effect the vertical TTS scores. This illustrates the minor trend occurring towards an interaction for vertical time to stabilization as well as the trend towards a main effect between fatigue protocols.

Despite the variations, which would have been noted across the pre and posttest trials, the trial mortality, might have affected the posttest sessions more severely. While the post test trials were initiated 30 seconds after completion of the respective fatigue protocols, the completion of the post test data collection took much longer than anticipated. This delay in data collection might have allowed some degree, if not complete, recovery of the fatigued muscles. This recovery would reduce deficits in proprioceptive awareness and muscular force, potentially increasing the subjects' neuromuscular control for the post-test sessions. The delay in data collection may also explain why some TTS scores were lower during post fatigue testing respective to the pre fatigue scores. This trend was concurrent with Maggio et al.[18] who also indicated that the scores of healthy subjects tended to improve during the post-test trials. If due to the trial mortality and delay in collection, subjects' proprioceptive feedback and muscular strength returned to normal, then the lower post-test scores can be explained by a learning effect.

Validity of Measure

It is also possible that TTS is not the best test to measure the effects of fatigue on neuromuscular control. Reliable methods commonly reported in the literature include single-leg-stance both on a force plate and unstable platform and the star excursion balance test.[9,13,16] These measures may be more sensitive to variations in ground reaction forces or center of pressure changes resulting from lower extremity muscle fatigue. This rationale forces a look at the assumption that the subject effort would be maximal. If subject effort was not maximal during the fatigue protocols, then the post-test scores are not true indicators of how fatigue would affect the said dependent variables. Furthermore, if subject effort was not full during the testing protocol, then the scores of the dependent variables are not accurate or true representations of the changes to them due to fatigue.

Ground Reaction Forces

This study did find significance for the peak vertical ground reaction forces at the heel strike (F2). This finding indicates that as fatigue of the lower extremity musculature increases, the body's ability to absorb the shock of a landing decreases, despite the lack of significance found in the other measures taken. This is due to the triceps surae muscle groups losing the ability to eccentrically decelerate the body from a jump landing. This inability to control deceleration creates a more unimodal or flat-foot landing style which could potentially increases the chances of ankle injury. These findings are concurrent with those of [10,24,55] whose studies also indicated an increase in GRFs due to fatigue. In Figure 5-1, the trend for the peak vertical ground reaction forces at point F2 can be seen. These charts illustrate that a trend did occur toward an interaction of test and protocol at the F2 collection point. Both these points, (F1, F2) in the ground reaction force history curve were also moderately correlated to the vertical TTS and medial/lateral as well as anterior/posterior TTS scores respectively.

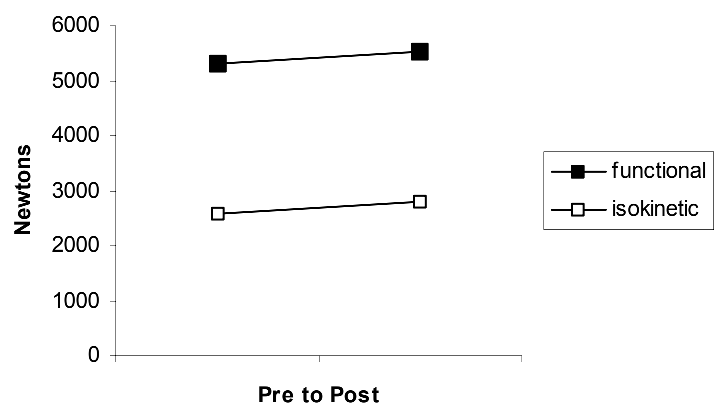

Figure 5-1. Peak vertical GRF at heel strike (F2).

Joint Kinematics

In this study, aspects of joint kinematics were measured during the dynamic stability protocol: including maximum ankle and knee flexion during the jump landing and the maximal knee valgum that occurred as a result of that landing. There were no significant differences found in any kinematic measurement as a result of this study.

However, a moderate negative correlation between maximal dorsi and knee flexion was found with vertical time to stabilization. This indicates that the less flexion of the said joint angle would indicate a greater vertical TTS score.

