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3-D Analysis of a Functional Reach Test in Subjects With Functional Ankle Instability

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“3-D ANALYSIS OF A FUNCTIONAL REACH TEST IN SUBJECTS WITH

FUNCTIONAL ANKLE INSTABILITY”

A Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Rehabilitation and Movement Science at Virginia Commonwealth University.

by

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Abstract

3-D ANALYSIS OF A FUNCTIONAL REACH TEST IN SUBJECTS WITH FUNCTIONAL ANKLE INSTABILITY

By Sarah J. de la Motte, PhD

A Dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Rehabilitation and Movement Science at Virginia Commonwealth University.

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Context: 3-D kinematics and kinetics of the lower extremity during the Star Excursion Balance Test (SEBT) have not been examined in FAI subjects. Additionally, the effects of Kinesio® tape use in subjects with functional ankle instability (FAI) during functional tasks is uninvestigated. **Objective:** To determine if lower extremity kinematics and kinetics differed in FAI subjects using Kinesio® tape during maximal SEBT reach. **Subjects:** Twenty subjects with FAI (Age=24.2±3.8yrs; Ht=169±11.6cm; Wt=69±12.4kg) and twenty uninjured subjects (Age=25.7±5.6yrs; Ht=170.1.4±8.8cm; Wt=69.9±10.5kg) with no history of ankle sprain. FAI was operationally defined as repeated episodes of ankle "giving way" and/or ankle "rolling over", regardless of neuromuscular deficits or pathologic laxity. All FAI subjects scored $\leq$ 26 on the Cumberland Ankle Instability Tool. **Methods:** SEBT reaches included the anteromedial, medial, and posteromedial directions. FAI subjects used their unstable side as the stance leg, while control subjects were side-matched to the FAI group. The stance leg ankle was taped using 1) Kinesio® tape and the Kinesio taping method (Kinesio method); 2) white linen tape with the Kinesio method; 3) Kinesio® tape along the distal peroneals tendons (lateral method); 4) white tape with the lateral method. Three-dimensional lower extremity kinematics, kinetics, and force plate data were collected during SEBT performance. A repeated measures ANOVA analyzed the effects of group, tape, tape method, and reach direction on all variables (α=0.05). Tukey HSD post-hoc analyses were performed for significant interactions. **Results:** Normalized reach distance was not significantly different between groups in any direction ($F_{2,76}$=1.16, P=.32). A significant four-way interaction for tape, method, direction, and group ($F_{2,72}$=3.874, P=.03) was found. Post-hoc testing showed FAI subjects exhibited hip abduction while control subjects used hip adduction (Condition 1: .65±8.23° vs. -2.14±8.51°; Condition 2: 1.29±7.71° vs. -1.75±8.29°; Condition 3: 1.08±8.39° vs. -1.88±18.33°; Condition 4: 2.13±7.62° vs. -1.54±6.61°). Additionally, a significant difference in FAI subjects' hip abduction angles between the white tape/Kinesio method (.65±8.23°) and Kinesio tape/Kinesio method (1.08±8.39°) was found. **Conclusions:** These results indicate that FAI subjects' movement strategies

differ from those of uninjured subjects. Furthermore, the use of Kinesio® tape at a distal joint can alter proximal joint movement in subjects with FAI.

INTRODUCTION

Subjects with functional ankle instability have long exhibited balance deficits, as identified by static single or double leg measurements of foot center of pressure(COP) taken from a force plate.[1-4] However, static measures of balance are inherently incapable of adequately representing lower-extremity function for active movements that are commonly problematic in those with FAI.[5-8] Dynamic balance has been suggested as a more appropriate testing method in FAI subjects, as it more closely represents lower extremity function during activity. It does this namely by challenging the subjects' base of support while simultaneously requiring stabilizing movements from the lowest part of the kinetic chain, the foot and ankle, all the way up the entire lower extremity.

The Star Excursion Balance Test (SEBT) is a valid and reliable dynamic balance test that proposes to quantify lower-extremity functional performance in FAI.[8, 9] Subjects' stability limits are constantly challenged as they perform a maximal reach task with one foot in a prescribed direction while attempting to maintain single leg balance on the other leg.[10] Functional performance is quantified as the normalized reach distance in each of a set of prescribed directions. Those who are able to reach further are deemed to have better functional performance.

Rationale for Study of Problem

Based on the theory that damaged joint receptors are, in part, responsible for poor balance and disrupted proprioception in FAI ankles, various studies have investigated influencing this by providing other types of afferent feedback at the ankle and foot, including the application of athletic tape.[11-13] Matsusaka et al.[13] reported that FAI subjects using 2 one centimeter strips of tape over the lateral ankle and foot with ankle disk training were able to achieve postural sway levels comparable to uninjured subjects faster versus an FAI control group. In uninjured subjects, Lohrer[14] found that the proprioceptive amplification ratio was increased after tape application and returned to baseline after tape removal, and Ricard[15] found decreased inversion velocity and time to maximum inversion under taped conditions.

However, results of these studies are disputed,[16] and no distinct mechanism for the demonstrated proprioceptive improvement has been proven. One method that does propose a mechanism for this is Kinesio Tape. Kinesio Tape use has been promoted to improve joint and muscle function through its specific design and application, including in ankle subjects.[13, 14, 17] Yet it has not been thoroughly scientifically investigated and no conclusions can be made about its usefulness. It remains unknown whether proprioception and postural control can be affected by tape use, Kinesio tape or otherwise, or by application method.

Statement of Purpose

Therefore, the purpose of this research study is twofold: 1) to identify particular patterns, or reach strategies, as defined through the below proposed 3-D kinematic and kinetic components, in FAI subjects on the SEBT, and 2) to investigate the effects of tape type and application method on SEBT performance in FAI subjects. Additional information on associated deficits beyond those already identified purely at the ankle may be revealed. Furthermore, the influence of tape and/or tape application method may provide new information on its use as a proprioceptive rehabilitation tool.

Research Questions

A. Specific Aims
    1. Determine the difference between FAI and uninjured subjects on
        a. Maximal reach distance on the Star Excursion Balance Test (SEBT) in 3 reach directions:
            i. Anteromedial
            ii. Medial
            iii. Posteromedial
                1. <u>Hypothesis</u>: FAI subjects will have significantly decreased reach versus uninjured subjects for all 3 reach directions

b. Lower extremity kinetics at maximal reach on the SEBT in 3 reach directions

    i. Center of Mass (COM)

        1. Hypothesis: COM for FAI subjects at maximal reach in all 3 reach directions will be significantly different versus uninjured subjects

    ii. Hip joint torques

        1. Hypothesis: Hip joint torques for FAI subjects at maximal reach in all 3 reach directions will be significantly different versus uninjured subjects

    iii. Knee joint torques

        1. Hypothesis: Knee joint torques for FAI subjects at maximal reach in all 3 reach directions will be significantly different versus uninjured

    iv. Ankle joint torques

        1. Hypothesis: Ankle joint torques for FAI subjects at maximal reach in all 3 reach directions will be significantly different versus uninjured subjects

c. Lower extremity kinematics at maximal reach on the SEBT in 3 reach directions

   i. Trunk movement

      1. Hypothesis: Trunk flexion and lateral flexion for FAI subjects at maximal reach in all 3 reach directions will be significantly different for FAI subjects versus uninjured subjects

   ii. Hip joint angles

      1. Hypothesis: Hip joint angles for FAI subjects at maximal reach in all 3 reach directions will be significantly different versus uninjured subjects

   iii. Knee joint angles

      1. Hypothesis: Knee joint angles for FAI subjects at maximal reach in all 3 reach directions will be significantly different versus uninjured

   iv. Ankle joint angles

      1. Hypothesis: Ankle joint angles for FAI subjects at maximal reach in all 3 reach directions will be significantly different versus uninjured subjects

   v. Foot center of pressure distribution

      1. 95% confidence ellipse – area encompassing 95% of all sway data points

2. Sway velocity

3. Sway pattern

    a. Hypothesis: Foot center of pressure distribution during the performance of the SEBT in the 3 reach directions will be significantly different in FAI subjects versus uninjured

2. Determine the effect of tape on

    a. Maximal reach distance on the SEBT in 3 reach directions

        i. Hypothesis: Subjects will have significantly different maximal reach in all 3 reach directions under the following conditions:

            1. Condition 1: Kinesio Tape

            2. Condition 2: White linen tape

    b. Lower extremity kinetics at maximal reach on the SEBT in 3 reach directions

        i. COM

            1. Hypothesis: COM for Condition 1 will be significantly different from all other conditions in all 3 reach directions

ii. Hip joint torques

1. Hypothesis: Hip joint torques for Condition 1 will be significantly different from all other conditions in all 3 reach directions

iii. Knee joint torques

1. Hypothesis: Knee joint torques for Condition 1 will be significantly different from all other conditions in all 3 reach directions

iv. Ankle joint torques

1. Hypothesis: Ankle joint torques for Condition 1 will be significantly different from all other conditions in all 3 reach directions

c. Lower extremity kinematics at maximal reach on the SEBT in 3 reach directions

i. Trunk movement

1. Hypothesis: Trunk flexion and lateral flexion for Condition 1 will be significantly different from all other conditions in all 3 reach directions

ii. Hip joint angles

1. Hypothesis: Hip joint angles for Condition 1 will be significantly different from all other conditions in all 3 reach directions

iii. Knee joint angles

1. <u>Hypothesis</u>: Knee joint angles for Condition 1 will be significantly different from all other conditions in all 3 reach directions

iv. Ankle joint angles

1. <u>Hypothesis</u>: Ankle joint angles for Condition 1 will be significantly different from all other conditions in all 3 reach directions

v. Foot center of pressure distribution

1. 95% confidence ellipse
2. Sway velocity
3. Sway pattern

a. <u>Hypothesis</u>: Foot center of pressure distribution during the performance of the SEBT in the 3 reach directions will be significantly different for Condition 1 versus all other conditions

3. Determine the effect of taping method on:

a. Maximal reach distance on the SEBT in 3 reach directions

i. Subjects will have significantly different maximal reach in all 3 reach directions using the following methods:

1. Method 1: Kinesio method

2. Method 2: Lateral application method

b. Lower extremity kinetics at maximal reach on the SEBT in 3 reach directions

    i. COM

        1. Hypothesis: COM for Method 1 will be significantly different in all 3 reach directions

    ii. Hip joint torques

        1. Hypothesis: Hip joint torques for Method 1 will be significantly different in all 3 reach directions

    iii. Knee joint torques

        1. Hypothesis: Knee joint torques for Method 1 will be significantly different in all 3 reach directions

    iv. Ankle joint torques

        1. Hypothesis: Ankle joint torques for Method 1 will be significantly different in all 3 reach directions

c. Lower extremity kinematics at maximal reach on the SEBT in 3 reach directions

    i. Trunk movement

        1. Hypothesis: Trunk flexion and lateral flexion for Method 1 will be significantly different in all 3 reach directions

ii. Hip joint angles

1. Hypothesis: Hip joint angles for Method 1 will be significantly different in all 3 reach directions

iii. Knee joint angles

1. Hypothesis: Knee joint angles for Method 1 will be significantly different in all 3 reach directions

iv. Ankle joint angles

1. Hypothesis: Ankle joint angles for Method 1 will be significantly different in all 3 reach directions

v. Foot center of pressure distribution

1. 95% confidence ellipse
2. Sway velocity
3. Sway pattern

a. Hypothesis: Foot center of pressure distribution during the performance of the SEBT in the 3 reach directions will be significantly different for Method 1

Definition of Terms

Independent Variables:

Group

1. Control (uninjured) – No previous history of ankle sprain to either ankle

2. FAI – At least one lateral ankle sprain; repeated episodes of “giving way” and/or “rolling over”

Tape

1. Kinesio Tape – multi-directional elastic tape with specific design
2. White linen tape – non-elastic cloth tape

Tape method

1. Kinesio method
2. Lateral application method

Reach direction (relative to the stance leg)

1. Anteromedial
2. Medial
3. Posteromedial

Dependent Variables

Kinetics

1. Hip joint torques
    a. X – sagittal (flexion/extension) moment
    b. Y – frontal (abduction/adduction) moment
    c. Z – rotation moment
2. Knee joint torques
    a. X - sagittal (flexion/extension) moment
    b. Y – frontal (varus/valgus) moment
    c. Z – rotation moment

3. Ankle joint torques

    a. X – sagittal (dorsiflexion/plantarflexion) moment

    b. Y – frontal (inversion/adduction) moment

    c. Z – rotation moment

Kinematics

1. Body center of mass (COM)

    i. COM X – location in the frontal plane

    ii. COM Y – location in the sagittal plane

    iii. COM Z – location in the transverse plane

2. Foot center of pressure (COP)

    a. 95% confidence ellipse

    b. Sway pattern

        1. COP X – medial/lateral sway

        2. COP Y – anterior/posterior sway

    c. Sway velocity

        1. COP X velocity – velocity in medial/lateral direction

        2. COP Y velocity – velocity in anterior/post direction

3. Trunk movement

    a. Thorax – absolute angles; in relation to lab coordinate system

        1. X – backward tilt

        2. Y – lateral tilt

        3. Z - rotation

b. Spine – in relation to pelvis

    1. X – forward thorax tilt

    2. Y – thorax tilt

    3. Z – thorax rotation

c. Pelvis – absolute angles; in relation to lab coordinate system

    1. X – anterior tilt

    2. Y – upward obliquity

    3. Z - rotation

4. Hip joint angles – relative angles; in relation to pelvis

    a. X - Flexion/Extension

    b. Y – Abduction/Adduction

    c. Z - Internal rotation/External rotation

5. Knee joint angles – relative angles; between thigh & tibia

    a. X - Flexion/Extension

    b. Y - Varus/Valgus

    c. Z - Internal rotation/External rotation

6. Ankle joint angles – relative angles; between tibia & foot

    a. X - Plantarflexion/Dorsiflexion

    b. Y - Inversion/Adduction

    c. Z – Internal rotation/External rotation

Limitations

The most limiting factor of this study is the use of self-reported ankle instability. However, an attempt was made to verify injury status (i.e. functional ankle instability) and quantify and qualify disability through the use of the CAIT and FADI-Sport questionnaires. There is some error associated with 3-D motion analysis, but care was taken to ensure proper subject set-up and equipment calibration prior to data collection. Because this was not a prospective study, it is impossible to determine if any differences were present before the onset of functional instability, or are a result of it.

REVIEW OF LITERATURE

Epidemiology of Lateral Ankle Sprains

The ankle is among the most commonly injured sites of the human body.[18-20] Lateral ankle sprains in particular are most frequently incurred, accounting for over 75% of all injuries to the ankle.[18, 21, 22] It is estimated that one ankle sprain occurs for every 10,000 people in the United States, or over 30,000 sprains per day, and it does not distinguish between genders.[19, 21, 23-25] With sporting activity, ankle sprains account for up to 30-40% of all injuries, with the incidence in some sports even higher.[18, 20, 24, 26]

Lateral ankle sprains typically occur when the ankle is forced into combined plantarflexion and inversion, as is common with cutting or twisting motions, upon landing from a height, or stepping on an unstable surface. These mechanisms can cause a stretching or tearing of the lateral ankle ligaments, resulting in a sprain.[24, 27] The lateral ankle ligaments typically injured with this mechanism include the anterior talofibular ligament (ATF), calcaneofibular ligament (CF), and posterior talofibular ligament (PTF). The ATF is structurally the weakest of the three, and is usually the first ligament damaged during a sprain, followed by the CF, and lastly the PTF. It has been estimated by some reports that 30% of patients suffer an isolated rupture of the ATF, while an additional 20% have a combined ATF and CF rupture.[28]

Prevalence/incidence of functional ankle instability after sprain

What at the time may seem at the time like a relatively minor injury can indeed have long lasting major sequelae, including pain, swelling, and instability.[21, 22, 29-32] Conservative estimates show that 10-20% of those who sustain an initial lateral ankle sprain will develop recurrent injuries and/or instability,[21, 33, 34] while some authors claim this number up to be closer to 30-40%.[24, 29, 32, 35] One study even reported that 70% high school basketball players had a history of previous sprain, and 80% of these sustained multiple episodes.[36]

What may seem even more surprising is that these alarmingly high rates appear to occur regardless of the treatment received.[22, 23, 30, 32, 35, 37-39] While most mild to moderate sprains appear to do relatively well with non-operative conservative treatment,[35, 36, 40] Verhagen et al.[32] make the argument that there is no such thing as a "simple" ankle sprain. Their retrospective study of 577 ankle sprain patients showed that even six and a half years later, a surgically repaired Grade III ankle sprain has approximately the same prognosis as a more conservatively treated Grade I sprain. A seven year follow-up by Konradsen[31] showed that 32% of 648 subjects complained of continuing problems with their ankle.

Mechanical versus functional instability

Once a person has sustained an ankle sprain, they are more than likely to continue experiencing recurrent problems.[22, 29, 41, 42] In the ankle literature, instability has been classified as mechanical (involving general ligamentous laxity due to the initial sprain), or functional (described as a general sense of the ankle "giving way"). However, even this distinction has been confusing.

Many authors have highlighted the point that there does not appear to be an absolute association between MI and FI.[22, 43] Rather, mechanical and functional instabilities overlap, but are certainly neither mutually inclusive nor exclusive. MI been classically defined as anatomical disruption of the lateral ligaments, whether demonstrated on an anterior drawer test, or talar tilt.[23, 27, 28, 39, 41, 44] Functional instability however, appears to be incorporate more of a broad range of characteristics, not all of which, must be present to classify a person as suffering from FI. Some authors report recurrent sprains as means for classifying a patient with instability.[27, 39] Yet still others rely on the definition of instability as being the subjective sensation of the ankle "giving way", or being more susceptible to sprain.[22, 29] It is not uncommon for both to be used as inclusion criteria.

