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Effects of achilles tendon taping and bracing on landing biomechanics

Christy Rodenbeck
University of Tennessee

To the Graduate Council:

I am submitting herewith a thesis written by Christy Rodenbeck entitled "Effects of achilles tendon taping and bracing on landing biomechanics." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Human Performance and Sport Studies.

Song-Ning Zhang, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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Effects of Achilles Tendon Taping and Bracing on Landing Biomechanics

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Christy Rodenbeck
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I thank my family for their support and belief in my continued education.

Abstract

The purpose of this study was to test the effectiveness and biomechanical responses of an Achilles tendon tape and an Achilles brace (Cho-pat) in a landing activity. Ten female athletes from varsity sports of a NCAA-I school whose activities commonly contain repetitive eccentric loading participated in this study. Simultaneous recording of sagittal high-speed video (120 Hz) and ground reaction forces (GRF, 1200 Hz) were conducted during the trials. The first condition served as a control involving landings without any taping or bracing. The subjects were then asked to perform the 5 landing trials before and after a treadmill running for 15 minutes at a self-selected pace (inclined 7° for the last 10 min) with either the brace or the tape. The order of the devices was randomized. Selected GRF and kinematic variables were evaluated with a repeated measures analysis of variance using SPSS (statistical software program). Exercise decreased both first peak GRF (F1) and loading rate of F1 for both taping and bracing. Range of Motion, contact velocity, maximum velocity and maximum joint angle for the pre-bracing and taping conditions were significantly lower than the control condition. It was found that both the Achilles tendon taping and Cho-pat Achilles tendon strap could be suggested as a tool for helping prevent and/or reduce further injury to the tendon. However, the Achilles tendon tape should be considered as ideal choice of support.

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Chapter 1

Introduction

Many sport injuries occur at the time of landing and are repetitive in nature. Achilles tendinitis is defined as the inflammation of the Achilles tendon.[23] Also known as Achilles tenosynovitis, it is the inflammation between the Achilles tendon and its surrounding sheath. Individuals usually complain of pain 2-6 cm proximal to the calcaneal insertion of the tendon.[32,40] The result of this inflammation is a thickening of surrounding tissue and loss of smooth gliding movements. Etiological symptoms of Achilles tendinitis include a jerk moment in the tendon in which repeated eccentric loading leads to microtears. Other etiological factors that can predispose someone to Achilles tendinitis are training errors such as hill running, increased mileage, intensive training sessions, and running on uneven surfaces. In some cases, it can be caused by wearing a shoe that does not stabilize the heel sufficiently, increased tibia vara, foot rigidity, or tightness of hamstrings, gastrocnemius and soleus. This injury produces pain with palpation along the tendon and pain with activity. There is swelling along the tendon, crepitation with movement, and weakness or lack of normal range of motion, especially in dorsiflexion.[4,6,15,39] Athletes who participate in running and jumping sports (i.e., distance running, basketball) are more likely to be predisposed to Achilles tendinitis than other athletes.

During the acute stages of treating Achilles tendinitis, it is important to create a proper healing environment for the tendon by reducing the amount of stress on the tendon. Prentice notes that there is an area of hypovascularity that exists within the tendon that may further impede the healing response.[32] Other options for treatment include rest, ice, anti-inflammatory medications, pain-free stretching and crutches. In the later stages of treating tendinitis, ultrasound and deep-friction massage can be used to promote local healing. Alternative aerobic activity, such as swimming and cycling, should be used to maintain fitness; taping or bracing can be used to help prevent Achilles tendinitis from progressing when returning to functional activity.[19,27,32]

Henry studied the effects of Achilles tendon taping on angular displacement, velocity, and acceleration. Dorsiflexion angular displacement and angular velocity were determined for the landing phase of a single back tuck saltos in gymnastics. No statistical differences were found for the contact angular displacement, velocity, or acceleration between taping and non-taping conditions. One problem with the study, though, is that the conclusion was made based on the data of only two subjects, because the data from the other four subjects were lost during the collection process.[16] Morales studied the effects of Achilles tendon taping and a Pro M-P Achilles strap on peak plantarflexion torque on an isokinetic dynamometer. The author found a significant difference in peak eccentric torque output when comparing the strap to the tape or a control condition. The strap was effective in reducing the force in asymptomatic females, but no significant changes were found for males. It was suggested that further study in this subject matter should investigate the effects of the Achilles tendon taping and the strap during dynamic activities.[28]

McNair and Prapavessis studied the normative data of vertical ground reaction forces (GRF) associated with landing from a jump. They found that the mean peak vertical GRF for all subjects was 4.5 body weights. When comparing males to females, the peak vertical GRF was 4.6 and 4.2 bodyweights, respectively. When comparing subjects that that were involved in recreational activities to those playing competitive sports, VGRF was 4.4 to 4.5 bodyweights, which is relatively low.[24] Panzer, Wood, Bates, and Mason found that VGRF for six elite gymnasts during a double back somersault ranged from 8.8 to 14.4 BW.[42] It is the repetitive nature of these impact forces during running and jumping sports that are of concern to the athlete for injury prevention.

The importance of landing techniques in prevention of injuries is an important topic in landing biomechanics.[36] An increase in landing height will increase loading to the body and therefore increase loading in the Achilles tendon because of the musculature involved in trying to reduce such loading. Dufek and Bates also mention that an increase in height increases the force production at landing, along with footwear, landing surfaces, and skilled or unskilled athletes' Achilles tendinitis symptoms may develop as a consequence of the repetitive loading in landing of many sports.[11]

Problem Statement

The purpose of this study was to investigate the effectiveness of Achilles tendon taping and an Achilles tendon strap on landing biomechanics. Specifically, GRF and angular kinematics of lower extremity joints were examined for a drop landing activity in five conditions: control (no taping or brace), pre and post Achilles tendon taping, and pre and post Achilles tendon strap (Cho-pat). A 15 minute inclined treadmill run was performed between the pre and post conditions for the taping and brace. The results of this study may provide better understanding for injury prevention and treatment for taping and bracing, and prevention of sport injuries where repetitive loading may cause Achilles tendinitis.

Hypotheses

The following hypotheses were tested:

1) There are significant differences in GRF and kinematics before and after exercise when using Achilles tendon taping and Cho-pat Achilles tendon strap.
2) There are significant differences in peak ground reaction forces during landings between the control, Achilles tendon taping, and Cho-pat Achilles strap conditions.
3) There are significant differences in angular displacement and peak angular velocities of lower extremity joints during landings between the control, Achilles tendon taping and Cho-pat Achilles strap conditions.

Delimitations

The study was conducted with the following delimitations:

1) Ten active and healthy female athletes were selected as subjects from collegiate teams at The University of Tennessee. They had no injuries of their lower extremities at the time of the study.

2) Five test conditions included drop landings (45 cm) without taping/bracing, with Achilles tendon taping before and after exercise, and with Cho-pat Achilles tendon brace before and after exercise.

Limitations

The study was limited by the following factors:

1) Subjects were limited to the collegiate athletic population at The University of Tennessee.
2) Possible errors from placement and digitizing of reflective markers. Other errors such as perspective error and marker placement are acknowledged.
3) Inherent errors from the force platform and digital video systems. Errors of force platform and high-speed video systems are always present but were considered acceptable within the specifications of the manufacturers. Errors caused by out of plane motion were controlled by confining the activity to sagittal plane.
4) Potential errors due to the difference in sampling frequency of the force platform (1200Hz) and the digital video system (120Hz), and synchronization of the systems. Synchronization accuracy between the force and video systems was limited by the sampling rate of the slower system. The video system has a sampling error of $\pm$ 0.08 frames/second, resulting a maximum error of only 0.67 ms.

Assumptions

The following assumptions were made for this study:

1) Biomechanical instruments used were accurate.
2) All subjects were injury free in the lower extremity at the time of testing.
3) The performance of the subjects was symmetrical, so therefore only the right side was assessed for the kinematics and GRF.

Chapter II

Literature Review

The Achilles Tendon

Two heads from the gastrocnemius originate on the medial and lateral epicondlyes of the femur just proximal to the knee. The soleus originates on the head and proximal shaft of the fibula and the adjacent posteromedial shaft of the tibia. These two muscles converge to form the Achilles tendon, the largest tendon in the body, for about 2/3 of the lower leg length and inserts on the calcaneus.[19,23,39] As the tendon descends towards it insertion, the fibers rotate 90 degrees so that the lateral fibers end up superficial while the medial fibers become deep.[40] The main function of the Triceps surae is to plantarflex the foot, but it is also involved in inversion and adduction of the foot. When walking, running, or landing the Triceps surae contracts eccentrically to lower the heel to the floor. The tendon is also stressed during the late midstance phase of gait when it elongates to slow the advancing tibia. This stress is particularly high when running or walking uphill (the Triceps surae must slow the tibia eccentrically, but propel the body uphill concentrically). The Achilles tendon is also one of the strongest tendons of the body; it can withstand loads up to 400kp.[40]

Achilles Tendon Injury

Achilles tendinitis accounts for eleven percent of all lower limb injuries in the athletic setting.[28] Males and females over the age of thirty are at higher risks for developing Achilles tendinitis.[28] In a study done with the U.S. Marine Corps, Achilles tendinitis was one of the most frequently reported injuries in males at 2.8%.[41]

Achilles Tendon Forces

The increased eccentric loading on the Achilles tendon can predispose the tendon to Achilles tendinitis. It has been suggested that if a potential injury situation exists in an activity, the external forces should be measured and their effects evaluated.[10] Most research has concentrated on the impact forces associated with initial ground contact due. It is assumed that the impact force is related to pain and injury, but with little proof on how and why certain athletes may be predisposed to injury.[35]

Scott & Winter used inversed dynamics and a model of the lower extremity to examine loads at common injury sites during running. Data from a force plate, EMG, and kinematics were collected and analyzed. The results indicated that the peak stress in the plantar flexor muscles occurred at the same time as the peak ankle moment. Achilles tendon force during the stance phase of running reached a peak of 6.1 – 8.2 body weight (BW). It was suggested that the plantar flexor muscles provided an anti-shear force at the ankle and an anti-shear and anti-bending force within the lower leg.[35]

Self and Paine evaluated Achilles tendon force and Achilles tendon stiffness for four different landing strategies from a 30.48 cm height. The four landing techniques included: 1) normal landing, 2) stiff landing, 3) soft landing with calf muscle flexion (landing as soft as possible), and 4) soft landing but with flat-footed contact. The results suggested that Achilles tendon forces were the highest for those who landed with a stiff-land technique and that the plantar flexors absorbed most of the impact. This indicated that during normal landings, athletes may not use the full potential of the plantar flexors.[36]

In a study by Davis et al., the effect of ankle and knee position on tension in the Achilles tendon was investigated. Seven fresh-frozen cadaver lower extremities with a buckle transducer placed on the tendon were used to measure the Achilles tendon forces through full range of knee motion with the hindfoot flexed. It was shown that by positioning the hindfoot in 20-25 degrees of plantarflexion the tension in the Achilles tendon was effectively eliminated, regardless of knee position.[8]

Protective Devices

Bracing and taping have been widely used in athletic training to help prevent and reduce further injury by limiting motion of a body part. Achilles tendon taping is designed to prevent the Achilles tendon from overstretching and reducing the stress on the tendon.[4,32] It has been noted that the taping acts as a second tendon and consequently absorbs some of its stresses.[28]