Correlation

The results of this study indicate that there is a moderate relationship between vertical TTS and GRF-F1, as well as for anterior/posterior TTS and GRF-F2. A high correlation was found between medial/lateral TTS and GRF-F2. These results help illustrate that the measure of time to stabilization is in part determined by the force by which a subject lands for the jump protocol. This analysis also indicates that the higher a person's force at toe touch, the higher their vertical time to stabilization will be; while the force at heel strike is positively correlated to anterior/posterior TTS, the less force at heel strike the smaller the anterior/posterior TTS score will be. Force at heel strike was negatively correlated to medial/lateral TTS, indicating that the less force at heel strike, the greater the medial/lateral TTS score will increase.

Indications

The results of this study indicate that there is no difference between the effects of an isokinetic and a functional fatigue protocol of the lower leg and that there was no difference between the TTS, GRF, and joint kinematic scores prior to and after fatigue. These finding are contrary to previous studies that indicated that both isokinetic and functional fatigue protocols have significantly increased postural sway.[9,16-19] This study may however indicate that an isokinetic fatigue protocol could potentially be a valid and acceptable method to study the effects of fatigue. This would allow for faster, safer and more reproducible testing of subjects in an effort to better understand the effects of fatigue on neuromuscular control.

However, until a definitive and direct answer of whether or not an isokinetic or functional fatigue protocol is the best means to study fatigue's effect on neuromuscular control and postural sway can be made, comparative studies should be the basis for future research. It is also important that athletic trainers, coaches, therapists, and physicians continue to train their athletes in ways that will increase their proprioception and minimize any loss of neuromuscular control due to the fatigue of athletic competition until the exact cause of proprioceptive deficits and loss of neuromuscular control can be established.

Conclusions

The following conclusions are made as a result of this study:

- There was no difference in time to stabilization scores prior to and after an isokinetic and functional fatigue protocol of the lower extremity musculature.
- There was no difference between the effects of an isokinetic fatigue protocol on TTS, GRF and joint kinematics as compared to a functional fatigue protocol.
- There was a moderate correlation between vertical time to stabilization and maximal ankle and knee flexion. There was also a high correlation between GRF-F2 and medial/lateral time to stabilization.

Summary

The results of this study indicate that there is no difference between the effects of an isokinetic and a functional fatigue protocol on TTS, GRF, and joint kinematics. The results also indicate that there is a small to moderate correlation between several of the dependent variables.

While muscle fatigue has been shown to increase postural sway and vertical GRF in several studies, by incorporating isokinetic and or functional fatigue protocols, the results of this study indicate there no relationship between increases in fatigue and increases in time to stabilization. However, the results of this study do indicate that fatigue does increase the vertical GRF seen at heel strike. This increase has been associated with an increased latency period and altered joint kinematics in jump landing.[10,24,55] Two possible indicators of increases incidence of injury at the ankle.

These results benefit researchers indicating that an isokinetic fatigue protocol is a reliable method of mimicking the fatigue that takes place during athletic activity.

Until a definitive answer to the question of why the ankle is the most commonly injured structure in the body, and fatigue plays a role, athletic trainers, therapists, physicians, and coaches should encourage athletes to focus on improving their proprioceptive awareness and proper technique in landing from jumps. Improving proprioception and learning proper landing techniques may help in reducing an athlete's chances of suffering an ankle injury.

Implications for Future Research

This study has generated several new questions in which future researchers can explore. This study tested healthy subjects who had no previous history of lower extremity injury. Future research should examine subjects with previous injuries, including those with functional and anatomical ankle instability. The current study used a fatigue protocol that used 50% of peak torque and initial time as the standard for fatigue. Future research should be conducted with various levels of fatigue as a percentage of peak torque for an isokinetic protocol and initial time for a functional fatigue protocol. Future research should also examine further comparative studies of isokinetic and functional fatigue protocols measuring their effects with more tested and reliable measures of postural sway.