The "giving way" definition of functional instability was first described by Freeman et al.,[22] who was also the first to suggest that this functional instability was not necessarily caused by the classic mechanical instability. After a one-year follow-up of 62 lateral ankle sprains, half treated surgically and half non-surgically, Freeman[29] reported a total of 39% of patients subjectively complained of functional instability. Objectively however, only 22.5% of patients were classified as mechanically unstable, as demonstrated on stress x-ray (talar tilt 6 degrees or more versus the uninjured side). Of those subjects with mechanical instability, less than half (42.8%) complained of also suffering from functional instability, regardless of whether or not they had received surgical repair of the lateral ligaments.[29] Sixty-four percent of surgical patients continued to describe functional instability one year after repair. Of those treated conservatively (either strapping and mobilization, or immobilization), the incidence of FI was lower (42.8%). These results point to the conclusion that FI can still be present even in the absence of MI.

In a study conducted on 444 soccer players, a total of 29% of players had functional instability in one or both ankles. Of these players complaining of FI, only 42% also had MI, as demonstrated on an anterior drawer test. Only 36% of those with MI complained of FI. Lastly, MI was also present in some players who did not report having FI, constituting 16% of this subject population.[43] Evans[27] declared that symptoms of late functional instability could not necessarily be due to talar instability, as only 5.8% of FI patients demonstrated an increased talar tilt. Boisen[28] demonstrated interestingly that patients with abnormal findings on physical examination outnumbered patients with subjective symptoms two to one. Thus, the mechanical and function instabilities can occur simultaneously but neither appears to be a predictor of the other.

Hertel[45] described the individual symptoms of functional ankle instability (including mechanical instability) as not occurring in isolation, but rather as components of an "intercorrelated pathoetiologic paradigm". Tropp[46] presented a more distinct separation between MI and FI, elaborating on Freeman's original concept of "giving way" using the following definitions: mechanical instability equals ankle movement beyond the physiological limit of the ankle's range of motion, or "laxity". Functional instability was described as the subjective feeling of ankle instability or recurrent, symptomatic ankle sprains (or both) due to proprioceptive and neuromuscular deficits. Wilkerson[47] commended Tropp's definitions of these two conditions as recognizing that dynamic neuromuscular function, both reflexive and voluntary, as the clearest basis for the distinction between FI and MI.

Functional ankle instability inclusion criteria

Functional instability of the ankle has been described as being comprised of numerous contributing factors, including mechanical, muscular, and sensorimotor.[45] While this may be helpful for identifying functional instability as a syndrome, it lends itself to numerous problems as well. The definition of functional instability in the ankle literature varies greatly. In addition, the inclusion criteria for FI tend to vary from study to study, which makes comparisons amongst study outcomes extremely difficult.

MI has rather clearly been defined as anatomical disruption of the lateral ligaments, whether demonstrated on an anterior drawer test, or talar tilt,[23, 27, 28, 38, 39, 41, 44] no such clear cut distinction has been drawn for FI. Freeman's original concept of functional instability has evolved over the years to incorporate a broad spectrum of notable deficits, but still relies heavily on the subjective reports of "giving way".[22] Yet, there have been no requirements established as far as how often "giving way" must occur, how long disability must be present, how injuries incurred, among other factors.

In a review on factors contributing to ankle instability, Konradsen[48] points out that only distinction for qualifying a symptom of "give way" appears to be that these episodes must be experienced in situations where those with normally stable ankles would not incur problems. He describes dividing functional ankle stability into two major theoretical entities. First, the ability to avoid situation of forced inversion past the physiological limit; and second, when the ankle is in this compromising situation of inversion torque, the ability to prevent unstable situation from progressing to injury by counteracting sufficiently quickly and powerfully enough. He argues that this should not include subjects who repeatedly sprain their ankles during high risk sports participation.

Articular damage and nerve injury in functional ankle instability

It has been shown that the articular cartilage of the ankle may be damaged with lateral ankle sprains.[49-51] Taga[49] reports figures as high as 89% of acute ankle sprain patients demonstrated articular cartilage damage, while an astounding 95% of patients with chronic sprains showed damage upon arthroscopic examination. Hintermann[51] displays a lower incidence of damage in 66% of subjects with lateral sprains, while Takao[50] reports an even more conservative figure of 25%. Subjects in both studies were described as chronic, with symptoms lasting 2 months or longer.

In addition to articular damage, injury to the nerves of the lower leg may also play a part in functional ankle instability.[52-55] Injury to the common peroneal nerve in particular has been demonstrated in lateral ankle sprain patients, as it may be stretched with the inversion sprain mechanism. It has been suggested that the traction placed on the nerves during the spraining mechanism is enough to cause axon disruption, accounting for the disrupted nerve supply to the musculature, as demonstrated with decreased nerve conduction velocity.[54] One study reported mild to moderate peroneal nerve denervation in up to 86% of patients with a Grade III sprain (consisting of lateral ligament, deltoid, and anterior tibiofibular ligament damage), with a further 83% also demonstrating tibial nerve denervation. The incidence was much lower in subjects with less severe sprains (10-17% for tibial and peroneal nerves respectively).[54]

Kleinrensink et al.[53] showed lowered nerve conduction velocity of the peroneal nerve up to 8 days following a lateral ankle sprain. This was significantly different compared with a control group, though not when compared with the contralateral leg. The injured extremity appeared to return to normal, as there was no significant difference five weeks post injury. While the nerve conduction velocity appeared to return, this decreased axonal supply to the lateral ankle musculature is one argument behind the reason for disrupted proprioception and balance at the ankle, leading to symptoms of functional ankle instability. It is unknown how long it takes for these axons to heal, if at all.[54]

Ankle strength and functional ankle instability

One component of ankle instability that has been disputed in the relationship of ankle muscular strength to functional ankle instability. The musculature surrounding the ankle is responsible for controlling the movements of the ankle, including inversion, eversion, dorsiflexion, and plantarflexion. The peroneals in particular, are responsible for providing support for the lateral ankle ligaments.[45] However, there is no consensus on whether or not strength is related functional ankle instability. It has been hypothesized that these muscles suffer trauma during the inversion sprain mechanism, and may tend to become weaker following a sprain.[29, 56]

When strength of the ankle musculature has been manually assessed, weakness of the peroneals has been demonstrated.[28, 57] But manual testing may lead to an underestimation of the frequency and severity of muscle strength.[58] Thus, the more objective method of isokinetic assessment has been used to determine possible ankle strength differences in functional ankle instability. Still, even this method has resulted in conflicting reports.

Isokinetic strength assessment involves numerous testing methods of different types of muscle contractions at varying speeds in various testing positions. These differences continue to grow in the literature, as more reports are published. This may account for differing results. When isokinetically tested, a deficit in invertor strength deficits appears to be present in FAI subjects, both concentrically,[59, 60] and eccentrically.[61] However, numerous studies have found no difference with either type of contraction.[56, 62-64]

Varying results have been reported for evertor strength deficits as well. No difference has been demonstrated for concentric evertor strength,[56, 59, 62] while two studies have shown a deficit.[60, 64] Eccentric eversion strength does not appear be significantly affected with FAI,[61] though these findings are disputed.[64] However, the deficit in inversion, as well as pronation may be of consequence during the recovery strategy at the ankle with an inversion sprain mechanism.[65]

Balance deficits in functional ankle instability

Balance deficits have been found in subjects with functional ankle instability.[22, 43, 56, 66-69] Methods of measuring balance have evolved over the years, from the modified Romberg test,[22] to the adaptation of stabilometry,[3] to most recently, more functional measures such as the Star Excursion Balance Test (SEBT),[70] and Time to Stabilization (TTS).[71]

Subjectively, measures such as the modified Romberg and the Balance Error Scoring System (BESS) have been used to identify balance deficits, both with the eyes open and eyes closed. The modified Romberg test, a form of single leg balance test, was used by Freeman to compare the "stability" of the injured FAI ankle to the opposite uninjured ankle, and found subjects with FAI performed subjectively worse when compared with their other ankle.[22] He suggested that the demonstrated proprioceptive deficit resulted from a disruption in the afferent signal from the injured mechanoreceptors in the lateral ankle ligaments, and thus contributed to their symptoms of functional instability. Lentell[56] also used modified Romberg and over half of subjects demonstrated a deficit. However, this deficit did not appear to be a causative factor in all patients, as 30% of subjects complaining of FAI did not demonstrate a balance deficit.

Another subjective testing method, the Balance Error Scoring System (BESS), has been shown to highlight balance deficit in FAI ankles.[72] Commonly used as a pre- and post-concussion assessment tool, the test consists of 20 second single and double leg balance tasks on the ground and on a labile foam pad with the eyes closed, while examiners count the number of balance errors per task. Balance deficits in subjects with FAI were shown in 3 of 6 conditions, as well as overall BESS score.[72] Similar to this, Jerosch[73] used a single leg stance condition with a soft surface, and was also able to highlight significant balance deficits in injured subjects when compared with a control group.

Because of the extremely subjective nature of tests like the modified Romberg, and BESS, more objective measures of balance have been sought. One of these, stabilometry, uses a piezoelectric force plate to measure the center of pressure of the foot during single leg balance. With stabilometry, postural sway differences in functionally unstable subjects have been demonstrated when compared with the uninjured ankle, and when compared with a control group.[6, 43, 67, 74, 75]

A common concern in the literature on FAI and balance deficits is the argument that static balance measures (modified Romberg, stabilometry) are not indicative of true balance deficits because they are not "functional".[70] In other words, standing on a single leg is not provocative enough to tax the proprioceptive system that is called upon for enforcing ankle stabilization during movement. Therefore, more functional measures of assessing dynamic balance have been developed in order to attempt to address this concern. Dynamic measures of balance that have been used in FAI studies include the Chattex Balance System,[59] the Star Excursion Balance Test (SEBT),[10, 68, 70] and Time to Stabilization (TTS).[76] All have shown to have some ability to detect balance deficits in functionally unstable ankle patients.

The goal of the SEBT is to reach as far as possible with one leg in one of eight directions of the SEBT grid (8 lines at 45 degree angles to each other) while remaining as balanced as possible on the other leg. Reach distance is then marked by an examiner, measured from the center of the grid and is normalized to the subject's height. This test is argued to be more functional because it imposes more demands on the subjects' center of mass and corrective balance strategy.[70] Reach deficits on the SEBT have been shown in functionally unstable subjects, who were found to reach less versus their contralateral uninjured limb, as well as versus a control group.[5, 10, 68] Olmsted et al.,[10] who describe significantly decreased reach in FAI subjects when compared with the matched limb of the control group. However, Olmsted et al. did not normalize reach distance to limb length, nor did she report if the FAI and control groups were significantly different in height. Because those with longer legs are able to naturally reach further, normalizing reach distance is necessary in order to standardize the effect of a subject's height on their ability to reach.[77]

Time to Stabilization is another measure which has been purported to be more "functional" in terms of determining balance deficits. The outcome measure includes a two-legged vertical jump with a single leg landing onto a force plate. Subjects are instructed to "stick the landing" and remain as motionless as possible for 20 seconds while force plate data is recorded. The actual time to stabilization is ultimately mathematically derived from this data to determine the time elapsed until the signal mirrors that of a normal single leg balance task.[74] This method has been useful in determining that those with functionally unstable ankles take longer to stabilize when compared with a control group. This could prove clinically useful in monitoring unstable patients landing strategies, and therefore potentially be used to prevent further injury.[71, 74]

Despite the existence of numerous static and dynamic balance measurements, a recent meta-analysis by our group has shown that all measures of balance are able to detect differences in FAI subjects. Furthermore, these differences indicate that balance is decreased, concluding that universally, FAI subjects do indeed tend to demonstrate poorer balance. These results were not influence by study subject inclusion or exclusion criteria, such as sense of giving way, mechanical instability, or degree of initial sprain.[78]

The role of neuromuscular response in ankle instability

Though strength may or may not to be affected in those with functional ankle instability, the active role of the muscular defense system of the FAI ankle may possibly be linked to the disorder. Afferent information at the ankle appears to come from multiple sources, as mechanoreceptors have been found not only in lateral ankle ligaments, but also the capsule, retinaculum, and tendons surrounding the ankle.[79-83] The reaction of the ankle complex to a sudden inversion mechanism appears to be mediated by the muscle/tendon receptor system, and has been termed “neuromuscular response”.

Neuromuscular response of the ankle muscles has been studied using electromyography. In functional ankle instability, research has primarily been concerned with the response time of the peroneal muscles to a sudden inversion mechanism, which has been likened to the lateral ankle sprain mechanism. Here, the motor latency is divided into short, medium, and long loop latencies. Medium latency is most often reported, and is measured from the time of the start of the trap door mechanism (whether in to supination or inversion) until the onset of EMG activity.[84] The neuromuscular response includes motor latency, electromechanical delay, total reflex time, and motor reaction time. Electromechanical delay (EMD) is measured with a voluntary contraction, and here, is defined as the time lapse between the onset of EMG of the peroneus longus and the change of muscle force as initiated at actual motor response (start of the eversion movement of the foot).[85] The appearance of the actual movement of the ankle/foot is defined as the motor response, which is calculated by adding the electromechanical delay to the peroneal latency.

In uninjured subjects, the median peroneal reflex latency to sudden inversion has been shown to be around 48ms.[86] EMD is approximately 72ms.[86] However, it takes an average of 40-80ms for the platform to complete it's inversion movement, depending on the study. It does not seem possible that the peroneals have adequate time to establish an active response in order to protect the lateral structures, as the first substantial eversion countering torque has not been seen until 150ms.[87] Yet, what may be more important though, is how efficiently the appropriate muscles are able to counteract inversion.

Konradsen and Ravn[86] describe these occurrences in terms of peripheral versus central reaction mechanisms during a sudden inversion mechanism. They describe the motor latency of the peroneals as the time for a peripherally mediated reaction time to take place. The time from the motor response to the first response in the thigh musculature is designated as the time for central processing of the afferent input. They were able to demonstrate a prolonged peripheral reaction time in unstable subjects, while the central reaction time was no different.

The first EMG response of the peroneals after a sudden inversion has been shown to be between 49-90 milliseconds (ms).[88] Reports have demonstrated that unstable ankles showed shorter total supination time during platform movement of 50 degrees. Also, unstable subjects displayed a longer latency time.[85, 89] Together, these two factors seem to indicate less efficient deceleration of supination, which could translate to less protection in the unstable subjects through muscle contraction of evertors during the final phase of the supination. Other studies have also reported significant differences in peroneal reaction times of the unstable subjects,[84, 86, 89, 90] while others have demonstrated no difference.[1, 85, 91-93] These differences may be attributed to varying degrees of inversion (30-50 degrees), different recording equipment, and different signal processing methods.

A central disturbance of afferent information from an injured ankle has not demonstrated, though a peripheral disturbance appears to be present. These two facts together seem to substantiate the theory of proprioceptive deafferentation as being one of the possible mechanisms at play in functional ankle instability.

Proprioceptive/perceptual deficits and functional instability

Proprioception has been shown to be affected with functional ankle instability. Proprioception has classically been defined as the sensations related to movement and body awareness. The primary mechanism for proprioceptive deficits in FAI patients appears to be a disruption of afferent information from a broad range of mechanoreceptors present in the peripheral structures of the ankle, such as the capsule, musculotendinous, and cutaneous structures that may also be damaged with a lateral ankle sprain.[80, 82] Since these peripheral mechanoreceptors also contribute their afferent information to the central nervous system for regulation of proprioception, there may be less afferent information available to contribute to proprioception if they are damaged. This appears to account for certain deficits seen in subjects with functional ankle instability. For example a total block of afferent information from ankle and foot was performed, passive joint reposition sense was greatly affected. This leads to the assumption that afferent information regarding ankle positioning is contained within an area close to the ankle joint.[2]

Due to the suspected loss of proprioceptive input from mechanoreceptors, improper foot positioning, and therefore increased risk of inversion injury may result.[56, 86, 94, 95] Proprioception in functional ankle instability has been measured numerous ways, from joint movement sense,[96] joint position sense,[97, 98] joint reposition sense,[64, 98-104] threshold to detection,[105-108] and force sense.[109, 110] Some have been indicative of a disruption,[73, 102] while others have not.[111, 112]

Joint position sense is one of the most reported outcomes measures in FAI and proprioception. It is thought to be mediated by the muscle spindles, which are responsible for the awareness of the position of the limb, as anesthetization of the lateral ankle ligaments shows no significant reposition deficit.[2, 112] However, what some authors report as joint position sense, is actually joint re-position sense. This measure involves numerous methods, which may account for its reported outcome inconsistencies. It typically consists of movement of the ankle joint from a starting angle into a pre-defined point in the range of motion. The ankle is then returned to the starting angle before the subject is asked to return to the pre-defined point. The ankle may either be actively or passively moved in to plantarflexion, dorsiflexion, inversion, eversion, and either actively or passively repositioned.

While a wide variety of testing methods and angles have been used, so have a wide variety of error calculation methods. Among those reported are exact error (the exact difference in degrees from the pre-determined angle to the subject's reproduction); absolute error (the absolute value of the exact error); and variable error (the standard deviation of exact error, which shows the random error).

Glencross[95] reports that injured subjects showed the largest error on joint reposition sense at the largest angles of plantarflexion motion, up to 140 degrees. Because of the theorized damage to mechanoreceptors, they conclude fewer cells are available to provide information for sensing proper position at dangerous end ranges of motion to avoid injury, thus accounting for symptoms of FAI.