There are a few braces that are designed for reducing the stress on the Achilles tendon as well. The Pro M-P Achilles strap, by PRO Orthopedics, was designed to act as a compressive counterforce dispersing the forces transmitted through the gastrocnemius and soleus. It also relieved the stresses of contraction on the inferior aspect of the Achilles, which allowed for a decrease in inflammation. PRO Orthopedic has discontinued this brace due to a decline in growth from this product.[3] The CHO PAT® Achilles tendon strap is designed to reduce stress on the Achilles by spreading muscular contraction forces away from the Achilles tendon and by promoting an early heel rise.[2] The AchilloTrain, by Bauerfeind USA, is a brace designed with a silicone insert that lies alongside the Achilles tendon and under the heel. This insert provides intermittent compression for the reduction of edema. It also places the ankle in slight plantarflexion and there is a heel wedge to raise the heel for relief to Achilles tendinitis.[1]

Frignani et al., showed that the use of Achilles taping helped prevent/manage Achilles tendon injuries. The authors referenced 45 cases of Achilles tendon derangements treated by taping that had an elastic component. Taping was beneficial for the management of inflammatory conditions (i.e. tendinitis) and the prevention of tendon injuries. It was also indicated that the success of the tape depended on specific indications, materials, and techniques used.[13]

Researchers have concluded that taping in general is effective in preventing injuries because it may increase proprioception.[34,38] Robbins et al., studied the hypothesis that ankle taping may decrease the risk of injury through improving foot position awareness before and after exercise. They had 24 healthy blindfolded volunteers stand on a series of blocks and estimate the perceived slope direction and amplitude of the blocks. The results indicated that prior to the exercise the absolute position error was 4.23 degrees for a taped ankle and 5.53 degrees for an untaped ankle. Following the exercise the absolute position error was 2.5% worse when taped and 35.5% worse when untaped. The data supported their hypothesis that ankle taping improved proprioception after exercise.[34]

It is important to know that the tape and/or brace does not change the biomechanics of the athlete.[4,17] Hopper et al., examined the effects of taping and bracing on ankle kinematic, kinetic, and electromyographic variables during jumping. Fifteen netball players landed on a force plate with simultaneous recording of kinematic and electromyographic activity of the gastrocnemius, tibialis anterior and peroneus longus. The brace was found to reduce the electromyographic activity of the gastrocnemius and peroneus longus; however, the peak vertical ground reaction force was not affected by the bracing or taping.[17]

The question of the effectiveness of tape should be addressed first. Manfroy et al., found that fresh athletic tape is immediately effective after application, but the protection is short live. They compared taping on the skin and taping with prewrap to maximal active and passive ankle resistance to ankle inversion. No differences were found between the two after 40 minutes of vigorous exercise.[22] Riard et al., compared the effects of tape with and without prewrap before and after exercise on ankle inversion.[33] Thirty college age males and females participated in the study in which electrogoniometer measurements were taken at the ankle while the subjects balanced on their right leg on an inversion platform tilted about the medial-lateral axis to produce 15 degrees of plantar flexion. Sudden ankle inversion was induced during the balance by pulling on the platform support. Riard found there were no differences in the amount of inversion restricted when taping with prewrap or directly to the skin before and after exercise. Both techniques offered some inversion restriction after exercise.[33]

In a study where taping was investigated for biomechanical effects on combined ankle and foot motion, 16 collegiate male football players were tested before practice, immediately after taping, and after a 2.5 - 3 hour practice. It was found that plantarflexion-inversion became 50% less effective than the initial restriction with taping prior to exercise, and plantarflexion-dorsiflexion and plantarflexion-eversion lost more than 50% of the initial restrictions.[14] Pederson et al., compared ankle taping with spatting on ankle inversion before and after exercise. They used a video analysis system and inversion platform to test ankle inversion. Their subjects were tested before and then after 30 minutes of exercise. Pederson et al. found that the combination of spatting and taping was the most effective in controlling ankle inversion before and after exercise, when compared to tape only, spatting only or no taping. It was also shown that taping alone lost 21% of restriction within a short period of exercise (30 minutes).[30]

Paris, Vardaxis, and Kokkaliaris studied ankle range of motion (ROM) during extended periods of activity while taped and braced. They compared plantar-dorsiflexion and inversion-eversion ROMs of 30 subjects with nonelastic adhesive tape, no tape, Swede-O and SubTalar Support ankle braces. Measurements were taken before, during (at the 15, 30, 45, 60 minute marks), and after exercise on a treadmill. The results showed that when taped plantarflexion ROM increased within 15 minutes of exercise and with each 15 minute time period after that. It was therefore concluded that tape lost its effectiveness after exercise, and braces offered longer post-activity support than tape.[29]

Different techniques of taping have also been studied with little differences found between the techniques. Plummer compared the closed basket weave, moleskin stirrup, and Spartans taping to a control group receiving no taping. The taping techniques did not differ for each group, in both pre or post exercise conditions. It was also found that each technique allowed at least 25% more inversion after exercise.[31] Types of tape have also been examined for their effectiveness. Metcalfe et al. designed a study to examine moleskin tape, linen tape, or a lace-up ankle brace on restriction of joint range of motion. Both motor performance (vertical jump and agility test) and ankle/subtalar range of motion in each taping /brace condition was tested. Moleskin tape restricted all four types of ROM during exercise. Linen tape restricted all but plantar flexion, and the brace all but eversion. They found that moleskin tape was slightly more effective than the linen tape, because the linen tape allowed for more plantarflexion.[26]

Many studies have been done on effectiveness of ankle bracing and taping. The results have often suggested that bracing is more effective than taping by offering longer support during activity and restricted more ROM.[4,29] Cordova, Ingersoll, et al. also studied the effects of different types of braces (lace-up and semi-rigid) and tape. They surveyed 253 cases from 19 studies with conditions measured before and after exercise. The data were analyzed using a mixed-model factorial analysis of variance. It was found that a lace-up brace displayed greater support for frontal plane motion compared to taping, and taping was more supportive in limiting dorsiflexion than the bracing.[7]

In a study on the effectiveness of reducing the recurrence of ankle sprains, bracing was found to be more successful than taping.[37] By examining bracing, taping, combined bracing and taping, and control conditions (nothing), the recurrence frequency of sprains was 0%, 25%, 25%, 35% respectively.[37]

Achilles tendon taping is designed to reduce the stress on the tendon by preventing it from being overstretched.[4] The Cho-pat Achilles tendon strap is designed to reduce strain on the Achilles, by spreading the muscular contraction forces away from the tendon and by promoting an early heel rise.[2] These are important in the rehabilitation process of Achilles tendinitis by promoting a healthier/sheltered healing environment.

Henry studied the effects of Achilles tendon taping on angular displacement, velocity, and acceleration. Dorisflexion angular displacement and angular velocity were determined for the landing phase of a single back tuck saltos in gymnastics. No statistical differences were found for the contact angular displacement, velocity, or acceleration between taping and non-taping conditions. One problem with the study, though, is that the conclusion was made based on the data of only two subjects, because the data from the other four subjects were lost during the collection process.[16]

Morales used the Pro M-P Achilles tendon strap and found that it reduced the amount of eccentric peak torque on an isokinetic dynamometer compared to taping. Thirty-one asymptomatic males (15) and females (16) were tested at 30 and 120 degrees/second on a Biodex B-2000. Peak torque values at 120 deg/sec were significantly higher than those at 30 deg/sec, regardless of gender. No significant difference in peak torque production for male subjects were found, but female subjects produced significantly lower peak torque values in the Pro M-P Achilles strap condition than in the control condition at 120 deg/sec.[28]

Landing Biomechanics

Many lower extremity injuries occur during the landing phase of sport activities. The landing phase is of particular interest for this study, because of the importance of landing technique in injury prevention, and specifically for the prevention of Achilles tendon injuries.[36] An example of this would be from Ozguven et al., when male and female gymnasts landed from a 0.45m height onto a force platform. The vertical ground reaction force values (VGRF) ranged from 5.0 to 7.0 BW (without shoes).[43] Panzer et al. found that VGRF for six elite gymnasts during a double back somersault ranged from 8.8 to 14.4 BW.[42]

Dufek & Bates developed statistical models for predicting maximum forefoot (F1) and rearfoot (F2) ground reaction forces, maximum knee joint extensor moment and maximum knee joint eccentric power. They accomplished this by systematically increasing task demands during landing. The strongest prediction model was for rearfoot ground reaction force. The results also suggested the individual nature of subject performances and the need to identify critical landing performance factors on a single subject basis, so that a predictive model for insight into the relationships between injury mechanisms and landing biomechanics could be further studied.[12]

McNair and Prapavessis collected normative data of vertical ground reaction forces (GRF) associated with drop landing. They used 234 subjects categorized by gender, activity level, and type of sport played. The subjects landed from a box 0.3m high onto a force plate. The mean peak vertical GRF for all subjects was 4.5 BW. The peak vertical GRF was 4.6 and 4.2 BW for males and females, respectively. When comparing subjects that were involved in recreational activities to those playing competitive sports, VGRF was 4.4 and 4.5 BW, respectively (which is considered low).[24]

Dufek and Bates examined effects of landing techniques on impact loading. Two basic foot contact patterns were found in landing: toe-heel and flatfoot landings. The flatfoot technique usually produces a unimodal vertical ground reaction force curve while the toe-heel produces a bimodal ground reaction force curve. In the toe-heel landing the first peak ground reaction force is associated with the forefoot contact and the second peak with the heel contact.[10] It was suggested that using a toe-heel contact pattern as opposed to a flatfoot landing could reduce peak ground reaction force.[11] Kovacs et al., investigated foot placement on kinematics and kinetics during a drop landing. The foot placement strategies were investigated in spontaneous landing (forefoot contact used in sprinting) and normal landing used in a heel-toe contact in walking/running/jumping. Ten male subjects performed the two types of drop landings from a 0.4 m high box placed 1.0 m from the center of a force plate. They were instructed to land on the balls of their feet with no heel contact or land with heel-toe pattern. The plantar flexor muscles had the highest EMG activity in a fore foot landing than in a heel-toe landing. It was also found that the first peak and second peak ground reaction force was 3.4 times greater and 1.4 times lower for the heel-toe landing compared to forefoot landing.[21]

Stiff and soft landing techniques were studied by Devita and Skelly. Soft and stiff landings were defined by maximum knee flexion angles of greater than and less than 90 degrees, respectively. The results indicated that stiff landings produced greater GRF with the ankle plantarflexors producing a greater moment. It was also found that the hip and knee extensor muscles absorbed more energy in the soft landing while the ankle plantarflexors absorbed more in the stiff landing. The soft landing absorbed 19% more energy than the stiff landing.[9]

McNitt-Gray studied lower extremity kinetics in drop landings from three heights. Six gymnasts and six recreational athletes were used as subjects in this study. They performed drop landings from the heights of 0.32, 0.72, and 1.28 m. The results showed that the gymnasts used more ankle and hip extensor momentums at the higher impact velocities to dissipate the loads at contact than did the recreational athletes. The peak extensor moments and work done by the extensor muscles of the ankle, knee, and hip joints increased significantly as the impact velocity (height) increased.[25] Dufek and Bates also demonstrated that an increase in height landing increased the peak ground reaction in landing.[11]

Baca studied which technique gave the lowest errors when analyzing drop jump performance when compared to the results of a double force plate technique. The study concluded that video-based methods were the "most promising" alternative for determining accurate variables, when compared to flight-time, jump height, durations of phases of downward and upward movements of center of mass during foot contact after the drop for drop jump performance.[5]

Chapter III

Research Methods

Experimental Methods

Experiments were conducted to investigate the effects of Achilles tendon taping and bracing on landing biomechanics. The protocol for the experiment consisted of a warm-up, anthropometric measurements, and five test conditions. Five trials of drop landings in each of the five conditions, for a total of 25 trials, were performed by each subject.