In addition, future research should look to determine the learning effect associated with the time to stabilization single leg hop protocol, it's reliability and validity and the various methods of calculating it. Comparisons of a control and treatment group would add to the general body of knowledge and indicate the amount of practice needed to minimize the learning effect for this protocol. If valid and reliable, future studies should examine the differences in time to stabilization between males and females. Other research endeavors should explore the effect of various sensory deprivation on time to stabilization and more importantly the changes in postural sway and time to stabilization over the course of actual athletic practice and games in varying sports. Also, future research should include a prospective study to determine if time to stabilization is a predictor of the incidence of ankle injuries in the sports where jump landing is prevalent, such as basketball, soccer, and volleyball.

APPENDIX A
LETTER OF INFORMED CONSENT

Informed Consent Agreement
Project Title: Effects of isokinetic vs. functional fatigue protocol of the lower extremity on time to stabilization and peak vertical ground reaction forces.

Investigators: Erik A Wikstrom,ATC, Graduate Student, Department of Exercise and Sport Sciences & Michael E. Powers, PhD., ATC, CSCS, Assisstant Professor, Department of Exercise and Sport Sciences.

Purpose of the study: The purpose of this study is to compare and correlate the effects of two different methods of tiring out the lower leg, by measuring the required time to regain your balance and how much force you produce from landing during a single-leg-hop balance test. This study will also examine the amount of flexion or bend that occurs in the ankle and knee from the fatigued landing during the single-leg-hop balance test.

Please read this consent carefully before you decide to participate in this study.

What will you do in this study?
Upon reporting to the Athletic Training/Sports Medicine Research Laboratory (105D FLG), you will be asked to complete the medical history form to determine if you are eligible to participate in the study. If eligible, your maximum vertical leap (how high you can jump) will be determined. To do this, we will first measure how high you can reach while standing. You will then be asked to jump as high as possible and touch markers supported on a stand. Based on the number of markers you touch, the height of your jump is determined. We will have you do this two more times to asure that we get an accurate measure. Immediately following the jump test, we will place reflective markers on the outside of your ankles, knees, hips, and shoulders using tape. We will then measure how long it takes you to balance after jumping onto a platform. You will be asked to jump so that you reach a height equivalent to half of your maximum jump height and land on a platform 28” away. After you land on the platform you will be asked to balance yourself on one leg while your hands remain on your hips for a period of 20 seconds. You will be video taped while you do this. The video tape and the reflective markers will allow us to determine how well you balance. After the 20-second period you will be asked to return to the starting postion and repeat the measurement. This will be done one more time for a total of three trials. After the balance measurements are completed, we will attempt to fatigue (tire out) your lower leg muscles using one of two methods. Which method you do first will be randomly determined by a coin toss.

One of the fatigue protocols will require you to sit in a chair in a machine that will fatigue your muscles by providing maximum resistance at a set speed of movement as you bring and point the foot and toes upward and then point the foot and toes downward. You will warm up and determine your strongest movement and after a minute of rest proceed with the test by continuously repeated the above motions of the ankle until fatigue, which will be 50% of your strongest movement as determined by the computer on the machine.

The other fatigue protocol will requrie you to complete a series of timed sprinting, cutting and jumping stations. You will first warm up and received instructions. After a minute of rest you will start by running through a timing marker and then complete the stations in order until the series is complete. After each series of stations you must run back through the timing marker. You will be asked to continue performing the stations until a series takes you 1 ½ times as long as the first series (50% longer than the first series). The stations in each series will consist of the following;

Agility drill- A series of forward sprints, diagonal back-pedaling, and side stepping within a 12' x 12' area. (3 times)

Box jumping- A drill that mimics the rapid jumping and landing that would be experienced in athletic competition. This drill is a series of 3 boxes of 24" in height 18" apart. You will jump onto the first box, stabilize and jump down, immediately jumping back up onto the second box, stabilize and repeat onto the third box. (3 times)

Two-legged hop sequence- A series of markers spaced over a ten foot distance, must be jumped onto and immediately left for the next marker. You need to jump and land using both feet for each marker. (3 times)

Side-to-side bounds- An area 5' wide in which you will jump sideways from a center marker to the one side and back to the center to the opposite side. (30 times)

Mini-tramp- You will be ased to jump onto a mini-trampoline, stabilize and jump off onto the floor on the opposite side. (30 times)

Resistance arc- You will be asked to resist the tension of an elastic cord as you side shuffle around semi circle. (10 times)

Immediatley after you are done with the fatigue protocol you will be asked to return to the laboratory and complete another balance test identical to the one completed before the fatigue protocol. Once this is completed the session will be over. You will be asked to return to the laboratory 1 week later to repeat the entire protocol, however, you will perform the other fatigue protocol (the one you did not perform on the first day).