When it comes to movement detection, differences between injured and uninjured subjects have also been shown in the detection of ankle movement in to inversion,[106, 108] and eversion[108] Though the clinical relevance of these deficits is questionable, it can be argued that because of the deficit, the ankle could move further into eversion or inversion before this motion is detected, giving less time for the protective mechanism to act.[108]

While muscle spindles are responsible for the awareness of limb position, the Golgi tendon organs are responsible for sensing force in the musculotendinous structures, and may also be injured with a lateral ankle sprain. If, with lateral ankle sprains, the afferent information from the muscle spindles is disrupted, and the ability to sense the force needed as monitored by the GTOs is disrupted, the ability to produce a proper force to maintain or counteract a contraction may result in an increased “risk” for functional ankle instability. Force sense has been studied as a means to detect such deficits.[110, 113] A significant association between force sense and instability and variable error has been reported. When FAI subjects were asked to reproduce forces of 10 and 30% of their maximum eversion peak force, they exhibited greater variability between trials, showing less consistency with repetitive tasks.[66] This inconsistency may provide support for Konradsen’s theory that ankle sprains in FAI subjects occur not every step, but rather every 10,000 steps, accounting for the broad spectrum of patient problems.[31, 94]

Alteration at other joints/structures with functional ankle instability

Research has shown that other areas of the lower extremity may also be affected in subjects with functional ankle instability. It is noted that subjects react to a sudden inversion mechanism with ankle dorsiflexion, knee flexion, hip flexion, and hip adduction.[114] These motions serve to attempt to keep the subject's center of mass from falling outside the base of support in order to remain upright. However, when there is a disruption of afferent information from the injured ankle, these subjects must compensate in order to prevent falling over.

The same type of pattern appears to also be present in those presenting with mechanical instability. In a study on 10 mechanically unstable patients subjected to a sudden inversion mechanism, it was revealed that subjects generally exhibited shorter gluteus medius activation. This decrease in activation was most pronounced on the ipsilateral side after ipsilateral inversion. However, no differences in peroneal latencies were revealed, indicating that subjects with mechanically unstable ankles were compensating by prematurely recruiting hip muscles when compared with the healthy subjects. Additionally, unstable subjects contracted their contralateral gluteus medius before the ipsilateral (side of inversion). These factors combined could be indicative of an attempt to compensate in more proximal joints for disturbed proprioception in the mechanically unstable ankle.[91]

Research has also shown altered proximal kinematic strategies are present in subjects with functional instability. In addition to increased ground reaction forces acting on the injured ankle upon landing from a height,[115] Caulfield et al.[116] have been able to demonstrate that functionally unstable ankle subjects exhibit significantly greater dorsiflexion in the ankle during the early pre-landing phase to the early post-landing phase when compared with uninjured subjects. They were able to show that these subjects also exhibited significantly greater knee flexion in the later pre-landing to later post-landing phase. Due to the timing of these actions in the pre-landing phase, these actions appear to be occurring as a response to a pre-set landing pattern, instead of in response to the landing itself. The authors argue that this altered kinematic pattern in injured subjects could possibly reflect a learned adaptive landing strategy as a result of their previous injury. This is also important for the clinician to recognize in order to properly guide rehabilitation of these injuries.

METHODS

Research Design

The design of this study was case-control, with all subjects getting all treatments.

Subjects

Twenty subjects with unilateral functional ankle instability (FAI), and twenty uninjured subjects with no history of ankle injury were recruited for participation in this study. Functional ankle instability was operationally defined as repeated episodes of ankle “giving way” and/or ankle “rolling over”, regardless of the existence of neuromuscular deficits or pathologic laxity.[10] All subjects were required to be physically active, defined as a minimum of 3 hours per week of activity that required energy expenditure by skeletal muscles, and free of lower extremity injuries within the past month.

To determine eligibility, all subjects completed a medical history questionnaire pertaining to previous history of lower extremity injuries and incidence of ankle giving way (Appendix A). Additionally, all subjects recorded answers on two ankle instability questionnaires: 1) Cumberland Ankle Instability Tool (Appendix B), used to classify subjects as functionally unstable; and 2) the Functional Ankle and Disability Index, Sport (Appendix C), used to quantify FAI. Subjects were required to be free of cerebral concussions, vestibular disorders, upper respiratory infection, or ear infection at the time of study. All subjects read and signed an informed consent form before participation.

Instrumentation

A three dimensional optical motion capture system with accompanying Bertec force plates and software (Vicon Nexus, Version 1.3.109) were used for data collection (Vicon Motion Systems, Centennial, CO).

System Calibration

The Vicon system cameras were calibrated before data collection began on each subject. First, calibration masks were created for the twelve optical cameras in order to mask out unwanted reflections in the capture space that may have interfered with maker identification. Next, a calibration wand was carried throughout the collection space, with each camera set to capture 100 initial frames and 4000 refinement frames for calibration, and the volume origin was set. Lastly, the force plates were powered and zeroed.

Data Processing

Data were processed and filtered using Plug-in Gait modeling [117] through the Vicon Nexus software. Plug-in Gait uses a defined marker set and subject measurements in order to create kinematic and kinetic outputs. The subject's fixed anatomical measurements were entered in to the system, from which static parameters for each body segment were calculated. More specifically, rigid body segments are defined and joint angles created on a three-dimensional frame-by-frame basis. Masses and moments of inertia then applied to the subject's segments, resulting in frame-by-frame three-dimensional dynamic kinematic and kinetic outputs.[117] All torques defined were external torques. No additional filters were applied to the data.

Missing marker data (gaps) were spline-filled with the Vicon software on a frame-by-frame basis. Maximum reach was identified on each data file by tracing the Z-trajectory of the toe marker of the reach foot to its lowest point during reach. An event marker was placed in the data file for each reach and kinematic and kinetic values were pulled for these individual frames. A customized MATLAB program was used to average these values and create means used for analysis.

Procedures

SEBT

The Star Excursion Balance Test grid for this study consisted of the anteromedial, medial, and posteromedial directions, relative to the stance leg (Figure 1). These three directions have been shown to be representative of the larger 8 direction SEBT grid, and sensitive in detecting function performance differences in FAI subjects.[68] Reach lines were marked out on the testing surface, each at a 45 degree angle, and intersecting in the center. This intersection denoted the starting position for each reach.

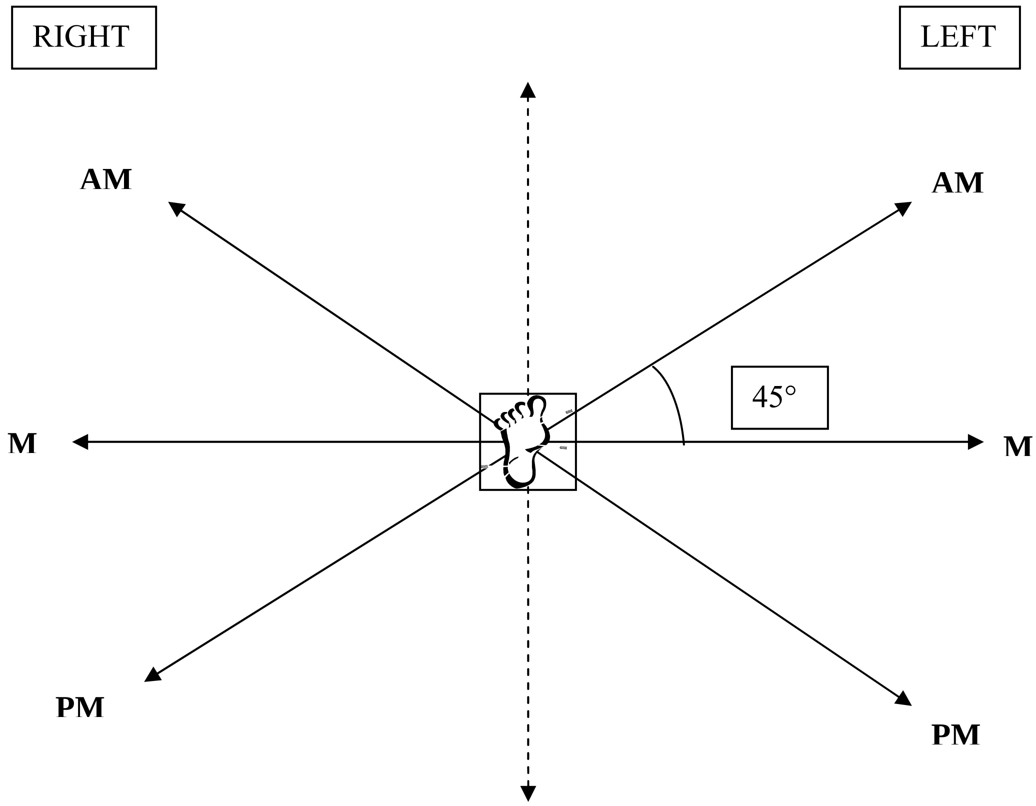

Figure 1. Star Excursion Balance Test Grid.

Counter-Balancing

Before testing began, subjects drew a pre-counterbalanced card to determine the order of SEBT reach direction and taping condition, which was then discarded.

Taping Conditions

Taping conditions consist of 1) Kinesio Tape applied using the Kinesio Method; 2) Kinesio Tape applied laterally along the peroneal tendons; 3) 1.5 inch white linen tape applied using the Kinesio Method (Figure 2); and 4) 1.5 inch white linen tape applied laterally along the peroneal tendons. The Kinesio Method was applied as follows: 1) Sixteen inch strip of tape placed from the anterior midfoot, stretched approximately to 115-120% of its maximal length (Kinesio tape only) and attached just below the anterior tibial tuberosity over the tibialis anterior muscle; 2) Sixteen inch strip beginning just above the medial malleolus, wrapped around the heel like a stirrup, attaching just lateral to the first strip of tape; 3) Four inch strip stretched across the anterior ankle, covering both the medial and lateral malleolus; 4) Twelve inch strip originating at the arch, stretched slightly, 4-6 inches above both the medial and lateral malleolus.[118]

Subject set-up

First, anatomical measurements were taken, and consisted of the following: height (in mm), weight (kg), ankle width, ASIS-trochanter distance, knee width, inter-ASIS distance, leg length, elbow width, hand thickness, shoulder offset, and wrist width, which were required for running the 3-D analysis Plug-in Gait specifications.

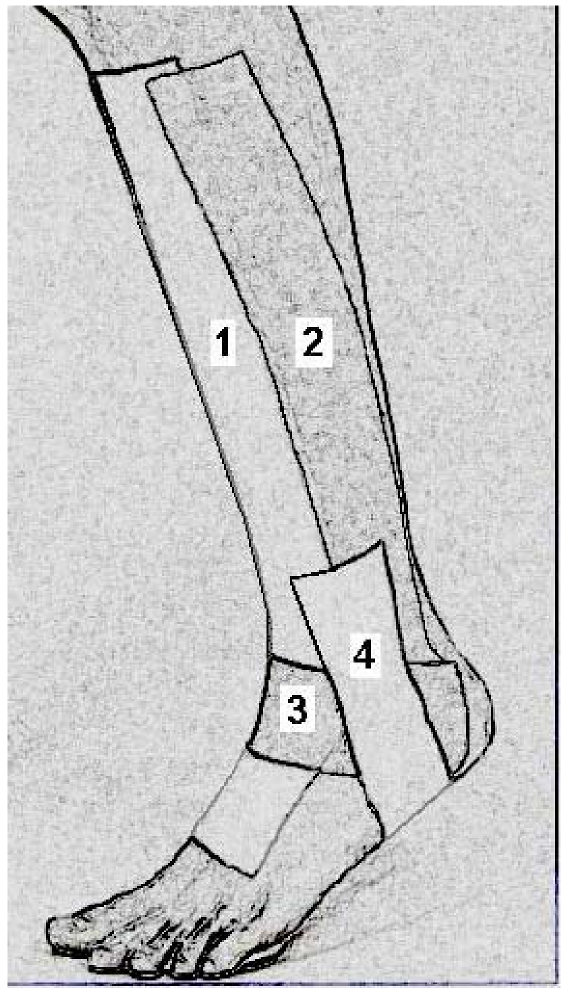

Figure 2. Kinesio Taping Method
(reprinted from Halseth et al).[118]

Additionally, leg length for each subject was measured in centimeters in supine from the anterior superior iliac spine distally to the medial malleolus, and was used to normalize SEBT reach distance.

Thirty-five three-dimensional reflective markers were attached to the subject at the following locations: 1) right front head; 2) left front head; 3) right back head; 4) left back head; 5) spinous process of the seventh cervical vertebrae; 6) spinous process of the tenth thoracic vertebrae; 7) sternum; 8) clavicle; 9) right back; 10) left acromioclavicular joint; 11) right acromioclavicular joint; 12) right elbow; 13) left elbow; 14) left wrist, ulnar side; 15) left wrist, radial side; 16)left hand, dorsal side; 17) right wrist, ulnar side; 18) right wrist, radial side; 19) right hand, dorsal side; 20) right PSIS; 21) left PSIS; 22) right ASIS; 23) left ASIS; 24) left thigh; 25) right thigh; 26) left knee, lateral joint line; 27) right knee, lateral joint line; 28) left lateral tibia; 29) right lateral tibia; 30) left lateral malleolus; 31) right lateral malleolus; 32) left heel; 33) right heel; 34) left metatarsals; 35) right metatarsals (see Figures 3 & 4). For the shank and foot makers, an outline of the marker was drawn on the subject's skin with a permanent marker.

Per protocol, a static trial was collected with the subject in a "T-pose", in order to record the real location of the subject's markers. The static trial was processed and the markers were manually labeled in the software in order to identify the 3D reconstructions, which were then specific to the subject. The reconstructed subject model was verified by the examiner and ensured that the subjects' movement mimicked the computer model before testing commenced.

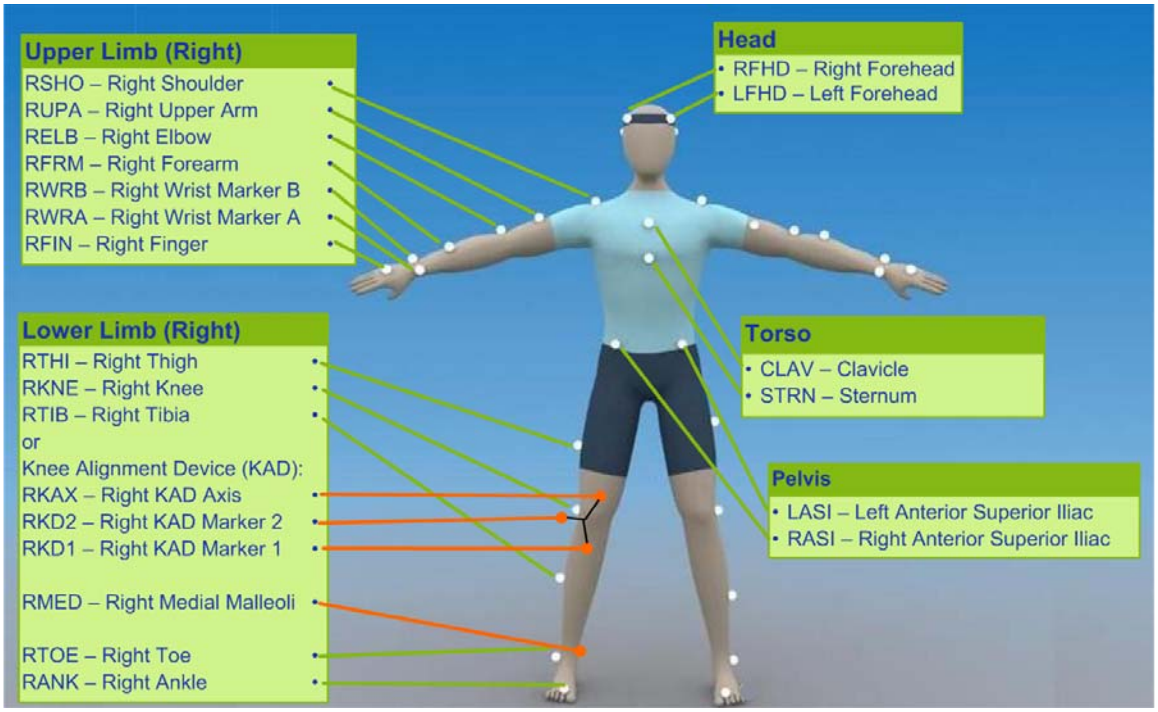

Figure 3. Anterior View of Subject Marker Placement. Note: No Knee Alignment Device was used (reprinted from Plug-in Gait Product Guide[117]).