Subjects

All subjects signed an informed consent form approved by the Institutional Review Board at the University of Tennessee (Appendix B) prior to their participation in the study. Subjects were recruited from the varsity sports of soccer, basketball, volleyball, track, and tennis teams at The University of Tennessee. Ten healthy female athletes (Age: 20 $\pm$ 1 yr, Body mass: 63.92 $\pm$ 10.21 kg, Height: 168.40 $\pm$ 10.67 cm) volunteered to participate in the study (See Appendix G for Individual Subject Information). A healthy athlete was defined for this study as one who had no current injury in the lower extremity at the time of the study. All subjects were briefed on the purpose, procedures, risks and benefits of this study before their participation.

Instrumentation

All testing was conducted in the Biomechanics/Sports Medicine Lab, Room 135, HPER Building at The University of Tennessee. The biomechanical instruments used in this study included a force platform (OR6-7, American

Mechanical Technology Inc.), a video camera (120Hz, GR-DVL 9800 JVC), Cho-pat Achilles tendon strap, 1 ½ inch Johnson and Johnson tape, 3 inch Elastikon, prewrap, a trigger device, a reference frame, reflective markers, an analog/digital (A/D) converter, and an Ariel Performance Analysis System (APAS, Ariel Dynamics, Inc.) for data collection and processing.

Kinematics

A video camera (120 Hz, GR-DVL 9800 JVC) was used to obtain kinematic data from the right sagittal view of the subjects during the test. The camera (120 Hz) was set parallel to the floor and the shutter speed was set at 1/1000 sec. A reference frame (width= 140.97 cm, length= 186.69 cm) was used to obtain scale factors in order to convert anatomical coordinates of the reflective markers. The reference frame had four coplanar reflective markers placed on the four corners of the structure.

Reflective markers were placed on the right side of the body at the midline below the last rib, hip, knee, ankle, heel, and at the head of the fifth metatarsal (Figure F-1). Using the Ariel system, the recorded video images were digitized to obtain coordinates of these markers throughout the activity. The digitized coordinates were then imported into a customized program to determine the time-history and discrete events of linear and angular positions, velocities, and accelerations.

Force platform

A force platform (OR6-7, American Mechanical Technology, Inc.) flush with the surrounding floor was used to measure ground reaction forces (GRF) and moments during the test. The GRF data included Fx, Fy, and Fz, representing medial-lateral, anterior-posterior, and vertical forces respectively. Mx, My, and Mz represented moments applied about Fx, Fy, and Fz axes. Signals from the force platform were sampled for 8 seconds at a frequency of 1200 Hz and amplified being stored in the APAS computer through the A/D converter.

Synchronization

The force platform and the sagittal view video were simultaneously recorded during the experiment. The synchronization between the kinematic and analog signals (the force platform) was achieved by using a customized trigger device with a light emitting diode (LED).

Braces and Tape

Subjects wore the Cho-pat Achilles tendon strap , donated by Cho-pat, Inc. The linen tape (1 ½ inch, Johnson and Johnson), elastic tape (3 inch, Elastikon), and prewrap were also provided by the Biomechanics/Sports Medicine Lab for the taping condition.

Experimental Protocol

Prior to their participation in this study, subjects were briefed on the purpose and the procedures of the study by the principal investigator. On the test day, the subjects were further informed about the purpose, the number of conditions, number of repetitions and performance requirements of this study. The test session took approximately 1 hour and 30 minutes, including practice and obtaining familiarity with the testing protocol. Twenty-five trials of drop landings were performed by the subjects in the five conditions. The five test conditions included landings without tape/brace (C1) and in pre-exercise (C2) and post-exercise (C3) conditions with a Cho-pat Achilles strap, and pre-exercise (C4) and post-exercise (C5) conditions with the Achilles tendon taping. The bracing and taping conditions were randomized. Subjects performed landing trials with each device in the pre-exercise condition first, followed by an exercise of running on a treadmill, and then by landing trials in the post-exercise condition. The drop landings were from a height of 45 cm (from the force platform to the bottom of the subject's heel). The bar from the ceiling was adjusted as necessary for each subject's height.

The subject began the test session with a warm-up by riding a stationary bike for 5 minutes. The retro-reflective markers were placed on the midline between the last rib and peak of the iliac crest, the greater trochanter, the lateral joint line of the knee, the lateral mallelous, the heel, and at the head of the fifth metatarsal (the last two markers were affixed to the corresponding sites on the lateral side of the shoe). During the taping and bracing conditions the lateral mallelous marker was affixed to the outside of the brace and tape over the mallelous. These markers were used to obtain right sagittal kinematics of the subjects during the landing activities.

Anthropometric measurements were obtained before the actual testing. The proximal and distal circumferences and length of the lower extremity segments were measured three times, and placed in the table on the Subject

Information Sheet (Appendix C); the mean value of these measurements was used in the subsequent analyses.

Prior to the experiment, the subject's body weight was measured on the force platform. During the test, the subject was instructed to land with the right foot on the force platform and their left foot on the adjacent floor in a symmetrical manner. The subjects performed running on a treadmill for 15 min (5 minutes level and 10 minutes inclined at 7°) at a self-selected pace (7-10 minutes/mile) between the pre- and post-exercise conditions of the taping and Cho-pat Achilles tendon strap.

Taping and Bracing Procedures

Achilles Tendon Taping

The Achilles tendon taping technique used in this study was from the *Principles of Athletic Training* by Arnheim and Prentice, because of the familiarity of this taping to athletic trainers (pgs 203-204).[4] The athlete was prone with the right foot hanging relaxed over the edge of the table. The area was sprayed with tape adherent and prewrap was applied to the lower one third of the calf. Two anchors with 1 ½ inch tape, one circling the leg loosely approximately 7 to 9 inches above the malleoli, and the other encircling the ball of the foot were applied. Two strips of 3 inch elastic tape were cut approximately 8 to 10 inches long. The first strip was moderately stretched from the ball of the athlete's foot along its plantar aspect up to the leg anchor. The second elastic strip followed the course of the first, but it was cut and split down the middle lengthwise. The cut ends were wrapped around the lower leg to form a lock. The taping was completed by placing two or three close down strips of elastic tape loosely around the arch and five or six strips around the athlete's lower leg (Figure F-2). It was cautioned that locking too tightly around the lower leg and foot will tend to restrict the normal action of the Achilles tendon and create more tissue irritation.

Cho-pat Achilles tendon strap

The athlete was placed in a Cho-pat Achilles tendon strap by first measuring the widest portion of ankle circumference. The size of the brace was determined by this measurement (Figure F-3). The brace was then applied to the subject's ankle with the help of the athletic trainer to make sure of proper placement. Two Velcro straps were adjusted according to each athlete's need: one around the lower leg right above the malleoli, and the second around the heel counter (Figure F-4).

Data Processing

The data processing procedure was divided into two categories: kinematic and kinetic.

Kinematic Data

Images collected from the video camera were used to obtain kinematic variables. The data was processed in five steps: capturing, trimming, digitizing, decoding/smoothing, and computing. First, a total of 120 frames of video images was captured and stored for each trial on the APAS, with 20 frames prior to and 100 frames following the foot contact with the force platform. Second, the captured frames were then trimmed within the APAS. In the third step, the reflective markers were digitized using the APAS. The reference frame was also digitized to obtain scale factors to convert the coordinates of digitized reflective markers from a screen reference system to a lab reference system. The fourth step, involved decoding, smoothing and reconstructing the digitized coordinates using a customized computer program written in Microsoft Visual Basic 6.0. The digitized coordinates were smoothed using an algorithm to obtain optimal cutoff frequencies individually for x and y coordinates of each reflective marker. A Shannon algorithm was used to reconstruct the video signal from 120 Hz to 240 Hz. In the fifth step, the decoded time-history file was imported into the second customized program to compute the linear and angular kinematic variables and determine corresponding discrete events. These variables included range of motion, contact position/velocity, maximum and time to maximum position/velocity for the hip, knee, and ankle joints.

Kinetic Data

Data collected from the force platform was analyzed in two steps. Analog data files stored on the APAS file were decoded using another Visual Basic program to obtain ASCII time-history of GRF and angular data. Second, using the fourth Visual Basic program, the decoded data files were imported to compute and obtain GRF and angular variables. Variables included the first (F1) and second (F2) maximum and vertical GRF and the times (T1 and T2) at which they occurred, the loading rate of F1 and F2, and Impulse.

Statistics

Selected GRF and kinematic variables were analyzed in a 2x2 (device x exercise time) repeated measures of analysis of variance. The pre-exercise conditions were also compared with the control condition 3 way (device x device x device) repeated measures of analysis of variance. Post hoc comparisons were analyzed by a Least Significant Difference (LSD). The statistical procedures were computed using SPSS statistics program (version 10.0) with a significant level set at $p< 0.05$. Due to a technical problem during data collection of one of the subjects, the kinematic data was only analyzed using 9 subjects. The vertical ground reaction force was analyzed statistically using all 10 subjects. The individual subject results of vertical ground reaction force and kinematics are provided in Appendix D and E, respectively.

Chapter IV

Results

The results of the ANOVA indicated a significant main effect of exercise for the first peak GRF (F1) and the loading rate of F1 (LRF1). F1 and LRF1 were decreased for bracing after exercise. The post-hoc comparison also showed that the LFR1 in the pre-exercising taping condition (pre-taping) was significantly greater than that of the control. A significant main effect of device for LRF1 was also found. The post-hoc comparisons showed that LRF1 was greater for pre-taping than that of the pre-exercise bracing (pre-bracing) condition (Table 1).

Table 1. Group Means and Standard Deviations of Vertical Ground Reaction Force Data

Condition		F1	T1	F2	T2	LRF1	LRF2	Impulse
Control	Mean	21.790	.011	43.492	.058	2177.065	932.891	2.316
	Std. Dev.	4.311	.003	10.817	.013	643.920	547.948	.422
Pre-bracing	Mean	22.469	.010	42.249	.056	2309.234	947.794	2.173
	Std. Dev.	3.757	.002	11.046	.014	632.980	482.703	.435
Post-bracing	Mean	21.293[a]	.010	42.272	.056	2212.226[a]	921.476	2.184
	Std. Dev.	3.356	.003	9.899	.013	696.472	476.616	.356
Pre-taping	Mean	22.502	.010	41.483	.053	2476.593[2,α]	968.459	2.200
	Std. Dev.	3.381	.002	10.183	.013	702.123	531.726	.271
Post-taping	Mean	21.931	.010	41.009	.054	2317.689	979.071	2.187
	Std. Dev.	3.622	.003	7.669	.016	703.472	552.220	.316

[1]. Significant difference between conditions Control and Pre-bracing for the joint.
[2]. Significant difference between conditions Control and Pre-taping for the joint.
[a]. Significant difference between conditions Pre-bracing and Post-bracing for the joint.
[b]. Significant difference between conditions Pre-taping and Post-taping for the joint.
[α]. Significant difference between conditions Pre-bracing and Pre-taping for the joint.
[β]. Significant difference between conditions Post-bracing and Post-taping for the joint.
Angle and ROM units are in degrees and time unit is in s.
Force unit is in N/kg and time is in s. Loading rate unit is in N/kg/s.
Impulse unit is in (N/kg)s.
The definitions of variables are in Appendix A.