Time requried:
Two sessions requiring approximately 45 minutes each.

Risks:
As with any type of exercise, there is a slight risk of musculoskeletal injury such as a sprain or a muscle pull. A certified athletic trainer will be present to evaluate and treat any such injuries should they occur.

Benefits/Compensation:
There are no direct benefits to you for participating.

Confidentiality:
Data will be kept confidential to the extent provided by the law. Your information will be assigned a code number. The list connecting your name to this number will be kept in a locked file. When the study is completed and the data have been analyzed, the list will be destroyed. Your name will not be used in any report.

Voluntary Participation:
Your participation is completely voluntary. There is no penalty for not participating.

Right to withdraw from the study:
You have the right to withdraw from the study at anytime without penalty.

Who to contact if you have questions about the study:

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Department of Exercise and Sport Sciences
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Gainesville, FL 32608
372-5592(home)
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148 Florida Gym
PO Box 118205
Gainesville, FL 32611-8205
(352) 392-0584, ext. 1332
Fax: (352) 392-5262
E-mail: mpowers@hhp.ufl.edu

Who to contact about your rights in the study:
UFIRB Office
Box 112250, University of Florida
Gainesville FL 32611-2250
(352) 392-0433.

Agreement:
I have read the procedure described above. I voluntarily agree to participate in the procedure and I have received a copy of this description.

Participant:______________________________ Date:__________

Principal Investigator:___________________________ Date:__________

APPENDIX B
MEDICAL ELIGIBILITY QUESTIONAIRE

1. Name____

2. Age______________________

3. Height / Weight__________________________

4. What leg would you kick a soccer ball with?

   Left________ Right_______

5. Have you had a lower extremity injury within the past six months?

   Yes________ No_________

6. Have you been diagnosed with a concussion within the past six months?

   Yes________ No_________

7. Have you been diagnosed with an equilibrium disorder?

   Yes________ No_________

8. Do you have a diagnosed disorder that affects neuromuscular control?

   Yes________ No_________

9. How often do you exercise?

   0-2 times a week_____ 2-4 times a week_____ 4+ times a week______

APPENDIX C
DATA COLLECTION FORMS

Subject #________________________ Stance Leg___________________
Maximal Vertical Leap_____________ Jump Height (50%max)____________

Isokinetic Protocol

PRE-TEST:	**Trial 1**	**Trial 2**	**Trial 3**
Time to stabilization	_______	_______	_______
GRF-F1	_______	_______	_______
GRF-F2	_______	_______	_______
Ankle Flexion	_______	_______	_______
Knee Flexion	_______	_______	_______
Knee Valgus/Verus	_______	_______	_______

Fatigue Protocol

Peak Torque	**PF_________**	**DF__________**
Fatigue	PF_________	DF_________
Actual Percentage	**PF_________**	**DF__________**

POST-TEST:	**Trial 1**	**Trial 2**	**Trial 3**
Time to stabilization	_______	_______	_______
GRF-F1	_______	_______	_______
GRF-F2	_______	_______	_______
Ankle Flexion	_______	_______	_______
Knee Flexion	_______	_______	_______
Knee Valgus/Verus	_______	_______	_______

Subject #________________________ Stance Leg___________________
Maximal Vertical Leap_____________ Jump Height (50%max)____________

Functional Protocol

PRE-TEST:	**Trial 1**	**Trial 2**	**Trial 3**
Time to stabilization	_______	_______	_______
GRF-F1	_______	_______	_______
GRF-F2	_______	_______	_______
Ankle Flexion	_______	_______	_______
Knee Flexion	_______	_______	_______
Knee Valgus/Verus	_______	_______	_______