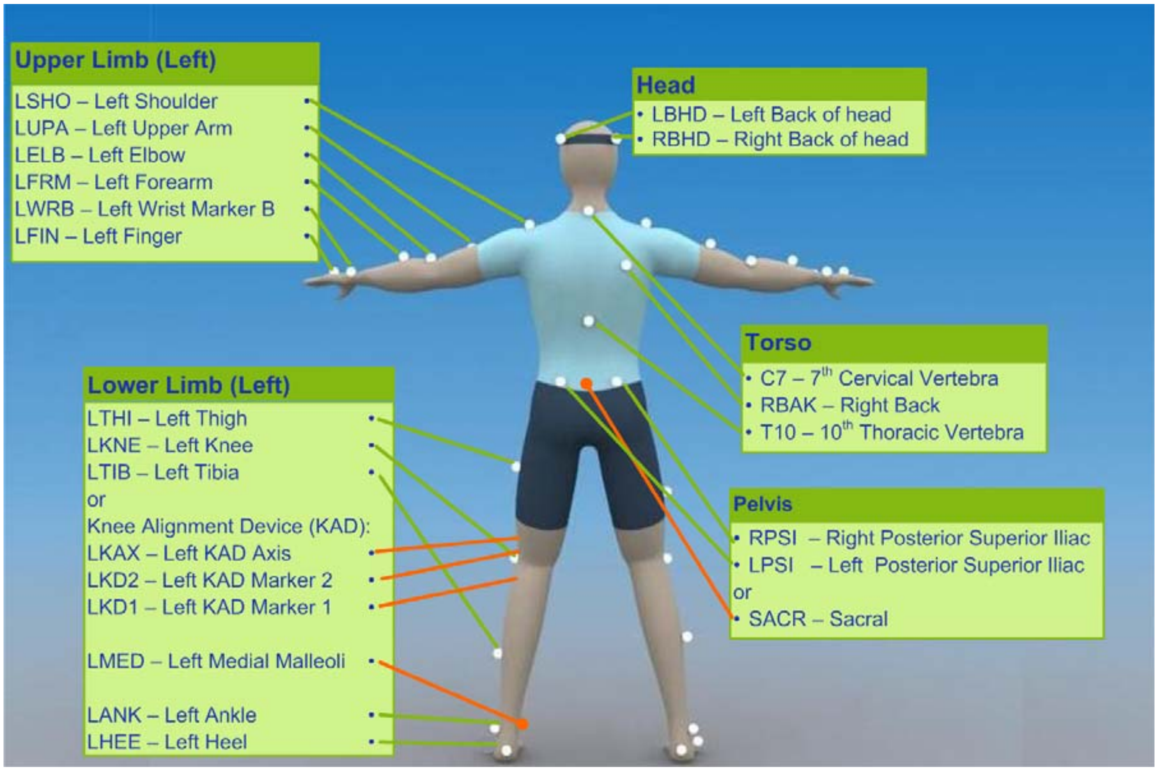

Figure 4. Posterior View of Subject Marker Placement. Note: No Knee Alignment Device was used (reprinted from Plug-in Gait Product Guide[117]).

Reach performance

A verbal and visual demonstration of the testing procedure was given by the examiner. Subjects were asked to perform six practice trials in each of the three testing directions in order to become familiar with the task.[119] SEBT reach consisted of subjects maintaining a single leg-balance on their test leg, while reaching as far as they could in the designated direction, keeping both hands on the hips. At the point of maximal reach, subjects were instructed to lightly touch down with the most distal part of the reach foot before returning to a bilateral stance at the start position.

Subjects had tape applied to the test ankle in the order previously determined. In the case that the tape interfered with the tibial, lateral malleolus, or heel markers, care was taken to lift the marker, apply the tape, and replace the marker to the marker outline on the skin. Once the tape and markers were secure, subjects completed additional practice trials in all three directions. Subjects began reach testing as instructed by the examiner, completing six good reach trials in the pre-determined order of directions before switching to the next tape condition.

An examiner recorded each reach distance from the center of the grid along the appropriate reach vector for each reach for each condition. Trials were discarded and repeated if the subject 1) lost his or her balance at any point during the trial; 2) did not touch the foot down on the reach line; 3) lifted a hand off the hips; or 4) placed a significant amount of weight on the reach foot so as to support the body by widening the base of support. Control subjects performed testing twice, once on each leg, and were side matched with FAI subjects, who completed testing on their unstable ankle side only. In the case that more than one ankle of the FAI subjects was unstable, the more subjectively unstable side was tested.

Subjective Taping Questionnaire

After all testing conditions had been performed subjects completed a questionnaire regarding their feelings about the tape's effect during testing. Using a 10-point Likert scale, subjects were asked to compare each taping condition to the no tape condition for four subjective aspects: performance ability, comfort, ankle stability, and confidence. Higher scores indicated more favorable ratings (Appendix 4).

Statistical Methods

Separate 2 x 2 x 2 x 3 Repeated Measures ANOVA were used to investigate the effects of FAI (injured, control), Tape (Kinesio, white linen tape), Tape Method (Kinesio method, lateral method), and Reach Direction (anteromedial, medial, posteromedial) on maximal reach distance and lower extremity kinetics, kinematics, and force plate measures during SEBT reach. Separate 2 x 4 oneway ANOVAs were used to look for a group effect (FAI, control) for the four tape/method combinations for each subjective area of the taping questionnaire.

RESULTS

Subjects

Forty subjects (FAI N=20, control N=20) completed all testing conditions. The force plate data for one subject was not included for analysis due to a disrupted data file. However, kinematic data was unaffected and was included. Additionally, a few trials were lost during data collection and processing, resulting in the discrepancies in the degrees of freedom for the reported F-ratios. Force plate data was corrupt for one FAI subject. However, kinetic data for this subject was unaffected for every tape condition and reach direction except the Kinesio tape/Kinesio method trial in the anteromedial reach direction. No kinetic data were available for this condition/direction combination. A further force plate data file was corrupt, though this resulted in the loss of force plate data for an additional FAI subject for the white tape/lateral method condition in the medial direction only.

Mean scores for subject and group characteristics are reported in Table 1. A one-way ANOVA indicated no differences in age ($F = 1$, $P = .33$), height ($F = .14$, $P = .72$), or mass ($F = .05$, $P = .83$) between groups. The one-way ANOVA revealed a significant difference between groups for both the CAIT ($F = 61.23$, $P < .05$) and FADI Sport ($F = 8.33$, $P = .01$). FAI subjects averaged 18.84±5.65 out of a possible 30 points on the Cumberland Ankle Instability Tool, with 30 indicating no ankle instability. Control subjects averaged 29.05±1.43 points. Hiller et al.[120] previously identified a

Table 1. Subject Characteristics

Group	Gender	Age (years)		Height (mm)		Mass (kg)		CAIT score		FADI-S score	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Control	Male (7)	24.57	5.56	1789.57	65.07	78.29	6.10	29.14	1.57	97	6.66
	Female (13)	26.23	5.73	1653.92	55.00	65.37	9.64	29.00	1.41	99.28	2.60
	Total (20)	25.65	5.58	1701.4	87.49	69.89	10.51	*29.05	1.43	*98.48	4.42
FAI	Male (7)	24.00	5.48	1806.29	97.46	87.14	11.48	21.50	6.47	89.06	13.66
	Female (13)	24.23	2.89	1626.62	64.79	59.15	7.58	17.62	5.03	90.39	12.33
	Total (20)	24.15	3.84	1689.5	115.68	68.95	16.29	*18.84	5.65	*89.97	12.39

cut-off score equal to 26 or lower to classify subjects as functionally unstable. All injured subjects and none of the control subjects met this criterion. FAI subjects averaged 89.97±12.39% on the FADI Sport, which quantified FAI as a percentage of full function (100% equals no function impairment), while control subjects averaged 98.48±4.42%. Lower scores indicated more instability. These results are similar to those reported by Brown et al.[121]

Reach Distance

Means and standard deviations for reach distance can be found in Tables 2-4. The repeated measures ANOVA for reach direction showed a significant interaction between method and tape ($F_{1,38} = 4.765$, $P = .04$). No post-hoc testing was significant. No main effects or other interactions were present (Appendices 5-6).

Kinetics

The results for the kinetic variables tested with the repeated measures ANOVAs are presented in Appendices 7-8.

Hip Flexion/Extension Torque (Hip Moment X)

There was a significant main effect for direction ($F_{2,72} = 38.249$, $P < .0005$) and method ($F_{1,37} = 8.984$, $P = .005$), with the Kinesio method condition significantly decreasing hip flexion torque than the lateral method . A significant four-way tape x method x direction x group interaction was also present ($F_{2,72} = 3.255$, $P = .04$)(Figures 5-7)(Tables 5-7). Tukey's post-hoc analysis showed significantly higher torque in FAI

Table 2. Normalized reach distance (% leg length) in the anteromedial direction.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Control	81.21±7.67	81.71±7.67	81.90±6.31	81.23±6.95
FAI	82.73±9.06	83.39±9.41	83.69±9.01	83.33±9.00

Table 3. Normalized reach distance (% leg length) in the medial direction.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Control	83.25±9.71	83.60±9.88	84.39±8.80	84.16±8.68
FAI	85.96±10.08	87.21±10.19	88.13±9.92	87.80±9.75

Table 4. Normalized reach distance (% leg length) in the posteromedial direction.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Control	85.90±11.34	86.07±11.45	86.95±11.38	85.84±10.97
FAI	88.06±11.01	89.75±11.35	90.82±11.03	90.07±11.28

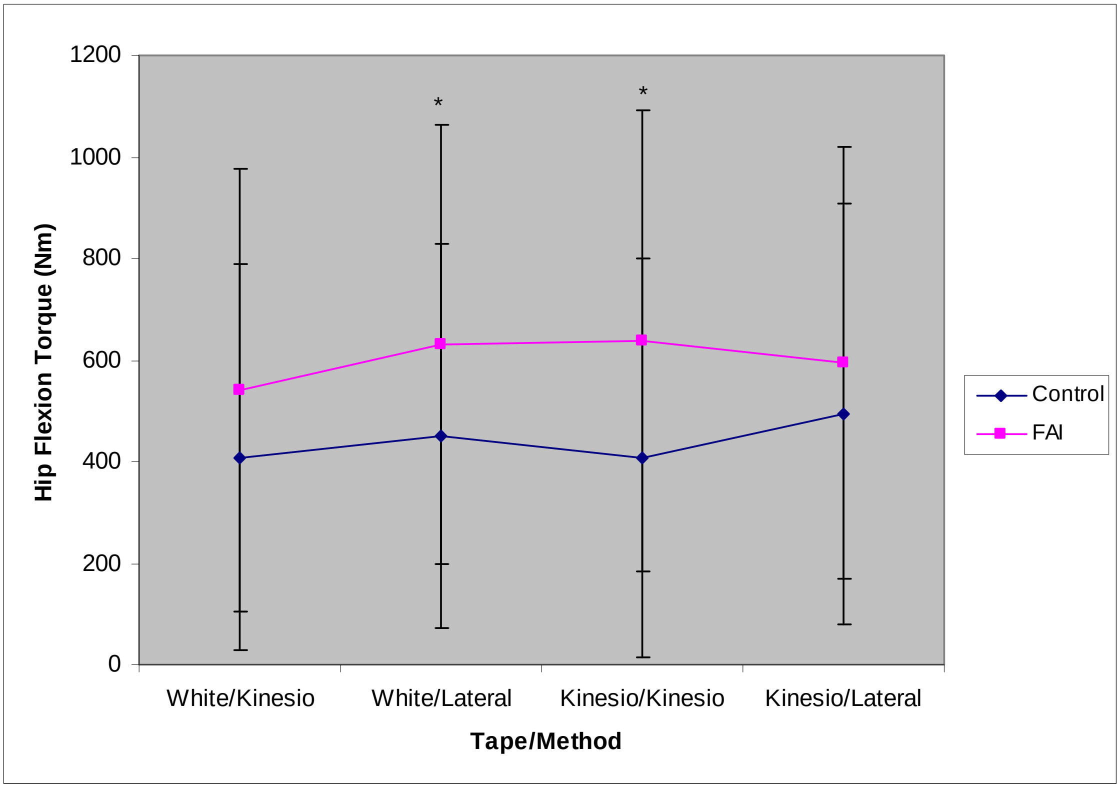

Figure 5. Tape-by-direction-by-method-by-group interaction for hip flexion torque (Nm) at maximal reach in the anteromedial direction of the Star Excursion Balance Test. *Indicates a significant difference between groups.

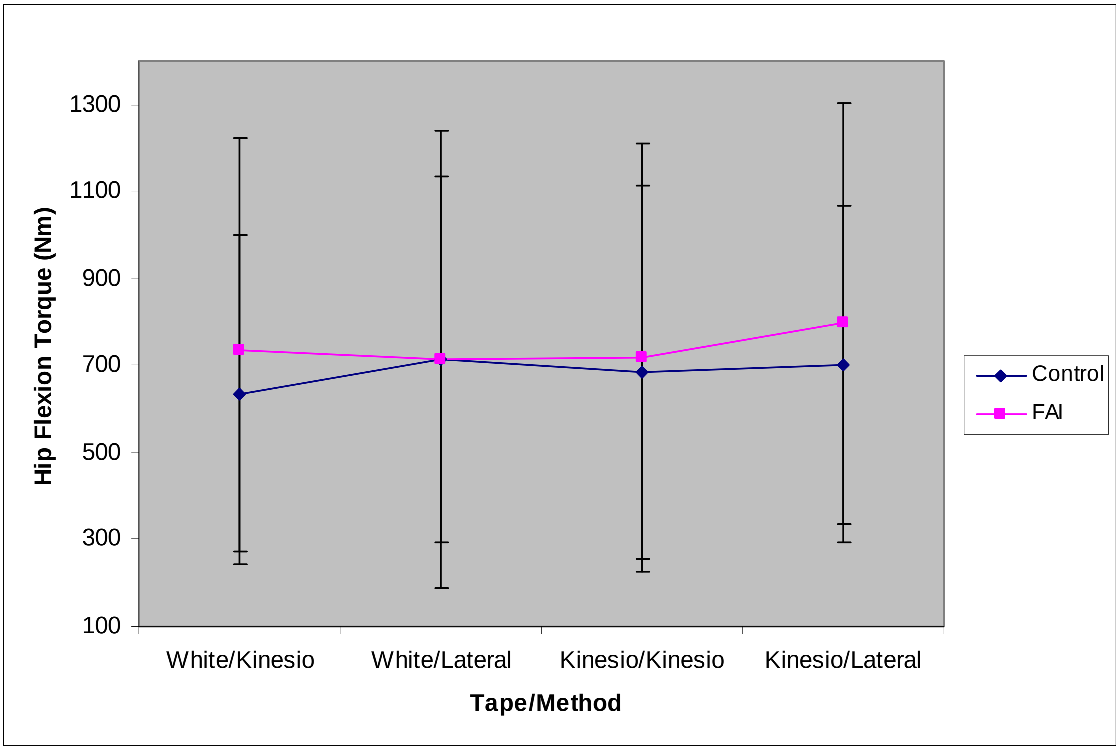

Figure 6. Tape-by-direction-by-method-by-group interaction for hip flexion torque (Nm) at maximal reach in the medial direction of the Star Excursion Balance Test.

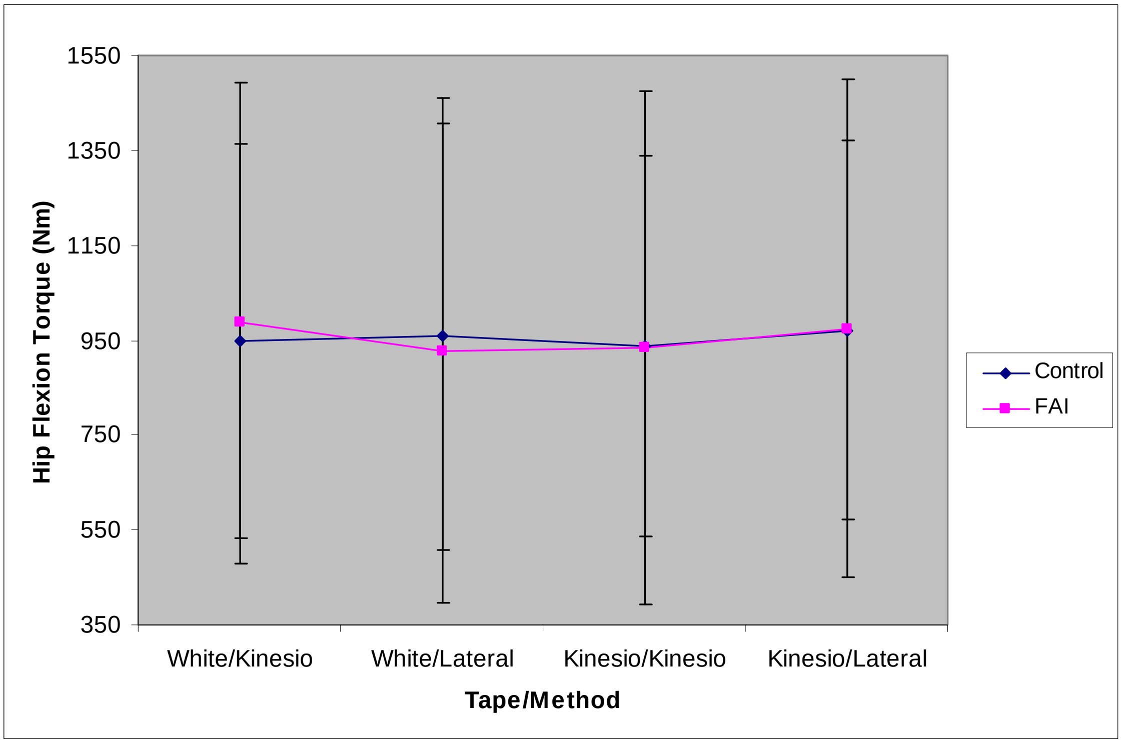

Figure 7. Tape-by-direction-by-method-by-group interaction for hip flexion torque (Nm) at maximal reach in the posteromedial direction of the Star Excursion Balance Test.

Table 5. Tape-by-direction-by-method-by-group interaction for hip flexion torque (Nm) at maximal reach in the anteromedial direction of the Star Excursion Balance Test.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Control	408.45±435.98	451.46±432.76	406.47±452.72	493.34±425.78
FAI	542.15±379.13	631.40±378.35*	637.45±392.40*	594.04±413.46

*Indicates a significant difference between groups.

Table 6. Tape-by-direction-by-method-by-group interaction for hip flexion torque (Nm) at maximal reach in the medial direction of the Star Excursion Balance Test.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Control	635.46±363.82	713.22±421.11	685.08±430.79	701.63±367.18
FAI	734.05±491.20	715.44±525.95	716.97±491.74	797.75±505.70

Table 7. Tape-by-direction-by-method-by-group interaction for hip flexion torque (Nm) at maximal reach in the posteromedial direction of the Star Excursion Balance Test.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Control	949.19±415.19	958.66±449.75	937.75±400.62	971.24±400.84
FAI	985.86±406.49	928.17±531.71	934.24±541.38	974.78±524.09

than control subjects with the white tape/lateral method (Tukey's HSD -5.76) and the Kinesio tape/Kinesio method (Tukey's HSD -7.39) conditions with anteromedial reach.