For the ankle kinematics, the ANOVA results indicated a significant main effect of exercise and device for the maximum joint angle (Max). The post-hoc comparison showed that a greater ankle Max after exercise for the brace and tape (Table 2). The Max values for both post-bracing and post-taping were significantly greater than those of the pre-bracing and pre-taping. The comparison demonstrated a significant increase of Max for device between the two pre-exercise conditions and their post-exercise counterparts. The statistical results also demonstrated a significant main effect of device for the contact angle (ContAng), range of motion (ROM), contact velocity (ContV), and maximum angular velocity (MaxV) for the ANOVA comparing the control to the pre-bracing condition. The post-hoc comparison showed a significant difference between the pre-bracing condition and the control for all of these variables. In addition, a significantly decreased value was observed for Max, ROM, ContV, and MaxV for the pre-taping compared to the control condition (Table 2). In the comparison of devices for ContV, the pre-bracing was greater than the pre-taping conditions. On the other hand, MaxV for the post-bracing was significantly greater than the post-taping (Table 2).

The results of the ANOVA indicated a significant main effect of device for the time to Max (Tmax) and MaxV at the hip joint. The post-hoc comparison indicated a significantly less Tmax for the pre-bracing compared to the control (Table 2). The result demonstrated that both pre-bracing and pre-taping conditions were greater when compared to the control. It also indicated a

Table 2. Group Means and Standard Deviations of Lower Extremity Joint Kinematic Variables

Joint	Condition		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Hip	Control	Mean	17.125	78.887	.433	61.762	209.095	339.211	.064
		Std.Dev.	9.047	23.201	.143	17.075	41.518	52.468	.013
	Pre-bracing	Mean	17.302	78.462	.385[1]	61.161	222.256	364.381[1]	.064
		Std Dev.	8.124	20.659	.078	14.446	53.595	54.213	.013
	Post-bracing	Mean	15.842	76.386	.368	60.545	219.993	366.515	.064
		Std Dev.	8.499	19.896	.082	13.783	44.930	42.984	.014
	Pre-taping	Mean	18.201	83.072	.397	64.871	227.206	377.987[2]	.064
		Std Dev.	8.557	16.145	.088	10.143	45.058	46.577	.014
	Post-taping	Mean	16.542	77.063	.365	60.521	226.841	371.859	.062[β]
		Std Dev.	9.556	21.088	.085	14.943	55.554	58.327	.014
Knee	Control	Mean	25.201	85.848	.324	60.647	352.431	487.458	.051
		Std Dev.	5.901	13.274	.132	9.402	56.429	66.548	.010
	Pre-bracing	Mean	26.356	85.698	.281	59.341	341.531	489.119	.052
		Std Dev.	5.079	12.181	.102	9.087	53.101	70.187	.012
	Post-bracing	Mean	27.037	88.034	.286	60.997	338.405	484.806	.054
		Std Dev.	5.825	13.801	.103	10.135	49.881	72.261	.012
	Pre-taping	Mean	25.226	83.684	.317	58.458	333.381[2]	476.548	.052
		Std Dev.	6.069	9.850	.130	8.866	45.904	88.785	.012
	Post-taping	Mean	25.333	84.839	.283	59.505	335.212	486.343	.051
		Std Dev.	5.641	13.452	.096	10.699	65.444	81.698	.010
Ankle	Control	Mean	-20.462	19.706	.202	40.167	414.735	489.701	.025
		Std Dev.	8.481	6.836	.102	5.233	61.937	64.062	.007
	Pre-bracing	Mean	-16.834[1]	19.226	.199	36.059[1]	372.431[1]	439.567[1]	.024
		Std Dev.	7.793	6.556	.104	6.045	53.646	68.308	.007
	Post-bracing	Mean	-16.312	20.105	.191	36.417	382.898	453.628	.024
		Std Dev.	7.250	5.860	.076	5.752	66.544	70.513	.008
	Pre-taping	Mean	-19.406	14.274[α,2]	.229	33.680[2]	351.996[2,α]	421.508[2]	.024
		Std Dev.	7.009	4.447	.130	5.975	57.133	73.522	.008
	Post-taping	Mean	-17.402	17.345[b,β]	.189	34.747	354.092	426.456[β]	.025
		Std Dev.	7.565	4.893	.066	6.502	59.117	73.640	.009

[1]. Significant difference between conditions Control and Pre-bracing for the joint.
[2]. Significant difference between conditions Control and Pre-taping for the joint.
[a]. Significant difference between conditions Pre-bracing and Post-bracing for the joint.
[b]. Significant difference between conditions Pre-taping and Post-taping for the joint.
[α]. Significant difference between conditions Pre-bracing and Pre-taping for the joint.
[β]. Significant difference between conditions Post-bracing and Post-taping for the joint.
Angle and ROM units are in degrees and time unit is in s.
Velocity unit is in deg/s.
The definitions of variables are in Appendix A.

significant difference for TmaxV when comparing post-bracing to post-taping (Table 2).For the knee joint, the post-hoc comparison indicated a significantly smaller ContV for the pre-taping than that of the control (Table 2).

Chapter V

Discussion

The vertical ground reaction force results indicated that both F1 and LRF1 for both taping and bracing decreased after the exercise. The ankle brace or taping placed the ankle joint at a greater degree of plantarflexion, which limited the amount of dorsiflexion possible during the landing phase. This is shown in Table 2, with ankle ROM significantly less for both the pre-taping and pre-bracing conditions compared to the control. The ContAng upon touchdown for the ankle was also less for the pre-bracing condition compared to the control. Because of this limitation, the landing could be classified more as a stiff landing than a toe-heel landing due to the lack of ability to be able to dorsiflex upon touchdown. Dufek and Bates suggested that using a toe-heel landing as opposed to a flatfoot landing could reduce peak ground reaction force.[11] Kovacs et al. found that the first peak and second peak GRF was 3.4 times greater and 1.4 times lower greater, respectively, for a heel-toe landing. The reduction of F1 and LRF1 were after exercising conditions, where the tape and brace had lost some off their effectiveness due to the exercise.[14,29] Because of this reduction of restricting the ankle ROM, the athlete would be able to land in a more toe-heel fashion, therefore possibly reducing the F1 and LRF1. Self and Paine indicated that those who landed more stiffly had the greater impact force on the Achilles and plantar flexors.[36] In addition, the results of this study showed a higher LRF1 for taping when compared to the control. Causing a greater impact force on the Achilles upon landing stiffly, would mean that interpreting the results would show that the taping and brace would be the most effective at reducing Achilles tendinitis symptoms after exercising for a period of time, allowing each to relax and allow for a more toe-heel landing.

In the study of ankle kinetics by Hopper, the peak vertical ground reaction force, rearfoot, and Achilles tendon angles were not affected by bracing or taping at foot strike.[17] The peak vertical GRF in this study was not affected by either the Achilles tendon taping or bracing, only the fact that the exercise decreased F1 for both devices.

An examination of the kinematic data of this study demonstrated some significant differences, unlike the Henry study that found no statistical differences for contact angle, velocity or acceleration between taping and non-taping conditions. This may be due to the small size of their study. Upon examining Table 2, you can see that there were significant differences for both the Achilles tendon taping and bracing when compared to the control. The Cho-pat Achilles tendon brace and the Achilles tendon tape each decreased ankle ROM during the landing phase for pre-exercise conditions compared to the control. Davis et al. showed that by positioning the hindfoot in 20-25 degrees of plantarflexion the tension in the Achilles tendon was effectively eliminated.[8] The results from this study support the bracing/taping philosophy of athletic training which helps prevent and/or reduce injury by limiting motion of the body part. In addition, the current study demonstrated that the inclined treadmill running for 10 minutes did not significantly reduce the effect of the tape and brace in limiting the ROM of the ankle. Many studies suggest that bracing restricts more ROM than taping.[4,7,26,29]

When comparing the specific Achilles tendon taping to the Cho-pat bracing, the tape was more effective maximum joint angle for both pre and post conditions, but the tape was significantly increased after exercising compared to before, but was still a lower value than the brace. Max also different for pre-taping to control unlike the brace. The contact angle for impact upon landing was significantly decreased for pre-bracing compared to the control.

Morales used an isokinetic dynamometer to control the velocity at which a subject plantar and dorsiflexed their foot, and found that there was a significant difference in the amount of peak torque produced in females and not in males.[28] The contact and maximum angular velocities for the ankle joint during landing may prove to be more functionally significant. The results indicated significant reductions (Table 2) in comparing both pre and post exercise conditions to the control. These results may also indirectly suggest that the Achilles tendon force was reduced due to the application of the devices. The results also indicated that there was a reduced amount of ContV for pre-taping compared to pre-bracing and for MaxV between post-exercise condition, which could lead to the deduction that the tape was more effective.

At the conclusion of each subject's testing they were asked to rank the Cho-pat Achilles tendon strap to the Achilles tendon taping on a rating of perceived support scale (RPS) and to indicate which they preferred. The average RPS score for the Cho-pat was a 5, indicating a moderate support; whereas the average RPS score for the Achilles taping was 7.8 indicating a strong support. This RPS goes hand-in-hand with the results indicating that taping offered more support. On the other hand, the result about the preference of device indicated that the Cho-pat and tape were equally chosen with five subjects choosing the brace and the other five choosing the tape.

Based on the findings of this study, when the onset of Achilles tendinitis was detected or suspected in a female athlete both the Cho-pat Achilles tendon strap and the Achilles tendon taping could be suggested as a tool for helping prevent and/or reduce further injury to the tendon. However, the Achilles tendon tape should be considered as ideal choice of support. Since the general population that happens to develop Achilles tendinitis are not likely to be around an athletic trainer who could correctly administer an Achilles tendon taping, it would be better for the athlete to use a brace. The brace is an affordable investment to help reduce and or prevent their Achilles tendinitis from making them functionally impaired.

Recommendations for future studies of bracing and taping on the Achilles tendon include:

1) The functional activity should be performed for a longer extended period of time, so that the brace and/or tape can be examined in a more realistic time period (such as the time period of a game).

2) Both males and females should be tested and compared to see if there exists a significant difference between the male and female populations.

3) Different landing heights, shoes, and surfaces can be used to examine if the Achilles tendon taping and bracing are still functionally useful in these different conditions.

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Appendices

Appendix A

Definitions of Variables

Definitions of Variables

Vertical Ground Reaction Force

F1	First maximum vertical ground reaction force
T1	Time to first maximum vertical ground reaction force
F2	Second maximum vertical ground reaction force
T2	Time to second maximum vertical ground reaction force
LRF1	Loading rate of first maximum vertical ground reaction force
LRF2	Loading rate of second maximum vertical ground reaction force
Impulse	Impulse of vertical ground reaction force from contact to 100ms

Kinematics

ContAng	Contact joint angle at ground contact
Max	Maximum joint angle
Tmax	Time to maximum joint angle
Min	Minimum joint angle
Tmin	Time to minimum joint angle
ROM	Range of Motion of joint
ContV	Angular joint velocity at ground contact
MaxV	Angular joint maximum velocity
TmaxV	Time to angular joint maximum velocity

Appendix B

Informed Consent Form

Effects of Achilles tendon taping and bracing on landing biomechanics.
INFORMED CONSENT FORM

Principal Investigator:
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You are invited to participate in a research study entitled "Effects of Achilles tendon taping and bracing on landing biomechanics" which examines the effectiveness of taping and bracing the Achilles tendon during landing activities.