Fatigue Protocol

Initial Time	**PF_________**	**DF__________**
Fatigue	PF________	DF_________
Actual Percentage	**PF_________**	**DF__________**

POST-TEST:	**Trial 1**	**Trial 2**	**Trial 3**
Time to stabilization	_______	_______	_______
GRF-F1	_______	_______	_______
GRF-F2	_______	_______	_______
Ankle Flexion	_______	_______	_______
Knee Flexion	_______	_______	_______
Knee Valgus/Verus	_______	_______	_______

APPENDIX D
ANOVA TABLES

Tests of within-subjects effects

Table D-1. Vertical TTS ANOVA table

Source	Sum of Squares	Df	Mean Square	F	Sig.
Protocol	1371.747	1	1371.747	.496	.490
Error(protocol)	52545.726	19	2765.565		
Time	41138.323	1	41138.323	2.239	.151
Error(time)	29418.152	19	1548.324		
Protocol*Time	337.779	1	337.779	.393	.538
Error(protocol*time)	16342.684	19	860.141		

Table D-2. Medial/Lateral TTS ANOVA table

Source	Sum of Squares	Df	Mean Square	F	Sig.
Protocol	74416.930	1	74416.930	.388	.541
Error(protocol)	3644487.244	19	191815.118		
Time	109031.775	1	109031.775	.434	.518
Error(time)	4776494.299	19	251394.437		
Protocol*Time	23209.609	1	23209.609	.287	.598
Error(protocol*time)	154370.268	19	80756.330		

Table D-3. Anterior/Posterior TTS ANOVA table

Source	Sum of Squares	Df	Mean Square	F	Sig.
Protocol	1117970.407	1	111970.407	8.529	.009*
Error(protocol)	2490392.677	19	131073.299		
Time	1162682.933	1	1162682.933	7.725	.012*
Error(time)	2859804.258	19	150516.014		
Protocol*Time	68.859	1	68.859	.001	.978
Error(protocol*time)	1747346.945	19	91965.629		

Indicates significance; $p<.05$

Table D-4. GRF-F1 ANOVA table

Source	Sum of Squares	Df	Mean Square	F	Sig.
Protocol	21760.031	1	21760.031	.459	.507
Error(protocol)	805763.143	17	47397.832		
Time	19669.628	1	19669.628	1.441	.246
Error(time)	232056.582	17	13650.387		
Protocol*Time	13237.474	1	13237.474	1.211	.286
Error(protocol*time)	185829.458	17	10931.145		

Table D-5. GRF-F2 ANOVA table

Source	Sum of Squares	Df	Mean Square	F	Sig.
Protocol	92866.586	1	92866.586	.797	.383
Error(protocol)	2213852.009	19	116518.527		
Time	291813.119	1	291813.119	8.644	.008*
Error(time)	641402.224	19	33758.012		
Protocol*Time	161712.712	1	161712.712	3.673	.070
Error(protocol*time)	836419.613	19	44022.085		

Indicates significance; p<.05

Table D-6. Ankle Flexion ANOVA table

Source	Sum of Squares	Df	Mean Square	F	Sig.
Protocol	125.572	1	125.572	.940	.344
Error(protocol)	2537.431	19	133.549		
Time	.129	1	.129	.015	.905
Error(time)	167.522	19	8.817		
Protocol*Time	.409	1	.409	.064	.803
Error(protocol*time)	121.710	19	6.406		

Table D-7. Knee Flexion ANOVA table

Source	Sum of Squares	Df	Mean Square	F	Sig.
Protocol	23.671	1	23.671	.666	.425
Error(protocol)	675.398	19	35.547		
Time	6.173	1	6.173	.580	.456
Error(time)	202.287	19	10.647		
Protocol*Time	1.710	1	1.710	.209	.652
Error(protocol*time)	155.197	19	8.168		

Table D-8. Knee Valgum ANOVA table

Source	Sum of Squares	Df	Mean Square	F	Sig.
Protocol	4.033E-05	1	4.033E-05	.069	.796
Error(protocol)	1.116E-02	19	5.873E-04		
Time	1.296E-05	1	1.296E-05	.116	.737
Error(time)	2.127E-03	19	1.119E-05		
Protocol*Time	9.288E-05	1	9.288E-05	.788	.386
Error(protocol*time)	2.239E-03	19	1.178E-04		

APPENDIX E
RAW DATA TABLES

Table E-1. Subject Demographics.