Hip Abduction/Adduction Torque (Hip Moment Y)

The results of the repeated measures ANOVA for hip abduction torque revealed a significant main effect for direction ($F_{2,72} = 43.998$, $P < .0005$), and a significant interaction between tape and method ($F_{1,38} = 5.65$, $P=.02$)(Figure 8)(Table 8). No post-hoc testing was significant.

Hip Internal/External Torque (Hip Moment Z)

The results of the repeated measures ANOVA for hip abduction torque revealed a significant main effect for direction ($F_{2,72} = 31.443$, $P < .0005$). No other main effects or interactions were present.

Knee Flexion Torque (Knee Moment X)

The results of the repeated measures ANOVA for knee flexion torque showed a significant main effect for direction ($F_{2,72} = 4.056$, $P = .02$), and a significant interaction for tape by direction ($F_{2,72} = 5.833$, $P = .004$)(Figure 9)(Table 9), and significant three-way interaction for tape by method by direction ($F_{2,72} = 3.65$, $P = .03$)(Figure 10)(Table 10). No post-hoc testing was significant.

Knee Valgus Torque (Knee Moment Y)

The results of the repeated measures ANOVA for knee abduction torque showed a significant main effect for method ($F_{1,37} = 37.695$, $P < .0005$), and direction ($F_{2,72} = 33.096$, $P < .0005$).

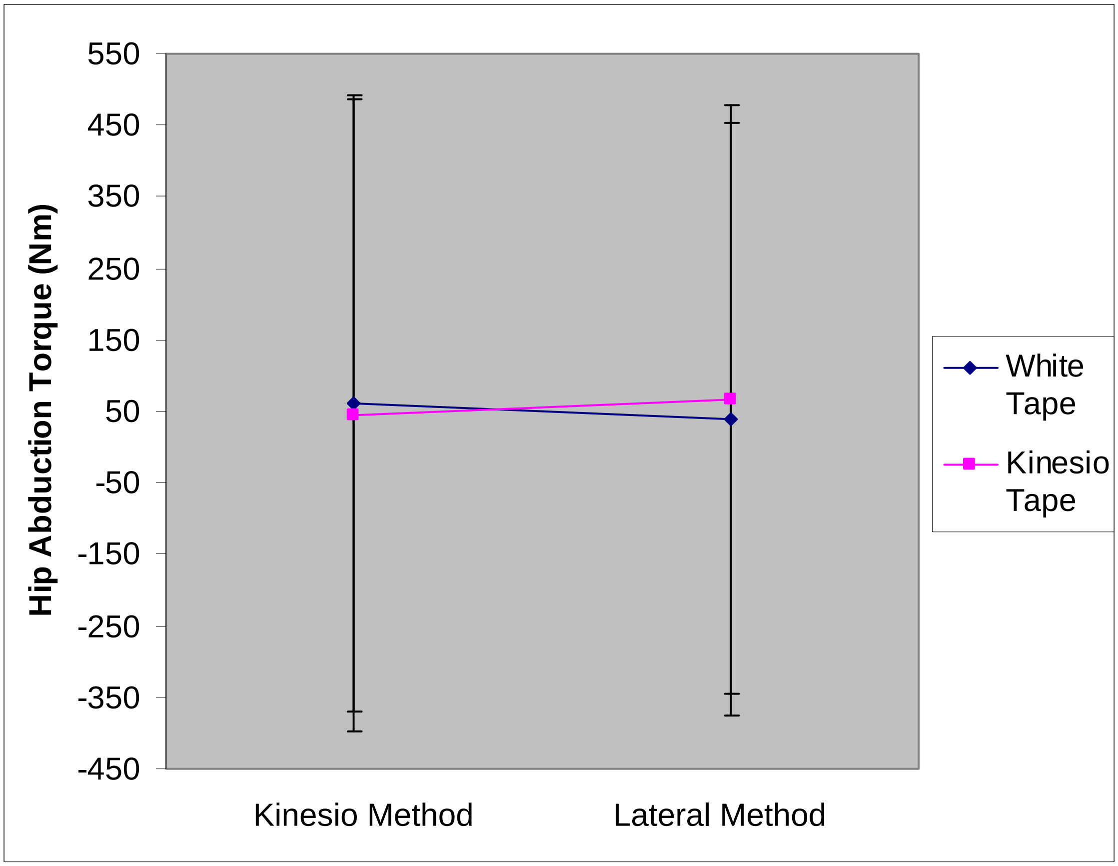

Figure 8. Tape-by-method interaction for hip abduction torque (Nm) at maximal reach on the Star Excursion Balance Test.

Table 8. Tape-by-method interaction for hip abduction torque (Nm) at maximal reach on the Star Excursion Balance Test.

	White Tape	Kinesio Tape
Kinesio Method	60.74±431.09	39.01±441.98
Lateral Method	43.22±414.14	65.96±411.19

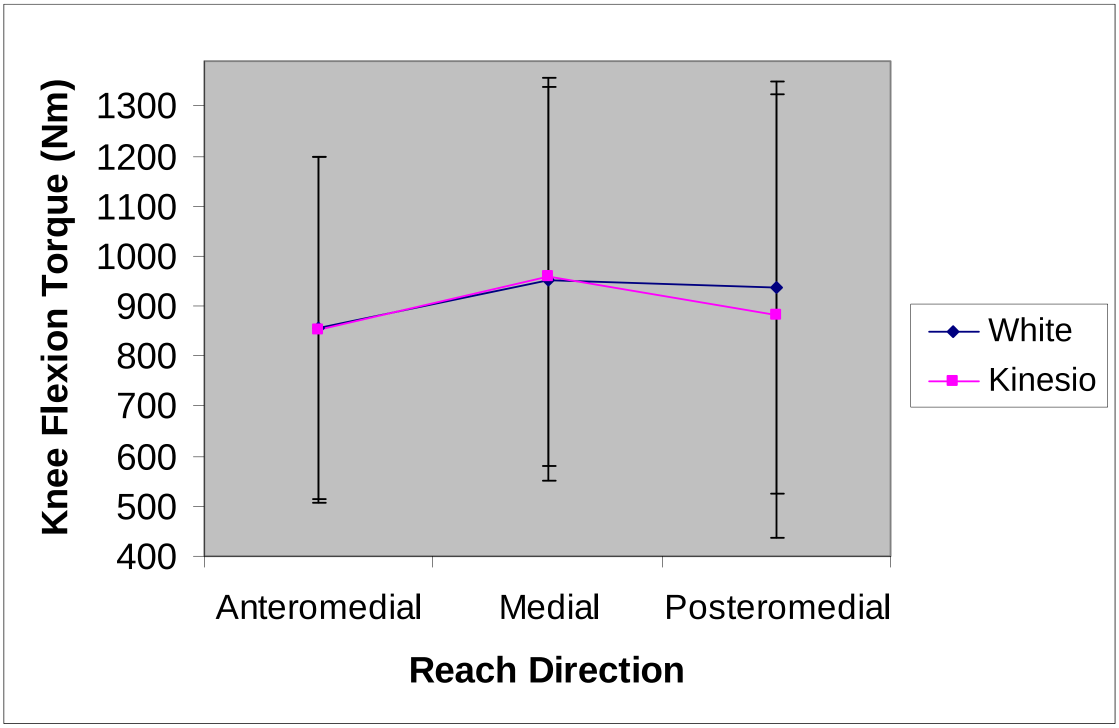

Figure 9. Tape-by-direction interaction for knee flexion torque (Nm) at maximal reach on the Star Excursion Balance Test.

Table 9. Tape-by-direction interaction for knee flexion torque (Nm) at maximal reach on the Star Excursion Balance Test.

	White Tape	Kinesio Tape
Anteromedial Reach	857.06±341.77	852.35±346.56
Medial Reach	953.23±402.25	959.93±378.64
Posteromedial Reach	937.34±412.07	880.31±442.18

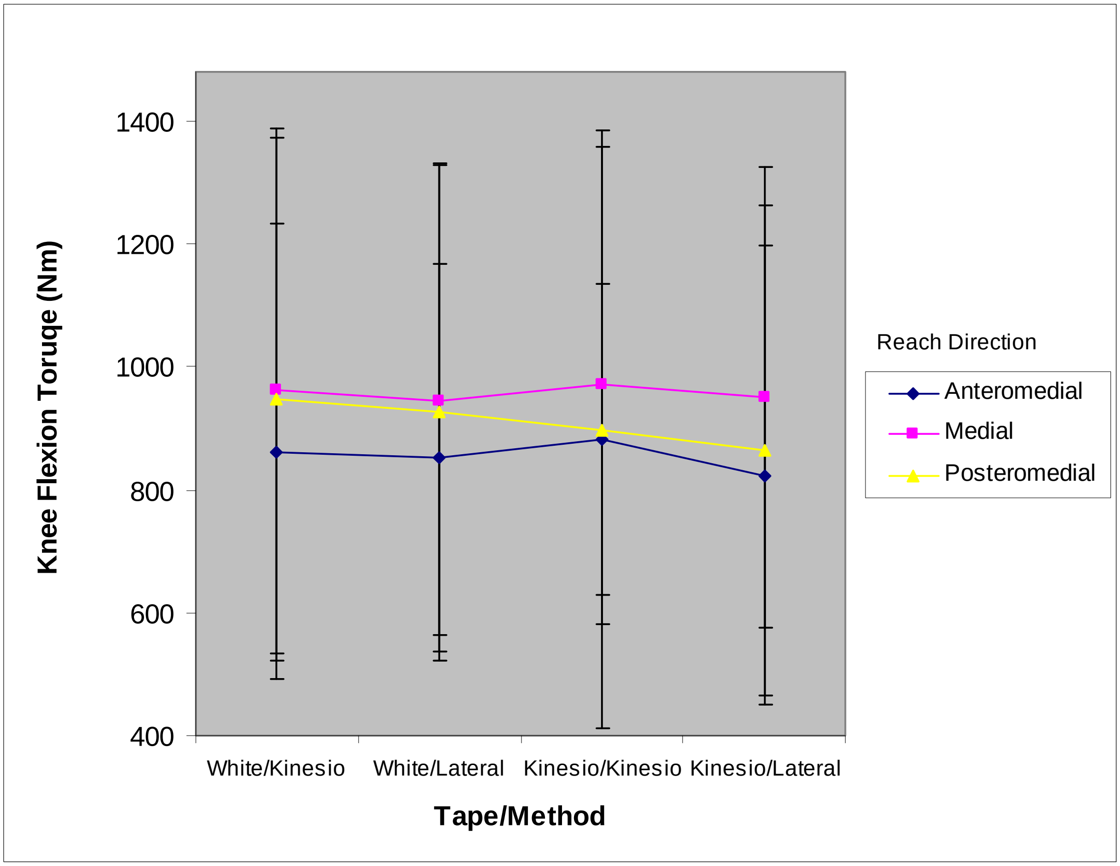

Figure 10. Tape-by-method-by-direction interaction for knee flexion torque (Nm) at maximal reach on the Star Excursion Balance Test.

Table 10. Tape-by-method-by-direction interaction for knee flexion torque (Nm) at maximal reach on the Star Excursion Balance Test.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Anteromedial Reach	862.07±370.18	852.04±315.47	881.80±253.37	823.64±372.50
Medial Reach	961.19±425.89	945.26±382.41	969.82±386.90	950.05±374.86
Posteromedial Reach	947.98±424.63	926.70±404.25	897.31±486.61	863.31±398.34

Knee Rotation Torque (Knee Moment Z)

The results of the repeated measures ANOVA for knee rotation torque showed a significant main effect for direction ($F_{2,72} = 13.832$, $P < .0005$), and a significant interaction between direction and group ($F_{2,72} = 3.646$, $P = .03$)(Figure 11)(Table 11). No post-hoc testing was significant.

Ankle Dorsiflexion Torque (Ankle Moment X)

The results of the repeated measures ANOVA for ankle dorsiflexion torque revealed a significant main effect for tape ($F_{1,36} = 10.364$, $P = .003$), method ($F_{1,37} = 54.391$, $P < .0005$), and direction ($F_{2,72} = 277.679$, $P < .0005$). A significant interaction between tape, method, and direction was also present ($F_{2,72} = 3.946$, $P = .02$). No post-hoc testing of interest was significant.

Ankle Inversion Torque (Ankle Moment Y)

The results of the repeated measures ANOVA for ankle inversion torque revealed a significant main effect for method ($F_{2,72} = 6.342$, $P = .02$), and direction ($F_{2,72} = 12.669$, $P = .016$), as well as an interaction between method and direction ($F_{2,72} = 3.057$, $P = .05$). No post-hoc testing of interest was significant.

Ankle Internal Rotation Torque (Ankle Moment Z)

The results of the repeated measures ANOVA for ankle rotation torque showed a significant main effect for method ($F_{1,37} = 14.391$, $P = .001$) and direction ($F_{2,72} = 34.638$, $P < .0005$), and an interaction between method and direction ($F_{2,72} = 11.456$, $P < .0005$). A direction by group interaction ($F_{2,72} = 3.81$, $P = .03$) was also present, with Tukey HSD post-hoc testing revealing that FAI subjects exhibited significantly lower

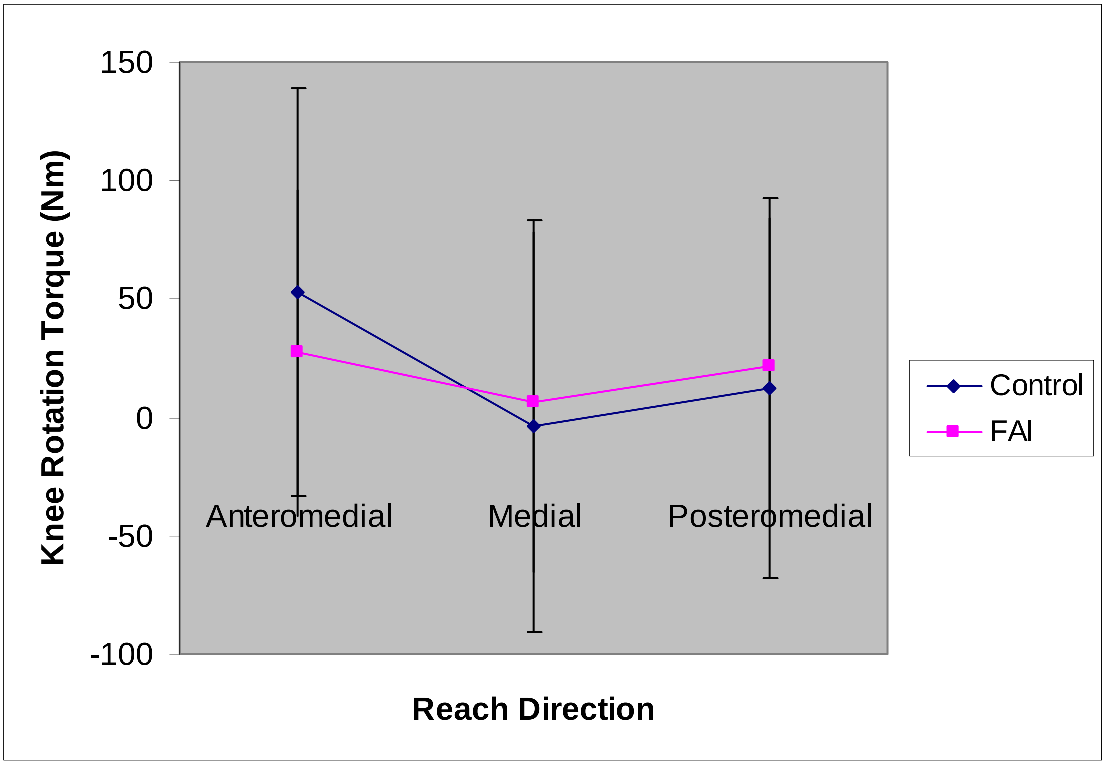

Figure 11. Direction-by-group interaction for knee rotation torque (Nm) at maximal reach on the Star Excursion Balance Test. Negative values indicate external rotation torque.

Table 11. Direction-by-group interaction for knee rotation torque (Nm) at maximal reach on the Star Excursion Balance Test. Negative values indicate external rotation torque..

	Anteromedial Reach	Medial Reach	Posteromedial Reach
Control	53.26±86.13	-3.61 ±87.23	12.11±80.20
FAI	27.36±68.82	6.41±71.93	21.49±62.50

ankle rotation torque in the anteromedial reach direction than control subjects (Figure 12)(Table 12).

Kinematics

Results from the Repeated Measures ANOVA for Kinematic Variables are presented in Appendices 9 and 10.

Center of Mass – Sagittal Plane (COM X)

The results of the repeated measures ANOVA for sagittal plane center of mass showed no significant main effects and no significant interactions.

Center of Mass – Frontal Plane (COM Y)

The results of the repeated measures ANOVA for frontal plane center of mass showed a significant main effect for direction ($F_{2,72} = 38.73$, $P < .0005$). No other main effects or interactions were present.

Center of Mass – Transverse Plane (COM Z)

The results of the repeated measures ANOVA for transverse plane center of mass showed a significant main effect for direction ($F_{2,72} = 38.64$, $P < .0005$). No other main effects or interactions were present.