You are aware that you should have no history of impairments to your lower extremity at the time of testing. If you decide to participate, you will be asked to attend one test session, in which you need to wear loose shorts and a comfortable short-sleeved shirt. The test session will take approximately two hours. At the beginning of the testing session, you will need to fill out an information sheet about your age and height. You will be asked to warm up riding a stationary bike for five minutes. The girth and length of lower extremity segments will be measured and recorded afterwards. Reflective markers will be placed on the right side of your body. You will perform 25 drop landings onto a force platform, 5 trials in each of the five experimental conditions. These conditions will include landings from a predetermined height of 45 cm without tape or bracing, the brace before and after a bout of 15 minutes of inclined treadmill running, and taping before and after the treadmill running. The 15 minutes of treadmill running will include 5 minute level running and 10 minute inclined running at 7°. The running pace is selected by you between 7-10 minutes/mile. Once the pace is determined, it will be recorded and used for all two exercise sessions. You will wear one Achilles brace provided by the Biomechanics and Sports Medicine Lab during the brace condition, and the taping will be applied in the lab by the principal investigator. At the end of the study you will be asked to fill out a questionnaire to rank the brace and the tape. The five experimental conditions will be randomized. During the landing test, biomechanics instrumentation will be used to make visual and force measurements. Reflective markers will be placed on the right side of your body and a digital video camera will be used to record images of the right side during landing trails. None of the instruments will impede your ability to engage in normal and effective motions during the test. If you have any further questions, interests, or concerns about any instrumentation, please feel free to contact the investigator.

The potential risks of this investigation include an ankle sprain and/or a muscular strain of the lower extremity from landing in an unbalanced fashion. These risks will be minimized through proper warm-up and sufficient practice before the test. All tests will be conducted and the equipment handled by the qualified research personnel in the Biomechanics/Sports Medicine Lab. You will be encouraged to warm-up actively prior to the testing session so that you feel physically prepared to perform effectively and thus minimize any chances of injuries. In an event of physical injuries resulting from the test, standard first aid procedures will be administered as necessary, by a certified athletic trainer. The University of Tennessee does not automatically provide reimbursement for medical care or other compensation in the event of an injury. On the other hand, your benefits from participating in this study include assessment of your performance in landing and a better understanding on effects of taping and bracing on the Achilles tendon loading in landing. You are welcome to make an appointment to review the data from your test. In addition, if you wish to have a copy of the results of the study, please let the investigator know.

Your identity as a subject will be held in strict confidence and any description of your data will be referred to by a subject number only. Only the principal investigator, her advisor and qualified Biomechanics and Sports Medicine Lab personnel will have access to subject information and data. Any information that is obtained in connection with this study and that can be identified with you will remain confidential and will be disclosed only with your permission. The tapes will be destroyed after five years.

If you have any questions at any time about the study or the procedures or experience adverse effects as a result of participating in this study, you may contact Christy Rodenbeck at (865) 974-6484 or Songning Zhang (865) 974-1271. If you have questions about your rights as a participant, contact the Compliance Section of the Office of Research at (865) 974-3466. Your participation is entirely voluntary and that your decision whether or not to participate will involve no penalty or loss of benefits to which you are otherwise entitled. If you withdraw from the study before data collection is completed, your data will be destroyed.

Once you have read the above information and all of your questions have been answered, please sign and date the form below. Your signature indicates that you have read the above information and agree to participate in this study, and have received a copy of this form.

Participant's Name ______________________

Participant's Signature ____________________ Date __________

Investigator ________________________ Date __________

Appendix C

Subject Information Sheet

Subject Information

Subject name: ______________________ Subject #: ______ Date: _______

Weight: ____________ (N) Height: _________ Age: ________

Sport:

_____ Basketball
_____ Soccer
_____ Tennis
_____ Track
____ Volleyball

Condition Order: ____

Anthropometric Data (cm)

		Prox. Ht.	Dist. Circum.	Length
Foot	Trial			
	1			
	2			
	3			
	Mean			
	Ankle Moment Arm (cm)			
		Prox. Circum	Dist. Circum.	
Leg	Trial			
	1			
	2			
	3			
	Mean			
Thigh	Trial			
	1			
	2			
	3			
	Mean			

Appendix D

Vertical Ground Reaction Force Tables

Table D-1. **Means and Standard Deviations of Vertical Ground Reaction Force Data**

Subject	Condition		F1	T1	F2	T2	LRF1	LRF2	Impulse
1	Control	Mean	14.563	.015	37.456	.080	983.158	449.646	2.071
		Std. Dev.	1.955	.000	7.185	.008	141.640	159.279	.220
	Pre-bracing	Mean	17.336	.013	37.743	.077	1317.127	475.188	2.187
		Std. Dev.	1.179	.001	4.223	.005	213.544	102.944	.081
	Post-bracing	Mean	17.095	.015	38.014	.077	1179.648	475.625	2.104
		Std. Dev.	1.017	.000	1.507	.005	76.035	43.211	.076
	Pre-taping	Mean	16.266	.012	35.331	.074	1365.784	414.126	2.135
		Std. Dev.	.718	.001	7.072	.006	164.251	146.031	.211
	Post-taping	Mean	16.643	.015	35.286	.081	1152.219	417.074	2.025
		Std. Dev.	1.230	.001	4.034	.005	128.294	100.234	.050
2	Control	Mean	20.178	.006	56.858	.037	3206.746	1980.805	2.458
		Std. Dev.	1.894	.000	7.328	.002	463.077	299.064	.364
	Pre-bracing	Mean	22.262	.007	52.468	.038	3142.100	1674.156	2.283
		Std. Dev.	2.528	.001	6.804	.003	533.328	203.820	.400
	Post-bracing	Mean	22.055	.007	51.482	.039	3199.093	1635.384	2.324
		Std. Dev.	1.973	.002	4.668	.004	710.881	330.212	.211
	Pre-taping	Mean	23.343	.007	56.556	.038	3539.539	1884.394	2.409
		Std. Dev.	1.678	.001	2.643	.003	543.236	333.230	.109
	Post-taping	Mean	24.441	.008	53.772	.040	3096.418	1599.925	2.487
		Std. Dev.	1.596	.002	8.444	.004	609.494	469.062	.217
3	Control	Mean	22.273	.010	45.739	.052	2320.757	1425.823	1.917
		Std. Dev.	3.705	.001	7.640	.006	406.976	656.202	.097
	Pre-bracing	Mean	24.126	.010	36.493	.056	2482.938	850.545	1.764
		Std. Dev.	2.978	.001	5.012	.006	354.306	220.764	.064
	Post-bracing	Mean	20.303	.009	39.575	.049	2405.046	1029.730	1.770
		Std. Dev.	2.451	.001	6.395	.004	164.128	330.591	.140
	Pre-taping	Mean	25.257	.011	37.917	.055	2372.697	973.461	1.834
		Std. Dev.	2.730	.001	6.530	.008	52.662	398.750	.057
	Post-taping	Mean	22.839	.009	40.823	.050	2632.782	1133.180	1.792
		Std. Dev.	1.819	.002	4.026	.005	510.674	236.145	.091

Table D-1. Continued.

Subject	Condition		F1	T1	F2	T2	LRF1	LRF2	Impulse
4	Control	Mean	18.102	.010	29.973	.054	1859.439	501.681	1.785
		Std. Dev.	2.673	.002	8.407	.014	418.300	289.901	.203
	Pre-bracing	Mean	18.553	.010	36.687	.038	1931.020	1363.051	1.614
		Std. Dev.	1.019	.003	6.819	.007	547.854	592.031	.117
	Post-bracing	Mean	19.284	.011	30.667	.045	1921.273	730.300	1.657
		Std. Dev.	4.523	.004	5.724	.007	834.845	372.112	.196
	Pre-taping	Mean	20.522	.010	33.180	.043	2140.060	857.991	1.832
		Std. Dev.	2.417	.003	9.794	.009	666.358	724.668	.124
	Post-taping	Mean	19.246	.010	38.543	.036	2087.810	1323.708	1.671
		Std. Dev.	.789	.002	2.966	.005	374.840	237.902	.104
5	Control	Mean	26.012	.012	57.543	.061	2227.763	1091.225	2.781
		Std. Dev.	3.858	.003	5.245	.005	250.130	294.590	.151
	Pre-bracing	Mean	25.716	.010	52.445	.060	2571.593	939.289	2.695
		Std. Dev.	2.582	.000	8.987	.006	258.179	263.515	.278
	Post-bracing	Mean	23.610	.010	50.322	.060	2361.035	992.666	2.523
		Std. Dev.	2.329	.000	10.596	.005	232.930	467.983	.221
	Pre-taping	Mean	26.029	.010	53.802	.057	2602.916	1154.697	2.471
		Std. Dev.	1.498	.000	6.667	.005	149.769	242.376	.185
	Post-taping	Mean	25.977	.010	40.177	.059	2649.356	618.857	2.425
		Std. Dev.	1.780	.000	2.690	.006	276.568	54.299	.146
6	Control	Mean	20.112	.010	38.644	.076	2011.217	475.940	2.471
		Std. Dev.	1.555	.000	6.265	.004	155.488	150.698	.191
	Pre-bracing	Mean	17.978	.010	26.289	.074	1863.984	317.784	1.794
		Std. Dev.	.738	.000	5.045	.008	134.660	86.058	.232
	Post-bracing	Mean	17.754	.010	35.518	.067	1806.145	555.319	2.039
		Std. Dev.	.779	.000	6.624	.003	66.792	194.872	.071
	Pre-taping	Mean	20.786	.009	36.996	.056	2433.906	742.573	2.141
		Std. Dev.	1.843	.001	5.544	.010	423.305	281.700	.087
	Post-taping	Mean	20.150	.010	35.443	.066	2014.961	561.152	2.112
		Std. Dev.	1.257	.000	5.700	.006	125.673	175.101	.090

Table D-1. Continued.