Subject	Sex	Stance Leg	Height	Weight	Max Vertical	Jump Height	Peak Torque PF	Peak Torque DF	Intial Time	Units Body Wieght
			(cm)	(kg)	(cm)	(cm)	(newtons	(newtons	(min-sec)	(volts)
1	female	left	170.18	61.36	31.75	15.88	593	103	4:38	1.658
2	female	left	172.72	65.90	33.02	16.51	389	215	4:30	1.717
3	male	left	187.96	75.00	45.72	22.86	430	260	5;13	2.024
4	female	left	170.18	59.09	20.32	10.16	472	72	3:44	1.543
5	male	left	177.80	59.09	50.80	25.40	453	319	4:00	1.466
6	male	left	182.42	91.81	50.80	25.40	824	438	4:20	2.398
7	male	left	182.88	74.09	43.18	21.59	640	434	3:53	1.939
8	female	left	167.64	73.63	25.40	12.70	606	243	4:36	1.943
9	male	left	172.72	79.54	35.56	17.78	807	294	4:00	2.000
10	female	left	177.80	75.00	30.48	15.24	724	208	4:45	2.099
11	male	left	167.64	54.54	53.34	26.67	617	110	3:30	1.317
12	female	left	177.80	72.72	21.59	10.80	497	222	4:31	1.895
13	male	left	182.88	70.45	43.18	21.59	496	231	5:03	1.854
14	female	left	170.18	63.63	29.21	14.61	975	135	5:00	1.766
15	female	left	147.32	45.45	34.29	17.15	360	58	3:42	1.325
16	male	left	190.50	88.63	46.99	23.50	442	140	4;30	2.29
17	female	left	157.48	50.90	36.83	18.42	335	85	3:00	1.469
18	female	left	185.42	70.45	25.40	12.70	419	92	4:04	1.798
19	female	left	165.10	47.72	19.05	9.53	318	56	6:11	1.398
20	female	left	170.18	63.63	27.94	13.97	412	64	4:45	1.717
		Mean	173.840	67.132	35.243	17.621	540.450	188.950	0.181	1.781
		STD	10.452	12.462	10.720	5.360	179.668	118.130	0.030	0.305

Isokinetic Protocol Data

Table E-2. Pretest Isokinetic Data.

Subject	Ave-Vert-TTS	AveMed/Lat-TTS	AveAnt/Pos-TTS	Ave-GRF-F1	Ave-GRF-F2	Ave-Ankle	Ave-KneeF	Ave-KneeV
1	385.633	205.041	12.780	1196.825	2420.575	53.420	117.779	-0.005
2	305.617	815.163	10.558	1086.654	2242.276	73.726	137.275	0.020
3	284.501	31.117	443.978	1353.152	3534.042	62.067	128.099	0.051
4	304.505	78.905	204.485		2264.692	78.130	134.345	-0.009
5	255.051	1535.107	599.564	1309.569	3229.170	71.431	120.652	0.068
6	361.739	397.857	752.373	1459.059	3670.965	73.708	114.982	0.016
7	283.390	1364.162	74.459	1327.749	2334.919	70.296	119.922	0.023
8	276.722	1526.416	25.561	1053.979	2346.152	91.401	137.436	0.050
9	238.381	643.462	210.597	1505.630	3364.184	78.698	138.865	0.002
10	267.831	2008.735	370.074	1082.512	2643.388	66.220	136.940	-0.009
11	312.285	1211.909	640.683	1060.861	2398.784	63.890	119.608	0.090
12	312.285	87.795	472.872	824.468	2609.919	66.129	136.575	0.033
13	351.737	21.671	1775.355	1215.124	2858.848	58.991	120.478	0.012
14	265.053	877.953	10.558	1269.771	2026.384	81.686	131.165	0.066
15	252.828	436.198	7.779	998.953	1759.754	70.040	135.908	0.044
16	335.623	1208.019	470.761	1355.999	3059.619	61.809	120.026	0.037
17	262.275	11.113	1353.604	1181.891	2327.599	62.474	120.453	0.040
18	241.159	36.674	28.339	517.830	2675.810	89.628	141.883	0.033
19	248.383	686.804	17.781	829.357	1308.206	77.920	135.318	0.024
20	263.386	347.292	964.082	1209.251	2379.744	86.646	145.936	0.049

Table E-3. Posttest Isokinetic Data.