Spine Flexion/Extension Angles (Spine X)

The results of the repeated measures ANOVA for spinal flexion showed a main effect for method ($F_{1,37} = 4.215$, $P = .05$) and direction ($F_{2,72} = 163.19$, $P < .0005$), as well as a significant interaction for method, direction, and group ($F_{2,72} = 3.084$, $P = .05$). Tukey post-hoc testing revealed a FAI subjects using the Kinesio method during reach

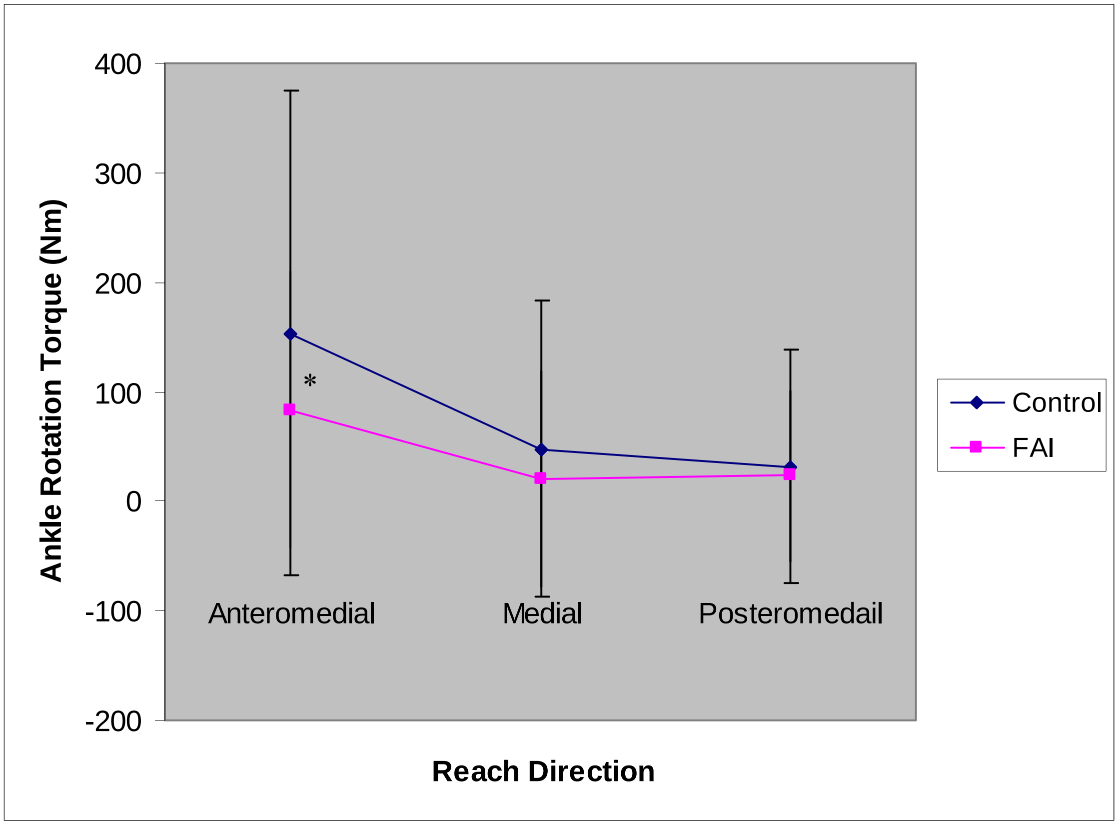

Figure 12. Direction-by-group interaction for ankle rotation torque (Nm) at maximal reach on the Star Excursion Balance Test. Negative values indicate external rotation torque. *Indicates a significant difference between groups.

Table 12. Direction-by-group interaction for ankle rotation torque (Nm) at maximal reach on the Star Excursion Balance Test.

	Anteromedial Reach	Medial Reach	Posteromedial Reach
Control	153.45±220.76	47.83±135.67	31.81±107.11
FAI	83.30±126.15*	19.54±98.63	22.99±77.89

*Indicates a significant difference between groups in the anteromedial and medial reach directions had greater spinal flexion versus controls (Figures 13)(Table 13). With the lateral method, post-hoc testing showed greater spinal flexion in FAI subjects versus controls in all three reach directions (Figure 14)(Table 14). In FAI subjects, the Tukey post-hoc test showed spinal flexion was significantly greater with the lateral method.

Pelvis Anterior/Posterior Tilt Angles (Pelvis X)

The results of the repeated measures ANOVA for pelvis anterior tilt revealed a significant main effect for method ($F_{1,37} = 6.759$, $P = .013$) and direction ($F_{2,72} = 144.867$, $P < .0005$).

Hip Flexion/Extension Angles (Hip X)

The results of the repeated measures ANOVA for hip flexion showed a significant main effect for method ($F_{1,37} = 11.179$, $P = .002$), and direction ($F_{2,72} = 206.089$, $P < .0005$).

Hip Abduction/Adduction Angles (Hip Y)

The results of the repeated measures ANOVA for hip abduction revealed a significant main effect for method ($F_{1,37} = 4.056$, $P = .05$), and direction ($F_{2,72} = 32.295$, $P < .0005$). A significant tape by direction two-way interaction was present ($F_{2,72} = 4.274$, $P = .02$). A three-way tape by method by direction interaction was found ($F_{2,72} = 4.122$, $P = .02$), with Tukey HSD post-hoc testing revealing a significantly higher hip abduction with the Kinesio tape/Kinesio method conditions compared to the white tape/Kinesio method and the Kinesio tape/lateral method conditions in the posteromedial reach direction (Figure 15)(Table 15). A significant four-way interaction

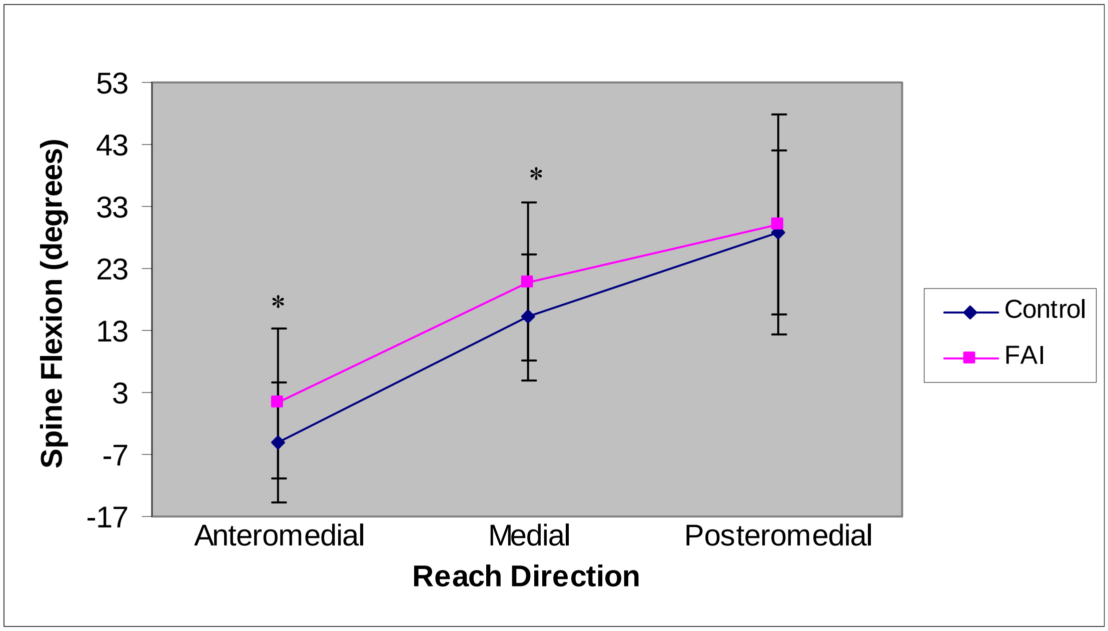

Figure 13. Method-by-direction-group interaction for spinal flexion at maximum reach on the Star Excursion Balance Test. Negative values indicate spinal extension.

Table 13. Method-by-direction-group interaction for spinal flexion at maximum reach on the Star Excursion Balance Test using the Kinesio method. Negative values indicate spinal extension.

	Anteromedial Reach	Medial Reach	Posteromedial Reach
Control	-5.03±9.59	15.18±10.2	28.79±13.11
FAI	1.36±12.09	20.84±12.84	30.06±17.86

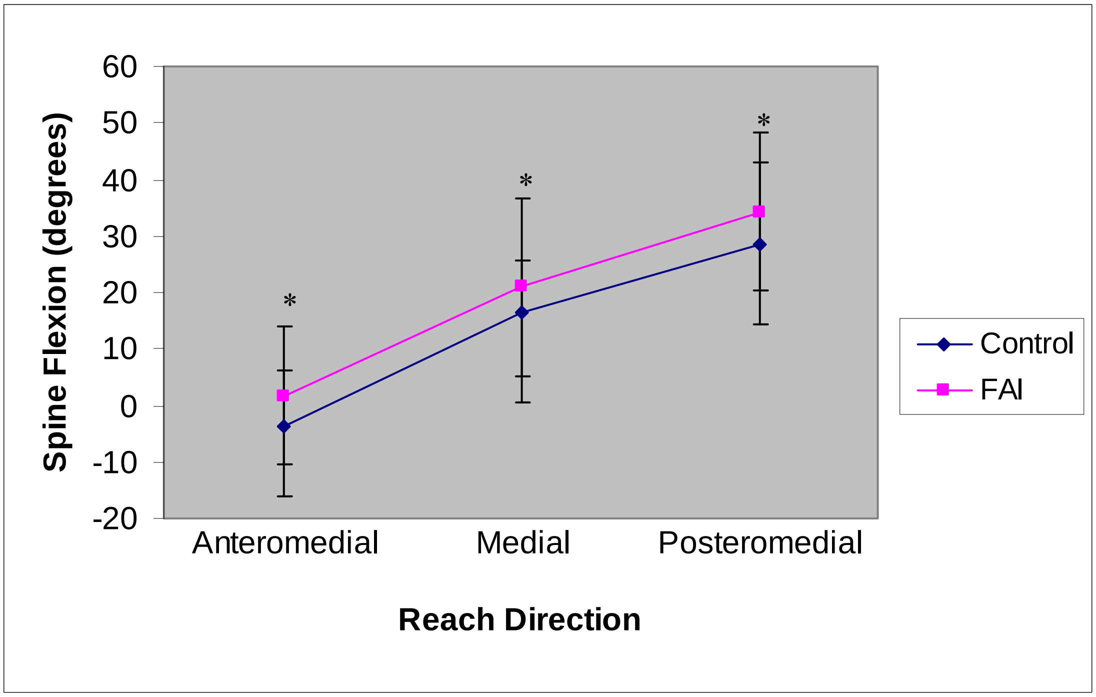

Figure 14. Method-by-direction-group interaction for spinal flexion at maximum reach on the Star Excursion Balance. Negative values indicate spinal extension

Table 14. Method-by-direction-group interaction for spinal flexion at maximum reach on the Star Excursion Balance Test using the lateral method. Negative values indicate spinal extension.

	Anteromedial Reach	Medial Reach	Posteromedial Reach
Control	-3.85±9.95	16.46±9.36	28.47±14.65
FAI	1.72±12.28	20.98±15.79	34.24±13.99

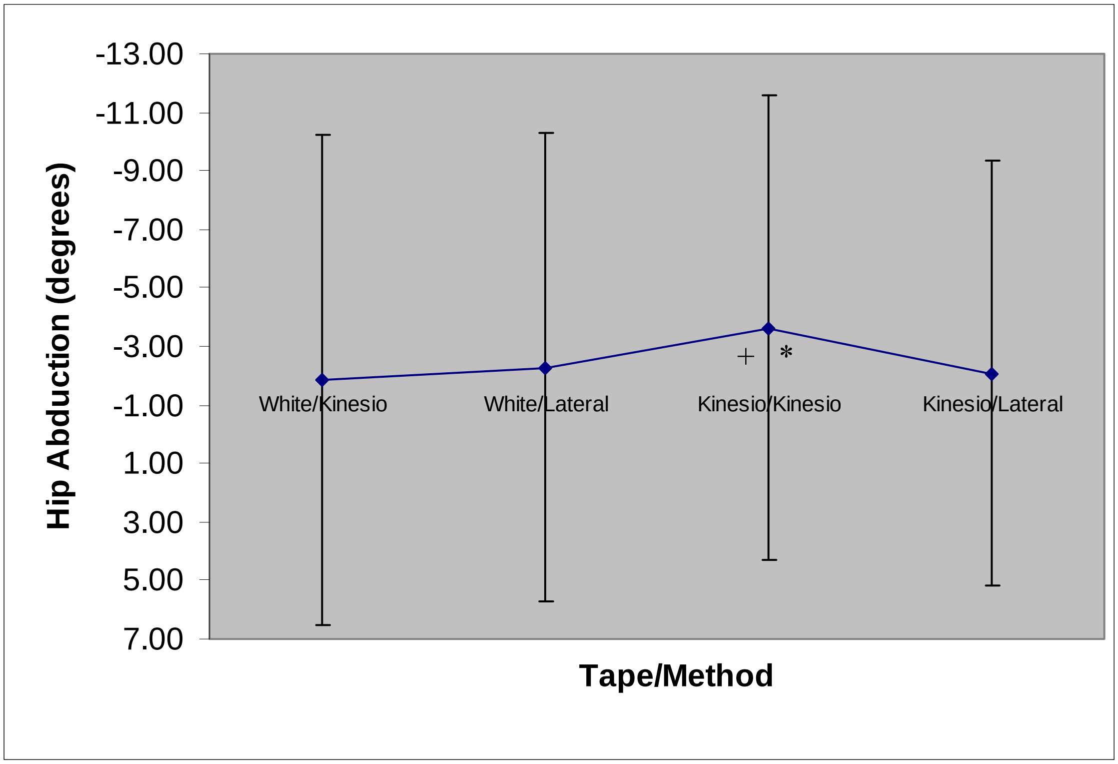

Figure 15. Tape-by-method-by-direction interaction for hip abduction angles at maximal reach in the posteromedial direction on the Star Excursion Balance Test. Negative values indicate hip abduction while positive values indicate hip adduction. *Indicates significant difference between the White/Kinesio and Kinesio/Kinesio conditions. +Indicates significant difference between the Kinesio/Kinesio and Kinesio/Lateral conditions.

Table 15. Tape-by-method-by-direction interaction for hip abduction angles at maximal reach on the Star Excursion Balance Test. Negative values indicate hip abduction while positive values indicate hip adduction.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Anteromedial Reach	5.19±13.48	6.01±6.33	5.58±6.27	5.72±6.26
Medial Reach	-0.75±6.01	-0.23±5.83	-0.40±6.55	0.30±6.37
Posteromedial Reach	-1.86±8.37	-2.27±8.00	-3.62±7.94*+	-2.07±7.25

*Indicates significant difference between the Kinesio/Kinesio and White/Kinesio conditions. +Indicates significant difference between the Kinesio/Kinesio and Kinesio/Lateral conditions.

for tape, method, direction, and group ($F_{2,72} = 3.874$, $P = .03$) was found. Tukey HSD post-hoc testing showed a significantly less hip abduction angles with the Kinesio tape/Kinesio method versus the white tape/Kinesio method condition in FAI subjects with posteromedial reach. Hip abduction angles were also significantly higher with the white tape/Kinesio method versus white tape/lateral method condition in FAI subjects in the posteromedial direction (Figure 16)(Table 16).

Hip Rotation Angles (Hip Z)

The results of the repeated measures ANOVA for hip rotation showed a significant main effect for direction ($F_{2,72} = 60.778$, $P < .0005$), and a significant three-way interaction for tape, method, and group ($F_{1,36} = 4.478$, $P = .04$)(Figure 17)(Table 17). No post-hoc testing of interest was significant.

Knee Flexion/Extension Angles (Knee X)

The results of the repeated measures ANOVA for knee flexion showed a significant main effect for method ($F_{1,37} = 29.521$, $P < .0005$), and direction ($F_{2,72} = 24.652$, $P < .0005$). Significant two-way interactions were found between direction and group ($F_{2,72} = 5.212$, $P = .008$)(Figure 18)(Table 18), and tape by method ($F_{1,36} = 4.242$, $P = .05$). No post-hoc testing of interest was significant.

Knee Varus/Valgus Angles (Knee Y)

The results of the repeated measures ANOVA for knee valgus showed a significant main effect for direction ($F_{2,72} = 7.037$, $P = .002$). A tape by method interaction was also present ($F_{1,36} = 8.963$, $P = .005$)(Figure 19)(Table 19). No post-hoc testing of interest was significant.