Subject	Condition		F1	T1	F2	T2	LRF1	LRF2	Impulse
7	Control	Mean	24.828	.009	34.219	.052	2696.372	905.646	1.816
		Std. Dev.	2.536	.001	2.692	.006	326.930	356.466	.177
	Pre-bracing	Mean	24.299	.009	35.634	.050	2676.769	853.566	1.806
		Std. Dev.	2.426	.001	2.924	.003	398.992	128.230	.197
	Post-bracing	Mean	23.756	.009	42.523	.050	2635.969	1166.243	2.055
		Std. Dev.	3.750	.001	16.247	.009	600.039	731.667	.363
	Pre-taping	Mean	22.384	.008	45.553	.040	2943.099	1413.142	2.038
		Std. Dev.	1.683	.001	6.412	.004	330.082	334.520	.155
	Post-taping	Mean	21.141	.008	42.294	.040	2754.868	1618.762	2.065
		Std. Dev.	4.600	.002	11.655	.014	472.320	1022.576	.195
8	Control	Mean	23.291	.010	49.106	.060	2377.287	817.433	2.824
		Std. Dev.	4.128	.000	4.101	.003	470.180	109.530	.177
	Pre-bracing	Mean	25.654	.009	49.085	.056	2976.050	973.183	2.605
		Std. Dev.	2.803	.001	13.235	.011	348.459	561.139	.163
	Post-bracing	Mean	23.809	.009	43.984	.053	2788.920	788.044	2.613
		Std. Dev.	1.778	.001	4.430	.007	447.837	228.078	.112
	Pre-taping	Mean	23.892	.009	40.791	.052	2800.512	810.396	2.518
		Std. Dev.	2.173	.001	9.070	.004	485.622	369.047	.209
	Post-taping	Mean	25.032	.009	42.429	.049	2891.406	976.021	2.489
		Std. Dev.	3.112	.001	1.958	.005	118.079	147.954	.073
9	Control	Mean	25.054	.015	42.181	.057	1727.504	810.678	2.563
		Std. Dev.	3.252	.000	9.207	.006	209.941	307.330	.296
	Pre-bracing	Mean	25.027	.014	50.328	.063	1795.394	1015.272	2.549
		Std. Dev.	2.672	.001	11.535	.010	227.175	458.713	.319
	Post-bracing	Mean	23.256	.014	38.747	.074	1623.957	620.723	2.187
		Std. Dev.	1.664	.001	5.974	.006	115.525	201.213	.163
	Pre-taping	Mean	21.048	.012	36.240	.066	1685.962	582.770	2.319
		Std. Dev.	2.700	.002	3.223	.006	100.432	85.917	.126
	Post-taping	Mean	19.700	.015	36.267	.075	1348.553	522.894	2.284
		Std. Dev.	2.760	.000	6.388	.004	230.465	153.567	.176
10	Control	Mean	23.483	.010	43.203	.053	2360.405	870.029	2.472
		Std. Dev.	2.278	.001	9.715	.008	258.711	413.885	.212
	Pre-bracing	Mean	23.739	.010	45.316	.049	2335.369	1015.902	2.430
		Std. Dev.	2.463	.001	6.717	.006	179.004	314.052	.215
	Post-bracing	Mean	22.010	.010	51.890	.049	2201.171	1220.723	2.573
		Std. Dev.	2.859	.001	6.934	.008	255.541	311.924	.123
	Pre-taping	Mean	25.489	.009	38.465	.046	2881.453	851.040	2.303
		Std. Dev.	1.899	.001	12.268	.005	438.360	465.397	.140
	Post-taping	Mean	24.145	.010	45.060	.048	2548.519	1019.139	2.525
		Std. Dev.	2.657	.000	6.532	.002	318.456	243.903	.110

Note: Force unit is in N/kg and time is in s.
Loading rate unit is in N/kg/s. Impulse unit is in (N/kg)s.
The definitions of variables are in Appendix A.

Appendix E

Kinematic Tables

Table E-1. Means and Standard Deviations of Subject 1 Kinematic Data

Condition	Joint		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Control	Hip	Mean	8.714	58.641	.478	49.927	174.049	311.976	.084
		Std. Dev.	3.282	4.285	.082	5.474	26.023	31.500	.004
	Knee	Mean	16.977	66.036	.270	49.059	240.152	340.658	.067
		Std. Dev.	1.417	9.554	.083	10.543	39.551	51.065	.016
	Ankle	Mean	-21.771	21.038	.316	42.808	326.124	444.619	.037
		Std. Dev.	1.516	2.884	.117	2.339	58.898	47.744	.007
Pre-bracing	Hip	Mean	9.147	66.763	.426	57.617	193.343	353.518	.082
		Std. Dev.	4.226	3.938	.039	6.850	18.824	41.754	.010
	Knee	Mean	19.803	69.063	.316	49.260	261.831	368.319	.071
		Std. Dev.	1.650	2.470	.123	1.391	17.395	22.185	.019
	Ankle	Mean	-18.545	19.719	.258	38.265	334.135	422.206	.032
		Std. Dev.	1.233	1.312	.189	2.047	44.291	38.006	.005
Post-bracing	Hip	Mean	6.467	70.604	.423	64.136	172.198	391.597	.089
		Std. Dev.	3.591	3.067	.032	6.405	25.219	19.721	.012
	Knee	Mean	19.590	66.978	.344	47.388	259.413	359.954	.068
		Std. Dev.	.397	2.459	.159	2.108	18.218	16.178	.020
	Ankle	Mean	-19.072	20.489	.162	39.561	326.377	435.363	.033
		Std. Dev.	2.348	1.064	.010	2.976	35.772	34.000	.007
Pre-taping	Hip	Mean	9.844	67.343	.413	57.499	186.678	337.994	.084
		Std. Dev.	4.616	3.549	.051	6.970	19.169	55.567	.011
	Knee	Mean	19.991	70.038	.333	50.048	259.280	354.932	.068
		Std. Dev.	1.668	2.969	.106	1.959	19.610	28.664	.018
	Ankle	Mean	-19.075	19.060	.286	38.135	332.142	419.108	.032
		Std. Dev.	1.517	2.407	.184	2.196	48.119	44.071	.005
Post-taping	Hip	Mean	5.844	66.496	.418	60.652	148.157	347.408	.089
		Std. Dev.	3.504	2.780	.052	4.967	45.799	29.314	.013
	Knee	Mean	17.824	63.091	.265	45.267	257.748	351.157	.056
		Std. Dev.	2.336	5.038	.160	4.795	26.315	42.864	.018
	Ankle	Mean	-22.380	17.391	.193	39.770	332.739	447.427	.033
		Std. Dev.	3.560	2.432	.051	3.614	28.830	45.528	.003

Note: Angle and ROM units are in degrees and time unit is in s.
Velocity unit is deg/s.
The definitions of variables are in Appendix A.

Table E-2. **Means and Standard Deviations of Subject 2 Kinematic Data**

Condition	Joint		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Control	Hip	Mean	10.380	35.798	.180	25.417	198.986	266.446	.040
		Std. Dev.	2.653	4.541	.022	4.927	26.749	36.324	.007
	Knee	Mean	28.343	81.416	.185	53.073	323.762	501.181	.048
		Std. Dev.	1.484	6.823	.027	7.701	33.233	36.776	.005
	Ankle	Mean	-1.805	30.731	.167	32.536	354.782	393.880	.020
		Std. Dev.	1.949	1.768	.021	1.594	38.814	30.714	.005
Pre-bracing	Hip	Mean	9.761	43.334	.233	33.574	177.118	308.691	.055
		Std. Dev.	3.246	6.939	.030	4.332	32.107	57.793	.007
	Knee	Mean	25.543	86.666	.220	61.123	277.493	527.175	.058
		Std. Dev.	3.365	11.020	.032	10.622	43.357	60.237	.008
	Ankle	Mean	-5.211	31.097	.185	36.308	339.000	414.157	.027
		Std. Dev.	2.485	2.448	.018	1.161	25.933	19.070	.005
Post-bracing	Hip	Mean	11.500	44.855	.201	33.355	185.812	302.916	.053
		Std. Dev.	2.847	6.902	.019	5.215	22.098	31.127	.009
	Knee	Mean	31.547	84.019	.193	52.472	273.333	472.226	.055
		Std. Dev.	2.289	6.687	.030	6.142	20.306	19.028	.007
	Ankle	Mean	-3.529	29.833	.180	33.362	331.253	391.352	.024
		Std. Dev.	2.161	1.520	.025	2.524	35.396	8.402	.006
Post-taping	Hip	Mean	10.041	36.095	.219	26.053	147.067	244.388	.055
		Std. Dev.	2.186	3.672	.080	3.237	30.132	37.395	.010
	Knee	Mean	28.104	76.000	.188	47.895	231.627	428.500	.059
		Std. Dev.	3.195	2.509	.023	4.399	42.866	29.348	.010
	Ankle	Mean	-6.099	24.963	.200	31.061	283.944	355.821	.028
		Std. Dev.	2.274	3.149	.061	4.088	12.547	35.053	.008

Note: Angle and ROM units are in degrees and time unit is in s.
Velocity unit is deg/s.
The definitions of variables are in Appendix A.

Table E-3. **Means and Standard Deviations of Subject 3 Kinematic Data**

Condition	Joint		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Control	Hip	Mean	26.590	94.185	.418	67.595	231.815	348.176	.067
		Std. Dev.	5.827	4.006	.059	5.001	22.361	29.470	.008
	Knee	Mean	27.491	89.110	.328	61.618	360.126	466.390	.053
		Std. Dev.	2.042	6.100	.063	5.983	21.421	37.793	.007
	Ankle	Mean	-21.053	17.803	.162	38.856	423.553	497.142	.023
		Std. Dev.	2.500	1.889	.033	2.642	12.134	41.699	.006
Pre-bracing	Hip	Mean	24.445	100.6	.401	76.196	269.014	386.112	.071
		Std. Dev.	2.464	1.582	.014	2.419	13.918	16.083	.007
	Knee	Mean	27.256	90.634	.375	63.378	349.209	452.607	.051
		Std. Dev.	2.499	4.138	.044	3.050	12.798	10.440	.006
	Ankle	Mean	-17.799	18.195	.180	35.994	377.902	441.644	.023
		Std. Dev.	2.416	2.319	.020	3.355	34.637	49.906	.002
Post-bracing	Hip	Mean	26.696	101.8	.395	75.137	286.197	384.380	.061
		Std. Dev.	3.084	1.691	.052	4.199	25.021	44.421	.005
	Knee	Mean	28.999	91.614	.324	62.614	373.290	469.085	.045
		Std. Dev.	1.278	3.983	.050	4.831	18.263	46.939	.007
	Ankle	Mean	-16.099	17.951	.168	34.050	388.844	445.583	.021
		Std. Dev.	1.574	1.289	.015	2.192	39.995	44.672	.005
Pre-taping	Hip	Mean	27.441	101.6	.433	74.195	246.054	356.770	.073
		Std. Dev.	2.676	2.796	.033	2.717	14.396	21.229	.006
	Knee	Mean	23.793	82.465	.384	58.672	321.613	408.600	.053
		Std. Dev.	1.658	2.145	.093	2.173	29.531	36.968	.009
	Ankle	Mean	-23.482	10.539	.238	34.021	361.360	423.056	.023
		Std. Dev.	1.330	2.150	.122	3.165	40.485	47.929	.004
Post-taping	Hip	Mean	28.272	101.2	.383	72.893	271.837	377.211	.063
		Std. Dev.	3.562	2.632	.006	3.025	9.320	23.812	.006
	Knee	Mean	23.485	83.719	.337	60.234	345.978	458.185	.048
		Std. Dev.	3.012	3.133	.044	3.123	14.448	15.795	.006
	Ankle	Mean	-20.606	12.393	.174	32.999	410.968	458.198	.019
		Std. Dev.	2.793	1.303	.033	2.809	48.773	47.417	.005

Note: Angle and ROM units are in degrees and time unit is in s.
Velocity unit is deg/s.
The definitions of variables are in Appendix A.