Subject	Ave-Verrt-TTS	AveMed/Lat-TTS	AveAnt/Pos-TTS	Ave-GRF-F1	Ave-GRF-F2	Ave-Ankle	Ave-KneeF	Ave-KneeV
1	272.832	99.464	606.788	963.901	2187.476	57.280	119.306	-0.008
2	322.287	371.182	7.224	1104.253	2419.854	68.562	131.715	-0.007
3	262.830	17.781	7.224	1352.413	3748.178	70.768	129.609	0.037
4	380.076	1503.634	741.815		2591.461	73.817	130.210	-0.004
5	352.570	442.311	6.112	1217.455	3682.615	67.285	118.652	0.043
6	368.407	55.011	1385.833	1500.296	3712.129	76.943	114.005	0.018
7	277.278	792.381	766.264	1210.546	2464.040	75.098	125.190	0.019
8	287.835	58.901	29.450	1107.363	2475.979	90.148	133.226	0.047
9	233.380	1047.432	1196.906	1307.471	3292.264	80.540	138.799	0.008
10	253.384	266.720	54.455	1125.072	2773.726	66.095	138.202	-0.002
11	263.386	20.004	26.672	1138.329	2864.930	64.069	118.787	0.072
12	261.163	1137.450	1007.424	962.746	3452.651	67.414	132.692	0.043
13	295.615	13.883	656.798	1507.215	3592.223	60.882	124.143	0.014
14	297.837	53.344	11.669	1216.453	2090.325	78.476	130.427	0.084
15	333.400	47.232	409.526	1037.868	1885.092	66.288	132.220	0.041
16	297.282	613.456	492.321	1145.531	3040.017	65.149	119.426	0.037
17	235.047	11.113	983.530	1208.829	2726.988	58.354	121.955	0.014
18	200.596	30.006	19.448		2587.511	94.440	143.115	0.042
19	225.601	383.410	13.336	859.659	1500.342	74.305	137.629	0.021
20	302.283	53.344	11.113	1248.515	2581.468	77.931	137.376	0.055

Functional Protocol Data

Table E-4. Pretest Functional Data.

Subject	AveVert-TTS	AveMed/Lat TTS	AveAnt/Pos TTS	Ave GRF-F1	Ave GRF-F2	Ave-Ankle	Ave-KneeF	Ave-KneeV
1	309.506	1036.674	1046.876	1141.116	2664.655	61.981	129.317	0.056
2	322.287	135.583	190.038	1523.935	2913.466	81.230	126.765	0.004
3	310.618	501.767	33.896	1034.437	3592.014	65.190	124.388	0.051
4	211.709	16.670	589.562	389.054	2348.944	87.639	128.753	0.042
5	320.620	345.625	953.524	1268.822	3275.869	63.958	128.112	0.027
6	371.185	503.990	45.009	1318.680	3737.407	63.673	111.110	0.027
7	357.849	974.639	31.673	1379.098	3279.761	68.593	118.702	0.013
8	258.941	734.591	23.338	925.211	2094.039	72.705	137.854	0.018
9	247.827	192.261	307.839	1432.648	3455.757	76.160	133.928	0.039
10	248.383	53.900	9.446	1037.202	3286.094	71.471	133.180	0.041
11	318.953	1536.418	772.377	1032.556	2544.800	66.229	111.482	0.053
12	270.610	703.474	57.789	1096.376	2571.184	76.160	136.207	0.001
13	280.612	1180.792	419.528	1258.754	2974.852	75.663	123.255	0.012
14	225.601	78.349	1193.572	1313.019	2176.464	71.891	141.148	0.055
15	206.708	127.248	340.068	826.179	1893.396	70.040	135.908	0.042
16	362.850	260.052	71.681	1768.491	2847.233	56.513	113.272	0.005
17	226.712	870.730	741.259	919.924	2639.913	60.717	121.356	0.020
18	240.604	36.674	28.339	501.276	2424.937	61.293	129.721	0.024
19	209.486	66.124	14.447	807.485	1465.027	74.818	141.765	0.006
20	259.496	1110.222	6.112	1099.160	2430.462	59.412	139.816	0.026

Table E-5. Posttest Functional Data.