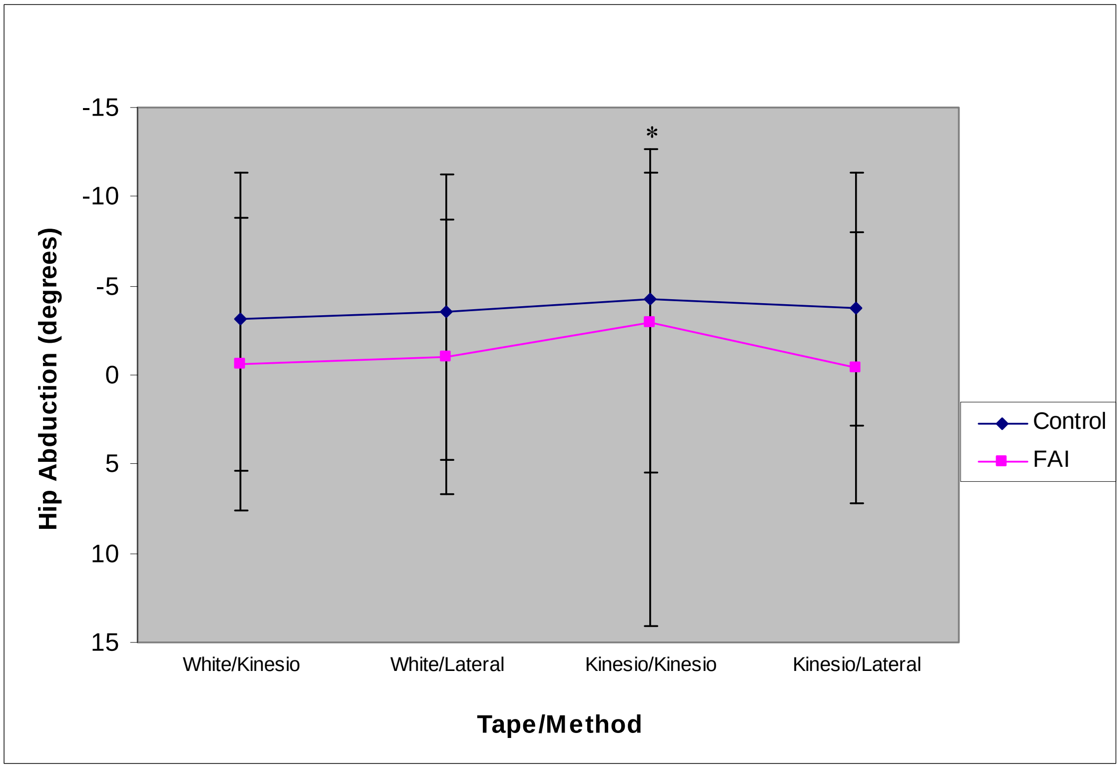

Figure 16. Tape-by-method-by-direction-by-group interaction for hip abduction angles at maximal reach on the Star Excursion Balance Test in the posteromedial direction. Negative values indicate hip abduction while positive values indicate hip adduction. *Indicates a significant difference between the White/Kinesio and Kinesio/Kinesio conditions in FAI subjects.

Table 16. Tape-by-method-by-direction-by-group interaction for hip abduction angles at maximal reach on the Star Excursion Balance Test in the posteromedial direction. Negative values indicate hip abduction while positive values indicate hip adduction.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Control	-2.14±8.51	-1.75±8.29	-1.88±18.33	-1.54±6.61
FAI	0.65±8.23*	1.29±7.71	1.08±8.39	2.13±7.62

*Indicates a significant difference between the White/Kinesio and Kinesio/Kinesio conditions in FAI subjects.

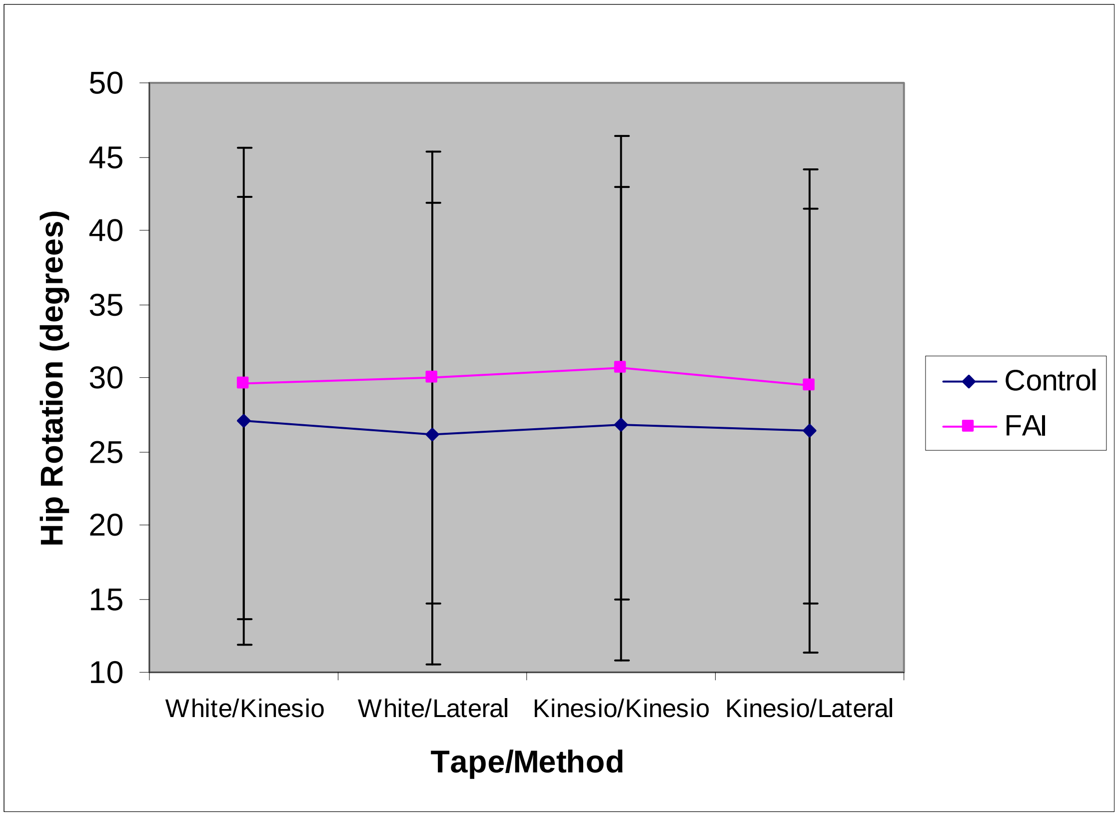

Figure 17. Tape-by-method-by-group interaction for hip rotation angles at maximal reach on the Star Excursion Balance Test. Larger values indicate more external rotation.

Table 17. Tape-by-method-group interaction for hip rotation angles at maximal reach on the Star Excursion Balance Test.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Control	27.08±15.22	26.14±15.67	26.83±16.06	26.43±15.04
FAI	29.62±15.97	30.03±15.33	30.71±15.74	29.42±14.77

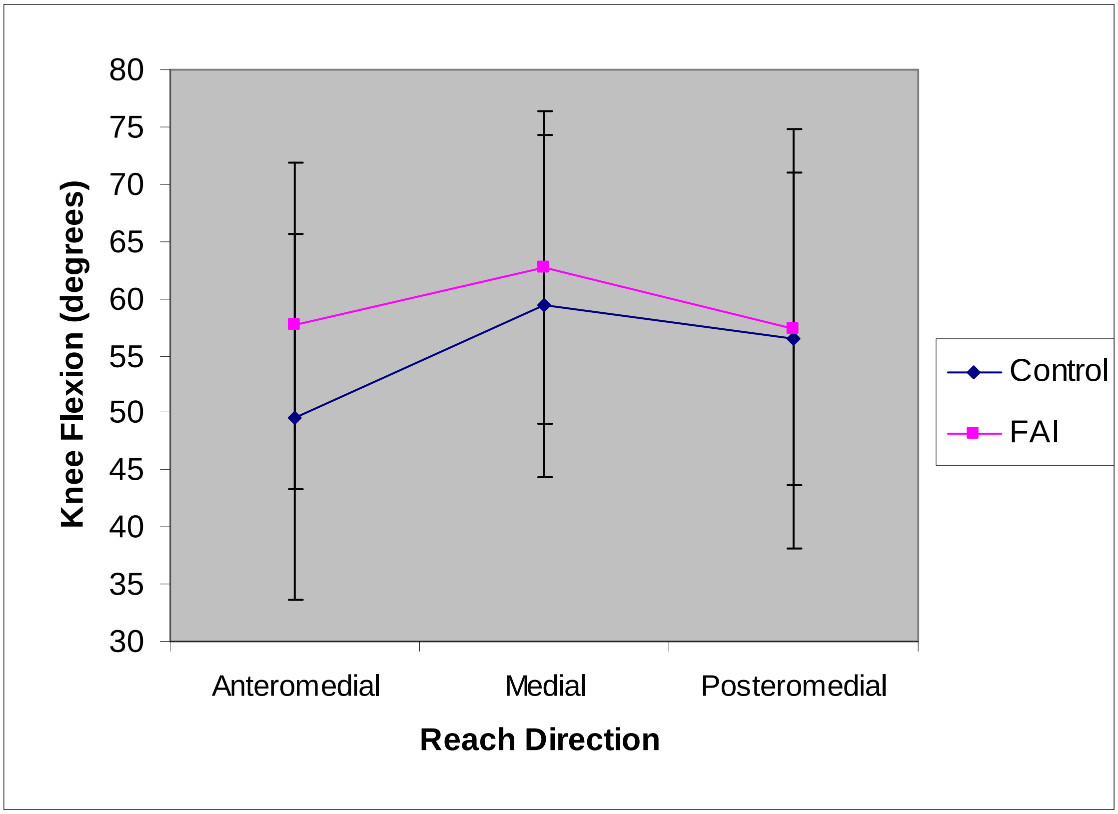

Figure 18. Direction-by-group interaction for knee flexion angles at maximal reach on the Star Excursion Balance Test.

Table 18. Direction-by-group interaction for knee flexion angles at maximal reach on the Star Excursion Balance Test.

	Anteromedial Reach	Medial Reach	Posteromedial Reach
Control	49.60±16.03	59.34±14.97	56.51±18.32
FAI	57.61±14.23	62.72±13.63	57.30±13.66

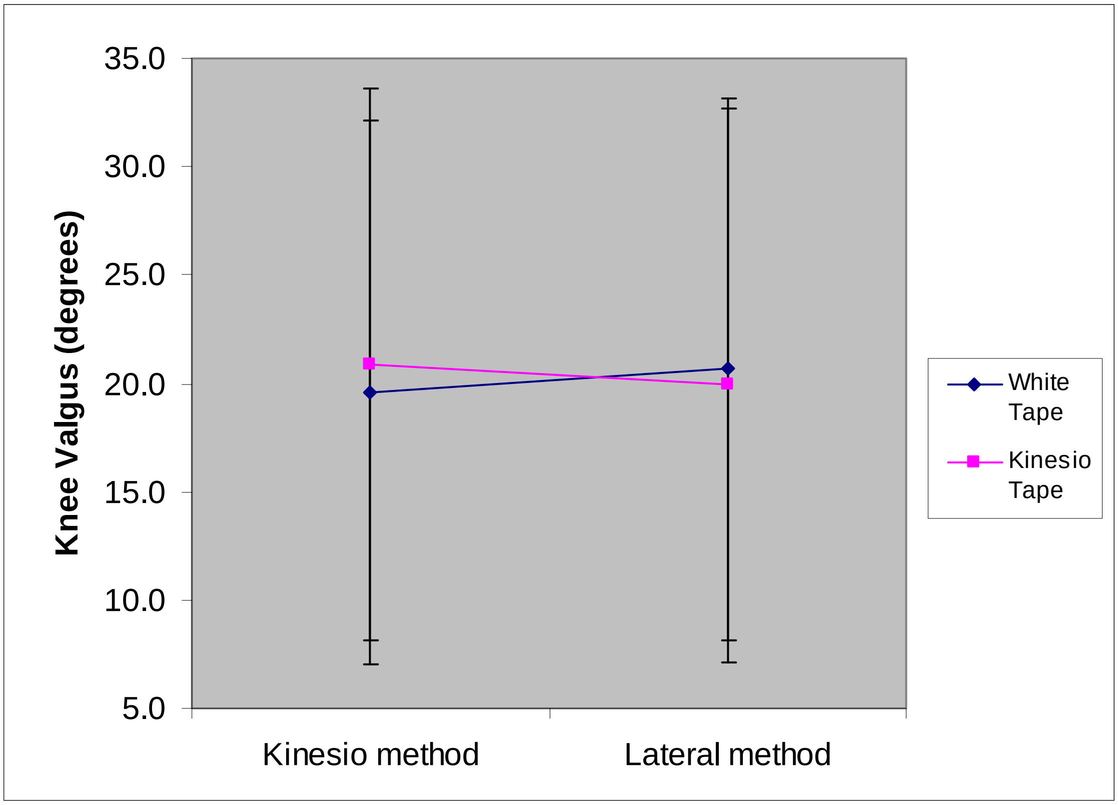

Figure 19. Tape-by-method interaction for knee valgus angles at maximal reach on the Star Excursion Balance Test

Table 19. Tape-by-method interaction for knee valgus angles at maximal reach on the Star Excursion Balance Test.

	White Tape	Kinesio Tape
Kinesio Method	19.62±12.55	20.89±12.75
Lateral Method	20.65±12.49	19.93±12.78

Knee Rotation Angles (Knee Z)

The results of the repeated measures ANOVA for knee rotation revealed a significant main effect for method ($F_{1,37}$ = 54.748, P < .005), and direction ($F_{2,72}$ = 5.981, P = .004).

Ankle Dorsiflexion/Plantarflexion Angles (Angle X)

The results of the repeated measures ANOVA for ankle dorsiflexion showed a significant main effect for method ($F_{1,37}$ = 27.04, P < .005), and direction ($F_{2,72}$ = 78.242, P < .0005).

Ankle Inversion/Eversion Angles (Ankle Y)

The results of the repeated measures ANOVA for ankle inversion revealed a significant main effect for method ($F_{1,37}$ = 15.875, P < .005).

Ankle Internal Rotation Angles (Ankle Z)

The results of the repeated measures ANOVA for ankle rotation revealed a significant main effect for tape ($F_{1,36}$ = 11.724, P = .002) and method ($F_{1,36}$ = 23.943, P < .0005). A significant two-way interaction between direction and group was also found ($F_{2,72}$ = 3.843, P = .03)(Figure 20)(Table 20). No post-hoc testing of interest was significant.

Force Plate Measures

Results for the Repeated Measures ANOVAS for the force plate variables are presented in Appendices 9 and 10.

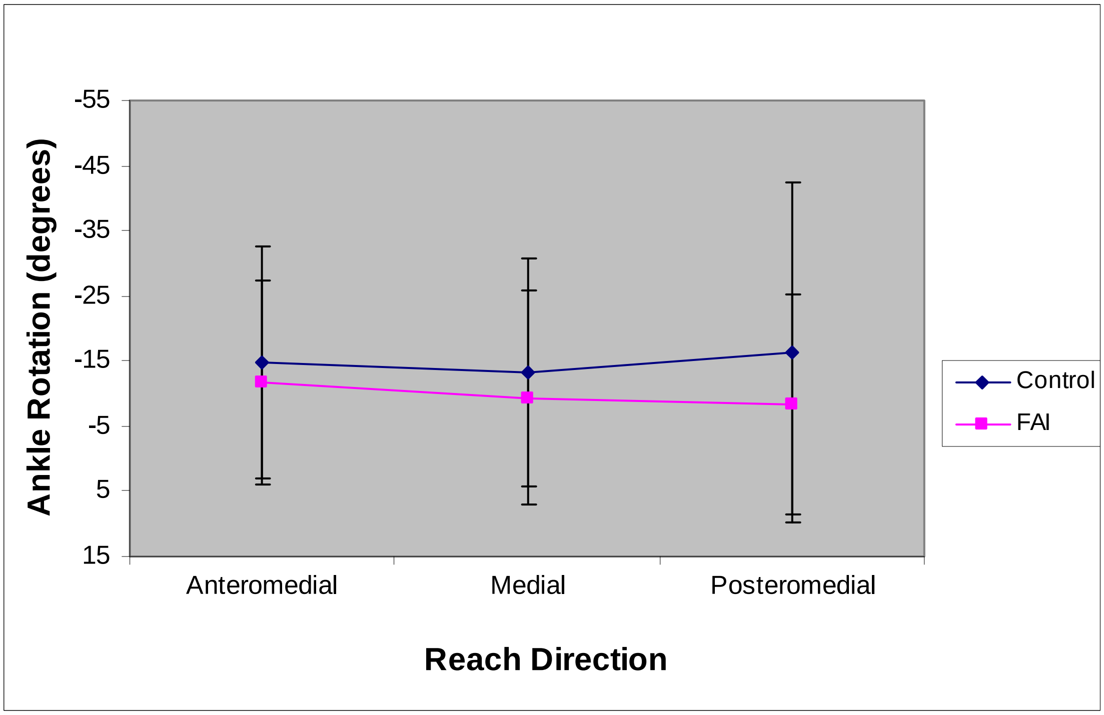

Figure 20. Direction-by-group interaction for ankle rotation angles for maximal reach on the Star Excursion Balance Test. Negative values indicate external rotation.

Table 20. Direction-by-group interaction for ankle rotation angles for maximal reach on the Star Excursion Balance Test. Negative values indicate external rotation.

	Anteromedial Reach	Medial Reach	Posteromedial Reach
Control	-14.69±17.76	-13.3±17.48	-16.34±26.11
FAI	-11.67±15.74	-9.39±16.48	-8.25±16.90

Area 95

The results of the repeated measures ANOVA for the 95% confidence ellipse did not reveal any significant main effects or interactions (Appendices 9-10).

Center of Pressure Medial-Lateral Sway Velocity (COP X Velocity)

The results of the repeated measures ANOVA for medial-lateral center of pressure sway velocity showed significant three-way interactions for tape, method, and group ($F_{1,36} = 4.468$, $P = .04$)(Figure 21)(Table 21); tape, direction and group ($F_{2, 72} = 3.385$, $P = .04$)(Figures 22, 23)(Tables 22, 23); and tape, method and direction($F_{2,72} = 5.292$, $P = .007$). For the tape by method by group interaction, Tukey HSD post-hoc testing showed significantly lower medial-lateral sway velocity for both tapes (white, Kinesio) and both methods (Kinesio, lateral) in FAI compared to control subjects. For the tape by direction by group interaction, post-hoc testing revealed significantly lower M/L sway velocity in FAI versus control subjects for both tapes in all three reach directions.

Center of Pressure Anterior-Posterior Sway Velocity (COP Y Velocity)

The results of the repeated measures ANOVA for anterior-posterior center of pressure sway velocity showed a significant three-way interaction for tape, method, and group ($F_{1,36} = 4.173$, $P = .05$)(Figure 24)(Table 24); method, direction, and group ($F_{2,72} = 3.066$, $P = .05$)(Figures 25, 26)(Tables 25,26); and tape by method by direction ($F_{2,72} = 3.052$, $P = .05$). For the tape by method by group interaction, Tukey HSD post-hoc testing showed significantly slower sway in FAI subjects compared to controls for both methods in all three reach directions.