Table E-4. Means and Standard Deviations of Subject 4 Kinematic Data

Condition	Joint		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Control	Hip	Mean	23.843	111.967	.469	88.124	223.746	417.506	.065
		Std. Dev.	3.001	3.869	.038	4.325	48.037	13.569	.013
	Knee	Mean	33.460	108.030	.501	74.570	386.736	520.644	.044
		Std. Dev.	4.280	4.317	.041	3.349	36.310	29.378	.008
	Ankle	Mean	-13.691	20.495	.159	34.186	367.425	421.950	.021
		Std. Dev.	3.781	.821	.006	3.353	71.267	56.093	.007
Pre-bracing	Hip	Mean	26.565	106.226	.460	79.661	317.639	439.730	.046
		Std. Dev.	3.097	2.403	.010	4.588	24.307	42.180	.005
	Knee	Mean	33.631	105.662	.435	72.030	391.333	529.866	.041
		Std. Dev.	3.446	5.989	.070	8.010	43.347	73.988	.006
	Ankle	Mean	-2.374	19.899	.183	22.273	271.011	284.797	.013
		Std. Dev.	2.199	.697	.011	2.441	26.762	23.069	.005
Post-bracing	Hip	Mean	26.169	104.528	.483	78.359	286.473	426.189	.051
		Std. Dev.	3.313	2.042	.030	4.357	27.229	30.104	.009
	Knee	Mean	35.164	109.952	.424	74.788	370.612	510.778	.044
		Std. Dev.	1.580	5.841	.055	5.284	26.429	23.602	.005
	Ankle	Mean	-6.791	19.464	.183	26.255	319.386	340.283	.013
		Std. Dev.	2.971	1.274	.012	3.013	21.627	16.815	.008
Pre-taping	Hip	Mean	21.271	101.565	.557	80.295	230.362	427.731	.062
		Std. Dev.	1.294	7.604	.152	7.830	59.013	55.280	.014
	Knee	Mean	33.755	96.250	.391	62.495	339.029	482.550	.050
		Std. Dev.	3.139	3.057	.093	3.952	28.807	71.422	.004
	Ankle	Mean	-5.983	16.481	.354	22.463	242.091	265.493	.016
		Std. Dev.	3.100	1.116	.131	3.021	43.522	51.219	.005
Post-taping	Hip	Mean	25.398	106.201	.502	80.803	283.933	450.073	.052
		Std. Dev.	4.131	4.213	.035	5.284	57.139	50.354	.011
	Knee	Mean	30.725	108.554	.451	77.830	389.892	573.443	.045
		Std. Dev.	.644	5.388	.028	5.547	31.966	32.829	.003
	Ankle	Mean	-5.814	19.634	.233	25.448	267.641	294.565	.017
		Std. Dev.	1.903	1.971	.075	2.434	19.855	17.049	.006

Note: Angle and ROM units are in degrees and time unit is in s.
Velocity unit is deg/s.
The definitions of variables are in Appendix A.

Table E-5. Means and Standard Deviations of Subject 5 Kinematic Data

Condition	Joint		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Control	Hip	Mean	28.202	100.108	.651	71.905	179.099	304.942	.069
		Std. Dev.	6.663	10.864	.167	7.490	50.648	23.157	.009
	Knee	Mean	23.796	82.645	.293	58.849	362.059	474.699	.053
		Std. Dev.	2.172	8.027	.155	6.374	39.449	24.620	.013
	Ankle	Mean	-32.849	7.738	.208	40.587	438.827	516.041	.025
		Std. Dev.	2.559	1.725	.081	1.294	19.052	15.780	.003
Pre-bracing	Hip	Mean	24.723	91.251	.474	66.528	189.927	338.913	.070
		Std. Dev.	3.251	5.140	.064	5.856	31.368	29.249	.005
	Knee	Mean	24.825	80.392	.238	55.566	344.921	482.188	.053
		Std. Dev.	2.404	5.654	.086	4.664	29.976	33.696	.006
	Ankle	Mean	-28.744	9.274	.275	38.019	402.898	478.230	.027
		Std. Dev.	1.139	1.448	.239	2.110	18.838	17.215	.002
Post-bracing	Hip	Mean	15.225	78.318	.426	63.093	207.185	340.198	.067
		Std. Dev.	2.727	2.515	.052	.801	10.898	29.106	.003
	Knee	Mean	19.994	73.876	.200	53.882	351.931	463.061	.052
		Std. Dev.	1.512	5.015	.014	3.695	23.955	23.095	.005
	Ankle	Mean	-28.597	8.037	.161	36.634	389.532	469.650	.026
		Std. Dev.	2.782	1.519	.027	4.118	62.913	37.376	.009
Pre-taping	Hip	Mean	20.276	87.170	.413	66.894	229.678	364.934	.067
		Std. Dev.	3.227	1.184	.032	3.282	24.362	28.784	.004
	Knee	Mean	19.585	78.065	.347	58.480	369.199	464.300	.050
		Std. Dev.	1.710	2.894	.228	3.655	12.454	28.864	.007
	Ankle	Mean	-31.619	4.872	.162	36.492	392.573	467.424	.025
		Std. Dev.	1.323	.561	.033	1.443	37.633	35.065	.005
Post-taping	Hip	Mean	16.098	82.990	.378	66.891	236.345	371.733	.061
		Std. Dev.	2.666	3.713	.038	5.443	24.052	7.891	.010
	Knee	Mean	22.276	79.174	.224	56.898	375.853	487.389	.049
		Std. Dev.	2.354	3.480	.028	3.691	14.509	29.741	.005
	Ankle	Mean	-25.975	8.745	.171	34.720	371.107	430.206	.025
		Std. Dev.	1.187	.927	.021	1.737	20.321	22.528	.003

Note: Angle and ROM units are in degrees and time unit is in s.
Velocity unit is deg/s.
The definitions of variables are in Appendix A.

Table E-6. **Means and Standard Deviations of Subject 6 Kinematic Data**

Condition	Joint		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Control	Hip	Mean	21.089	80.096	.414	59.007	194.645	317.051	.069
		Std. Dev.	1.256	3.766	.051	4.390	25.074	30.052	.007
	Knee	Mean	27.907	90.427	.243	62.520	397.376	501.458	.049
		Std. Dev.	2.724	7.200	.066	6.775	14.961	33.266	.010
	Ankle	Mean	-25.834	20.329	.210	46.164	479.080	554.512	.025
		Std. Dev.	2.117	2.808	.063	2.802	27.138	23.090	.003
Pre-bracing	Hip	Mean	24.068	84.527	.364	60.459	221.604	349.791	.062
		Std. Dev.	1.963	9.111	.021	8.721	24.168	60.066	.013
	Knee	Mean	31.056	84.654	.210	53.598	384.510	467.213	.037
		Std. Dev.	.808	4.648	.041	4.474	20.775	40.919	.006
	Ankle	Mean	-21.646	14.627	.168	36.273	384.902	461.927	.024
		Std. Dev.	2.197	1.828	.076	3.765	32.665	40.064	.005
Post-bracing	Hip	Mean	19.795	84.536	.377	64.741	205.986	369.864	.068
		Std. Dev.	1.181	3.751	.030	3.747	18.182	29.907	.006
	Knee	Mean	29.233	100.194	.297	70.961	378.595	538.961	.052
		Std. Dev.	3.830	5.190	.072	4.144	13.084	37.594	.004
	Ankle	Mean	-21.309	21.468	.192	42.776	406.505	510.445	.029
		Std. Dev.	1.875	2.967	.048	3.057	51.616	47.207	.007
Pre-taping	Hip	Mean	21.602	87.455	.360	65.853	239.026	398.010	.057
		Std. Dev.	4.078	2.542	.034	4.967	54.085	29.053	.009
	Knee	Mean	26.845	85.861	.284	59.016	378.512	531.620	.046
		Std. Dev.	2.892	3.506	.087	5.486	39.434	42.990	.007
	Ankle	Mean	-19.230	14.748	.143	33.977	409.017	469.694	.020
		Std. Dev.	4.644	.774	.017	4.454	57.062	12.021	.010
Post-taping	Hip	Mean	23.148	82.732	.370	59.584	230.066	370.823	.064
		Std. Dev.	3.240	3.428	.008	3.333	14.567	10.181	.008
	Knee	Mean	26.958	94.311	.316	67.354	377.059	509.601	.051
		Std. Dev.	2.097	2.186	.039	2.619	12.783	23.257	.003
	Ankle	Mean	-23.070	20.353	.207	43.423	397.855	505.475	.030
		Std. Dev.	1.517	1.402	.090	2.438	15.953	41.522	.002

Note: Angle and ROM units are in degrees and time unit is in s.
Velocity unit is deg/s.
The definitions of variables are in Appendix A.

Table E-7. Means and Standard Deviations of Subject 7 Kinematic Data

Condition	Joint		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Control	Hip	Mean	24.800	96.037	.369	71.237	274.690	415.215	.055
		Std. Dev.	5.025	3.337	.015	3.912	22.295	19.056	.008
	Knee	Mean	29.209	91.367	.372	62.157	391.980	511.413	.043
		Std. Dev.	1.997	4.645	.048	5.412	16.300	25.926	.006
	Ankle	Mean	-19.546	16.676	.216	36.222	454.379	494.098	.019
		Std. Dev.	1.107	1.572	.121	1.982	42.897	44.387	.002
Pre-bracing	Hip	Mean	23.548	97.940	.363	74.392	279.336	428.621	.056
		Std. Dev.	3.384	2.409	.024	3.163	31.026	24.786	.005
	Knee	Mean	31.302	94.705	.382	63.404	389.707	506.171	.044
		Std. Dev.	2.647	.517	.052	2.289	22.196	12.944	.007
	Ankle	Mean	-17.420	17.745	.144	35.164	393.675	449.305	.022
		Std. Dev.	2.520	1.364	.010	3.726	32.105	23.918	.008
Post-bracing	Hip	Mean	26.238	97.629	.394	71.391	248.926	396.024	.057
		Std. Dev.	3.631	4.541	.028	3.407	11.697	23.679	.007
	Knee	Mean	34.177	98.814	.393	64.637	344.207	473.554	.049
		Std. Dev.	1.918	8.972	.094	7.445	36.210	50.715	.005
	Ankle	Mean	-15.011	17.913	.238	32.924	384.490	422.238	.019
		Std. Dev.	2.753	4.695	.148	4.524	56.333	52.889	.005
Pre-taping	Hip	Mean	31.008	101.092	.355	70.084	277.824	407.741	.048
		Std. Dev.	2.027	2.992	.015	4.364	27.698	31.751	.005
	Knee	Mean	34.253	91.887	.383	57.634	356.115	471.143	.040
		Std. Dev.	1.794	3.034	.060	3.459	28.031	28.945	.006
	Ankle	Mean	-14.160	13.580	.209	27.740	360.391	382.186	.014
		Std. Dev.	.981	2.030	.153	2.846	20.777	19.980	.005
Post-taping	Hip	Mean	29.716	99.226	.357	69.510	279.085	417.717	.048
		Std. Dev.	6.746	4.023	.045	7.380	31.965	31.082	.010
	Knee	Mean	35.992	94.873	.345	58.881	389.431	494.112	.038
		Std. Dev.	4.791	5.568	.088	1.300	47.517	39.110	.007
	Ankle	Mean	-11.786	15.220	.213	27.006	373.828	396.339	.013
		Std. Dev.	8.329	2.618	.133	7.119	80.169	90.764	.009

Note: Angle and ROM units are in degrees and time unit is in s.
Velocity unit is deg/s.
The definitions of variables are in Appendix A.