Subject	AveVert-TTS	AveMed/Lat-TTS	AveAnt/Pos-TTS	Ave GRF-F1	Ave GRF-F2	Ave-Ankle	Ave-KneeF	Ave-KneeV
1	292.281	35.563	48.343	1013.738	2387.151	56.848	125.968	0.031
2	293.948	21.671	11.113	1339.626	3317.055	77.957	124.459	0.013
3	253.940	57.234	17.226	980.144	3533.226	64.820	130.208	0.045
4	247.272	485.653	740.704	1715.899	2650.022	90.775	138.095	0.039
5	342.291	25.005	632.904	930.004	3603.540	64.661	129.306	0.042
6	335.067	667.911	45.009	1450.396	3462.418	65.796	114.135	0.023
7	489.542	402.858	139.472	1188.296	2930.461	64.842	119.399	0.025
8	258.385	1308.039	47.787	512.813	2294.882	81.106	142.812	0.037
9	261.163	245.049	921.851	1574.336	3572.760	79.419	131.345	0.012
10	281.723	1124.669	176.702	928.309	3098.845	73.942	131.713	0.027
11	1175.591	804.050	583.450	900.689	2840.398	64.420	115.111	0.054
12	245.049	18.893	24.449	1198.330	2068.209	74.819	132.742	0.049
13	228.379	38.341	804.328	1138.250	2879.321	78.875	120.075	0.016
14	232.269	393.412	475.095	1184.164	2199.688	70.651	136.546	0.047
15	230.602	25.005	100.576	1006.931	2017.754	66.288	132.220	0.039
16	373.408	1561.979	35.563	1622.331	3135.602	59.549	122.086	-0.002
17	1149.474	821.275	8.335	1002.219	2474.581	60.538	121.455	0.016
18	220.600	273.388	20.560	928.113	2585.366	63.331	128.793	0.026
19	296.726	251.161	242.271	1074.852	2032.642	72.195	136.293	-0.001
20	252.273	2112.089	19.448	1054.508	2149.783	55.760	128.013	0.053

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BIOGRAPHICAL SKETCH

I was born in Jacksonville, FL, on October 16, 1978, to Mr. Raymond M. Wikstrom and Mrs. Geraldine A. Wikstrom. My younger sister and I grew up as Navy brats, moving around the country. Living in Jacksonville, FL, San Diego, CA, and Alexandria, VA, exposed me to very different and unique views of life. I attended two different high schools: Saint Augustine High School in San Diego and Bishop Ireton High School in Alexandria. While in school, I lettered in two varsity sports, basketball and tennis, and was a member of the National Honor Society. I graduated from high school in 1997 and decided to attend Roanoke College in Salem, VA.

I came to Roanoke to major in athletic training, because of the inspiration givin to me by the program director, Mr. Jim Buriak. While a demanding and time consuming major, I never doubted my decision to become an athletic trainer or my decision to attend Roanoke College. My time there was the best four years of my life. I graduated from Roanoke College in 2001 and was accepted to continue my education at the University of Florida.

As a first year graduate athletic trainer, I was sent to be the head athletic trainer at Trenton High School. Despite the sense of overwhelming pressure of being a head athletic trainer for the first time, I felt prepared and grateful for the mentoring of Mr. Jim Buriak and Roanoke College. As a second year graduate assistant, I was assigned to be the head athletic trainer at Eastside High School. Eastside has given me the opportunity to grow as a clinician, teacher, and mentor and feels like a second home. I will be sad to leave at the end of this year but excited to begin a new chapter in my life, as I begin work towards my doctoral degree here at the University of Florida.