Table E-8. Means and Standard Deviations for Subject 8 Kinematic Data

Condition	Joint		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Control	Hip	Mean	3.604	53.034	.309	49.430	186.626	323.911	.067
		Std. Dev.	1.463	4.099	.028	4.712	19.698	28.126	.008
	Knee	Mean	24.468	94.532	.261	70.064	415.015	586.780	.053
		Std. Dev.	2.865	4.467	.046	5.069	27.154	23.374	.008
	Knee	Mean	-17.991	26.829	.146	44.820	443.885	554.081	.027
		Std. Dev.	3.062	2.326	.006	3.934	54.113	49.433	.005
Pre-bracing	Hip	Mean	7.769	60.913	.313	53.145	172.938	356.200	.067
		Std. Dev.	2.827	7.863	.025	8.174	36.773	19.691	.012
	Knee	Mean	24.957	93.634	.229	68.677	375.855	589.912	.056
		Std. Dev.	2.594	8.854	.018	6.886	53.938	21.602	.007
	Knee	Mean	-17.271	24.976	.163	42.248	402.922	501.736	.029
		Std. Dev.	2.208	3.517	.026	2.385	38.339	36.978	.005
Post-bracing	Hip	Mean	5.274	59.369	.307	54.094	185.425	365.968	.066
		Std. Dev.	3.323	2.491	.027	5.236	35.984	26.315	.014
	Knee	Mean	22.563	94.464	.237	71.901	385.817	620.975	.054
		Std. Dev.	3.088	6.339	.043	6.702	42.918	21.713	.008
	Knee	Mean	-18.053	25.253	.172	43.306	402.628	517.310	.029
		Std. Dev.	4.160	1.336	.040	4.496	64.993	44.779	.009
Pre-taping	Hip	Mean	4.231	64.448	.306	60.217	179.785	400.128	.070
		Std. Dev.	1.940	6.911	.016	7.340	44.704	44.120	.011
	Knee	Mean	19.720	95.325	.228	75.605	351.041	653.309	.058
		Std. Dev.	4.960	5.076	.032	9.463	52.691	48.967	.011
	Knee	Mean	-21.973	17.944	.153	39.917	338.001	503.206	.034
		Std. Dev.	4.340	2.828	.044	5.099	29.834	57.552	.006
Post-taping	Hip	Mean	6.540	61.336	.283	54.795	216.348	409.229	.059
		Std. Dev.	.934	3.609	.020	3.655	23.638	17.571	.005
	Knee	Mean	23.732	96.737	.239	73.004	394.689	638.632	.052
		Std. Dev.	2.428	1.710	.026	2.158	49.168	26.878	.005
	Knee	Mean	-17.764	19.856	.170	37.620	396.466	477.386	.025
		Std. Dev.	1.852	1.097	.034	2.586	53.241	23.349	.009

Note: Angle and ROM units are in degrees and time unit is in s.
Velocity unit is deg/s.
The definitions of variables are in Appendix A.

Table E-9. **Means and Standard Deviations of Subject 9 Kinematic Data**

Condition	Joint		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Control	Hip	Mean	12.003	83.925	.582	71.922	231.009	363.352	.057
		Std. Dev.	3.592	5.504	.072	5.593	27.171	25.096	.002
	Knee	Mean	14.604	67.391	.314	52.787	316.172	485.944	.048
		Std. Dev.	2.730	5.362	.180	3.257	32.499	31.504	.004
	Ankle	Mean	-28.857	11.375	.279	40.232	405.961	476.152	.023
		Std. Dev.	.921	1.361	.226	1.148	48.424	39.561	.005
Pre-bracing	Hip	Mean	14.718	71.212	.430	56.494	209.719	324.909	.063
		Std. Dev.	1.470	11.831	.067	11.992	21.925	42.263	.015
	Knee	Mean	20.804	70.714	.211	49.910	309.212	438.186	.056
		Std. Dev.	5.579	8.286	.063	6.501	28.326	58.294	.008
	Ankle	Mean	-22.269	12.289	.265	34.558	395.256	440.805	.019
		Std. Dev.	4.843	4.498	.075	6.523	57.780	60.303	.006
Post-bracing	Hip	Mean	8.956	62.488	.363	53.532	213.163	343.768	.076
		Std. Dev.	2.964	6.422	.037	6.863	7.776	33.364	.005
	Knee	Mean	22.602	78.301	.245	55.699	295.066	428.099	.072
		Std. Dev.	2.323	4.874	.045	3.675	21.496	34.781	.008
	Ankle	Mean	-18.985	17.141	.323	36.126	384.106	457.028	.025
		Std. Dev.	2.941	2.014	.098	1.687	50.020	54.239	.005
Pre-taping	Hip	Mean	11.828	62.696	.341	50.868	202.759	332.121	.064
		Std. Dev.	1.898	7.100	.034	7.576	30.843	36.884	.013
	Knee	Mean	21.894	73.276	.188	51.382	304.216	444.972	.057
		Std. Dev.	2.116	2.577	.014	3.330	37.444	27.356	.014
	Ankle	Mean	-20.437	15.786	.221	36.224	374.166	440.289	.023
		Std. Dev.	2.074	1.391	.061	3.332	27.953	20.689	.004
Post-taping	Hip	Mean	6.933	70.249	.416	63.316	230.302	363.184	.069
		Std. Dev.	3.438	6.144	.063	5.248	24.604	24.053	.004
	Knee	Mean	19.826	73.512	.244	53.686	286.791	431.289	.063
		Std. Dev.	1.398	4.299	.060	4.690	28.200	20.600	.007
	Ankle	Mean	-22.138	14.811	.184	36.950	321.889	417.881	.033
		Std. Dev.	.689	1.397	.072	1.383	24.031	22.326	.003

Note: Angle and ROM units are in degrees and time unit is in s.
Velocity unit is deg/s.
The definitions of variables are in Appendix A.

Table E-10. **Means and Standard Deviations of Subject 10 Kinematic Data**

Condition	Joint		ContAng	Max	Tmax	ROM	ContV	MaxV	TmaxV
Control	Hip	Mean	12.022	75.078	.459	63.056	196.288	323.532	.062
		Std. Dev.	1.218	4.717	.057	4.524	36.345	34.579	.008
	Knee	Mean	25.756	87.524	.474	61.769	330.933	485.413	.049
		Std. Dev.	2.507	5.830	.149	5.415	26.032	38.279	.004
	Ankle	Mean	-21.218	24.045	.160	45.263	453.336	544.529	.026
		Std. Dev.	3.411	3.451	.021	5.147	22.136	16.424	.004
Pre-bracing	Hip	Mean	8.273	61.814	.383	53.542	191.917	357.322	.064
		Std. Dev.	2.114	5.037	.054	4.464	34.490	39.875	.007
	Knee	Mean	24.388	80.853	.196	56.465	331.240	529.548	.052
		Std. Dev.	1.984	5.825	.036	4.874	20.153	31.595	.004
	Ankle	Mean	-17.055	24.439	.173	41.494	422.612	500.858	.025
		Std. Dev.	2.410	2.489	.042	2.626	20.918	39.721	.003
Post-bracing	Hip	Mean	12.095	59.703	.308	47.608	208.567	344.242	.056
		Std. Dev.	3.992	3.067	.027	4.297	42.012	18.965	.010
	Knee	Mean	26.504	82.129	.202	55.625	351.787	511.373	.048
		Std. Dev.	2.598	7.132	.034	5.760	27.595	32.424	.006
	Ankle	Mean	-15.673	23.503	.133	39.175	495.856	547.024	.019
		Std. Dev.	3.907	1.122	.020	3.391	59.298	55.261	.004
Pre-taping	Hip	Mean	16.310	74.241	.397	57.932	252.685	376.453	.052
		Std. Dev.	2.615	2.320	.046	1.426	27.847	23.677	.005
	Knee	Mean	27.200	79.990	.317	52.790	321.420	477.503	.047
		Std. Dev.	4.112	9.944	.200	10.201	30.224	64.289	.005
	Ankle	Mean	-18.699	15.452	.295	34.152	358.228	423.112	.025
		Std. Dev.	1.417	2.430	.193	2.885	21.504	19.729	.006
Post-taping	Hip	Mean	13.432	64.139	.326	50.707	225.269	366.820	.057
		Std. Dev.	2.405	3.167	.042	3.519	49.808	32.453	.012
	Knee	Mean	24.414	78.418	.225	54.004	303.053	491.117	.051
		Std. Dev.	1.997	4.047	.028	5.866	38.627	50.741	.009
	Ankle	Mean	-18.383	20.087	.143	38.470	384.484	481.261	.027
		Std. Dev.	4.747	3.811	.016	6.547	22.311	56.930	.006

Note: Angle and ROM units are in degrees and time unit is in s.
Velocity unit is deg/s.
The definitions of variables are in Appendix A.

Appendix F

Figures

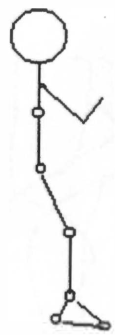

Figure F-1. Reflective Marker Placement

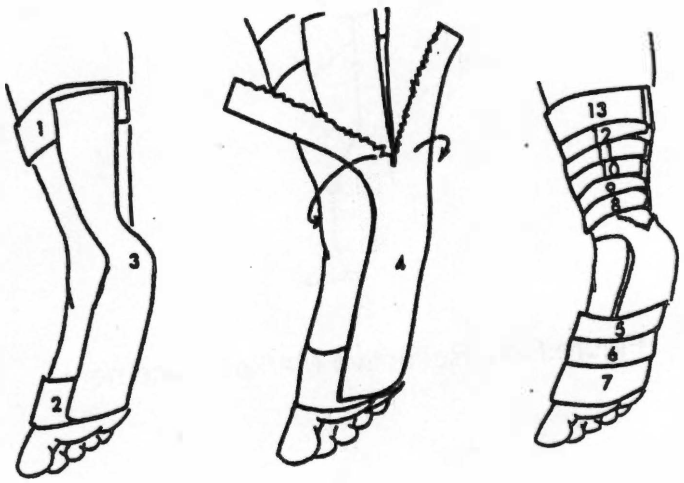

Figure F-2. Illustration of Achilles Tendon Taping

Size	Widest Portion of Ankle Circumference
Small	Below 10.5"
Medium	10.5" – 11.5"
Large	11.5" – 12.5"

Figure F-3. Chart for Determining Cho-pat Brace Size

Figure F-4. Picture of Cho-pat Achilles Tendon Strap

Appendix G

Individual Subject Information

Table G-1. Individual Subject Information

Subject	Age	Body Mass	Height
1	20	72.73	177.80
2	20	68.91	173.99
3	22	56.19	157.48
4	19	58.45	165.10
5	22	62.99	165.10
6	19	58.56	170.18
7	22	76.69	177.80
8	19	52.86	154.94
9	19	80.45	185.42
10	22	51.36	154.94
Mean	20.40	63.9190	168.2750
Std. Deviation	1.43	10.2099	10.5621

Age is in years. Body mass is in kg.
Height in cm.

Vita

Christy Rodenbeck was born in Highlands, NC on November 17, 1977. She attended Highlands School through her high school graduation in 1996. From there, she went to Asbury College in Wilmore, KY and received a B.A. in a Athletic Training and a minor in Biology. In 2000, she began her graduate studies in Exercise Science with a concentration in Sports Medicine and Biomechanics at the University of Tennessee, Knoxville. Upon completion of her thesis, she received the Master of Science degree in Human Performance and Sport Studies in May of 2002.