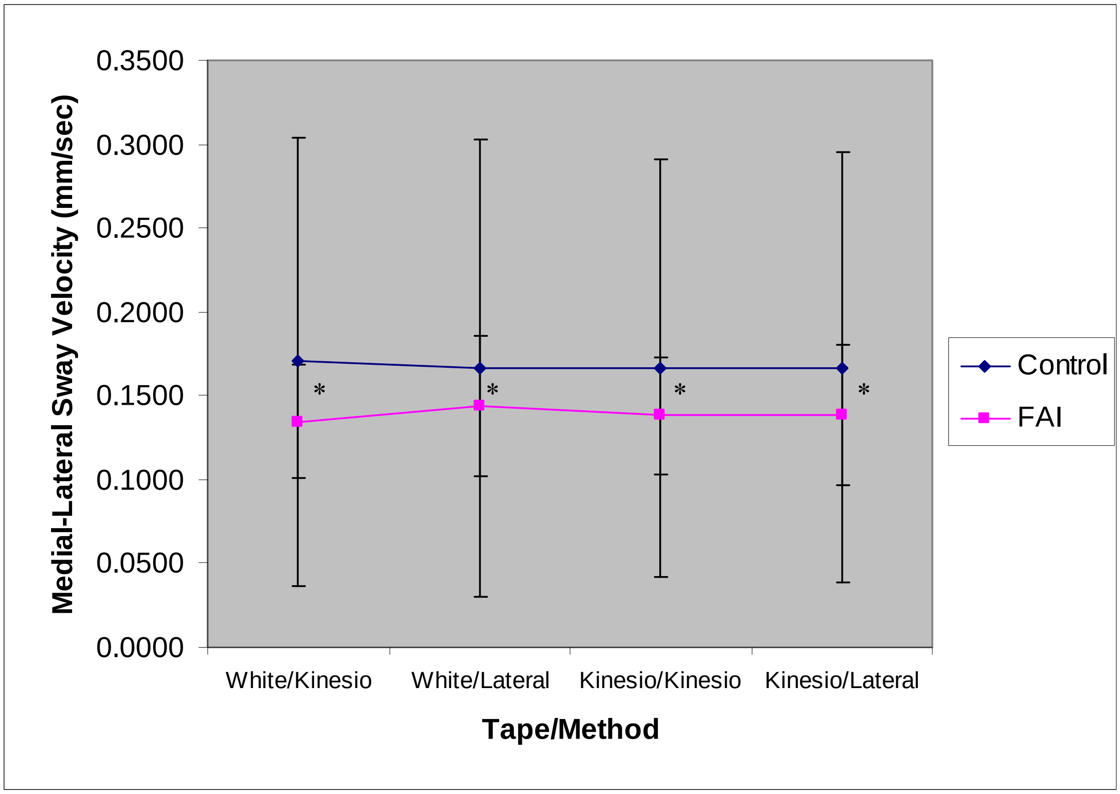

Figure 21. Tape-by-method-by-group interaction for medial-lateral sway velocity during reach on Star Excursion Balance Test. *Indicates a significant difference between groups.

Table 21. Tape-by-method-by-group interaction for medial-lateral sway velocity during reach on Star Excursion Balance Test. *Indicates a significant difference between groups

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Control	0.1705±.1338	0.1663±.1362	0.1667±.1244	0.1668±.1283
FAI	0.1346±.0337*	0.1435±.0419*	0.1382±.0348*	0.1389.0419*

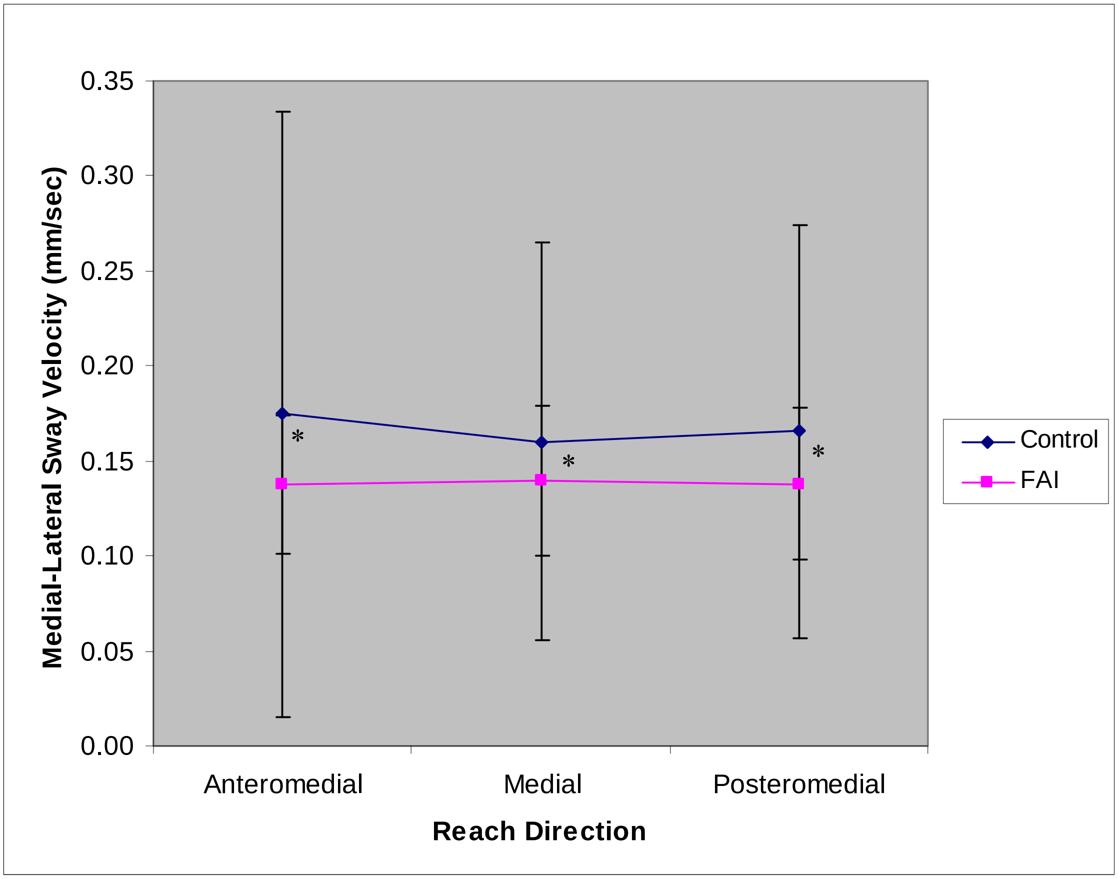

Figure 22. Tape-by-direction-by-group interaction for medial-lateral sway velocity with Kinesio tape during reach on the Star Excursion Balance Test. *Indicates significant difference between groups.

Table 22. Tape-by-direction-by-group interaction for medial-lateral sway velocity with Kinesio tape during reach on the Star Excursion Balance Test.

	Anteromedial Reach	Medial Reach	Posteromedial Reach
Control	.1746±.1596	.1603±.1043	.1654±.1090
FAI	.1377±.0367*	.1400±.0395*	.1379±.0398*

*Indicates significant difference between groups.

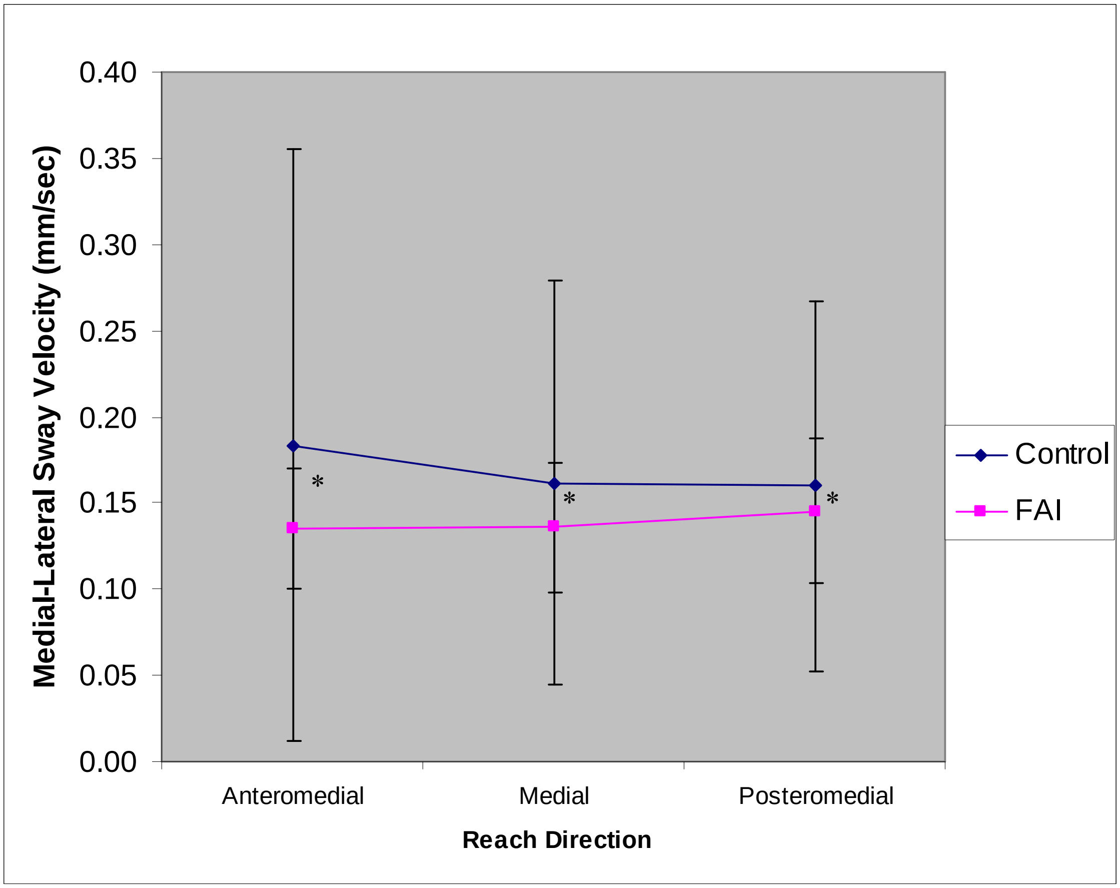

Figure 23. Tape-by-direction-by-group interaction for medial-lateral sway velocity with white tape during reach on the Star Excursion Balance Test. *Indicates significant difference between groups.

Table 23. Tape-by-direction-by-group interaction for medial-lateral sway velocity with white tape during reach on the Star Excursion Balance Test.

	White Tape		
	Anteromedial Reach	Medial Reach	Posteromedial Reach
Control	.1836±.1719	.1615±.1172	.1601±.1073
FAI	.1355±.0348*	.1362±.0376*	.1453±.0418*

*Indicates significant difference between groups.

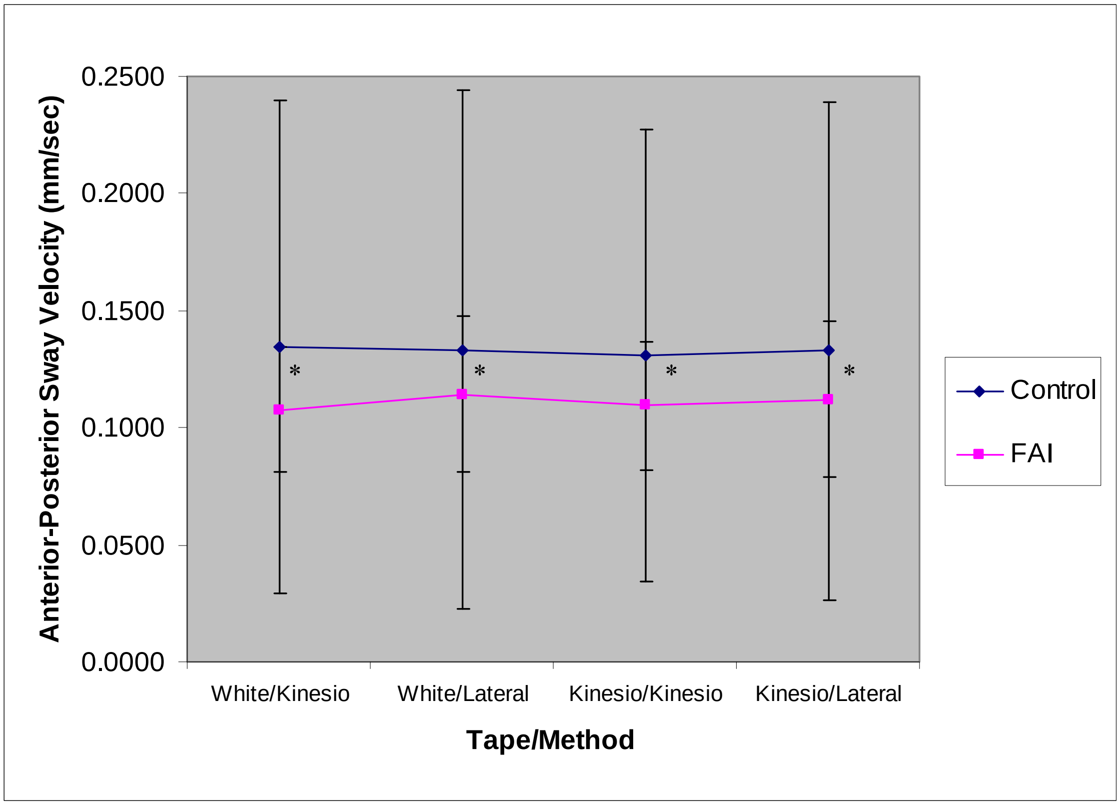

Figure 24. Tape-by-method-by-group interaction for anterior-posterior sway velocity during reach on the Star Excursion Balance Test. *Indicates a significant difference between groups.

Table 24. Tape-by-method-by-group interaction for anterior-posterior sway velocity during reach on the Star Excursion Balance Test.

	White Tape		Kinesio Tape	
	Kinesio Method	Lateral Method	Kinesio Method	Lateral Method
Control	.1344±.1052	.1334±.1109	.1309±.0963	.1327±.1064
FAI	.1076±.0268*	.1144±.0333*	.1094±.0275*	.1121±.0332*

*Indicates a significant difference between groups.

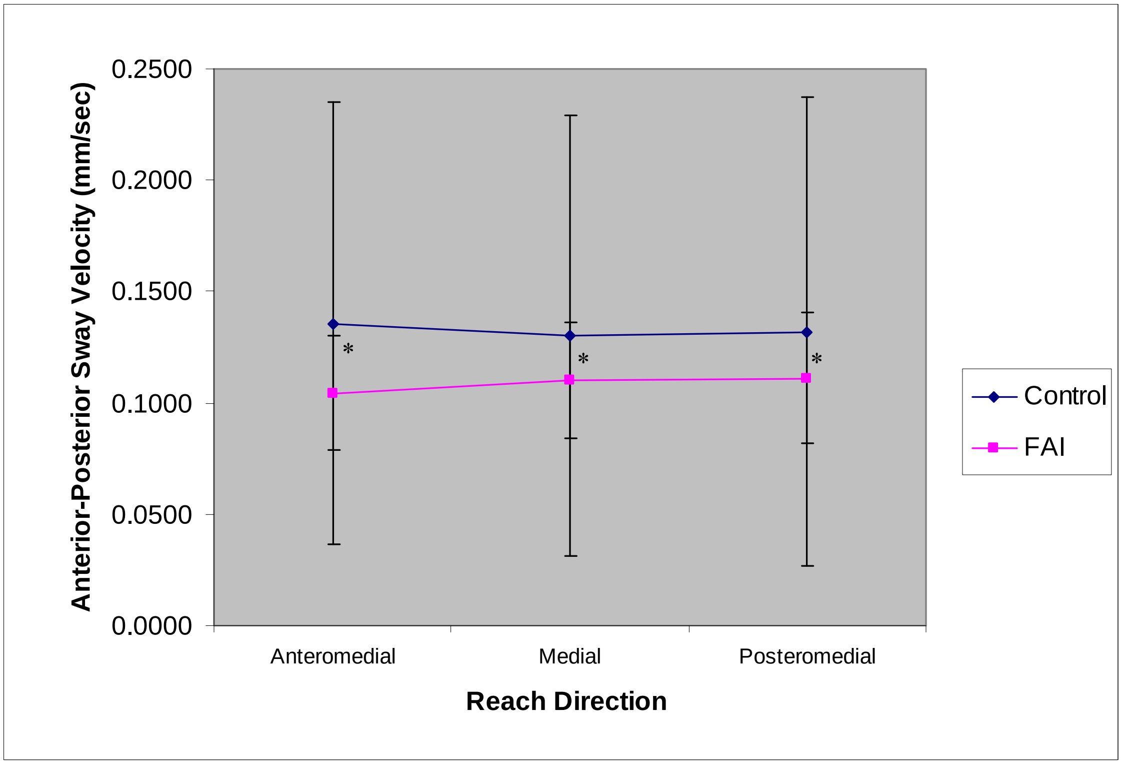

Figure 25. Method-by-direction-by-group interaction for anterior-posterior sway velocity using the Kinesio method during reach on the Star Excursion Balance Test. *Indicates significant difference between groups.

Table 25. Method-by-direction-by-group interaction for anterior-posterior sway velocity using the Kinesio method during reach on the Star Excursion Balance Test.

	Kinesio Method		
	Anteromedial Reach	Medial Reach	Posteromedial Reach
Control	.1357±.0991	.1303±.0992	.1321±.1055
FAI	.1045±.0259*	.1101±.0259*	.1109±.0294*

*Indicates significant difference between groups.

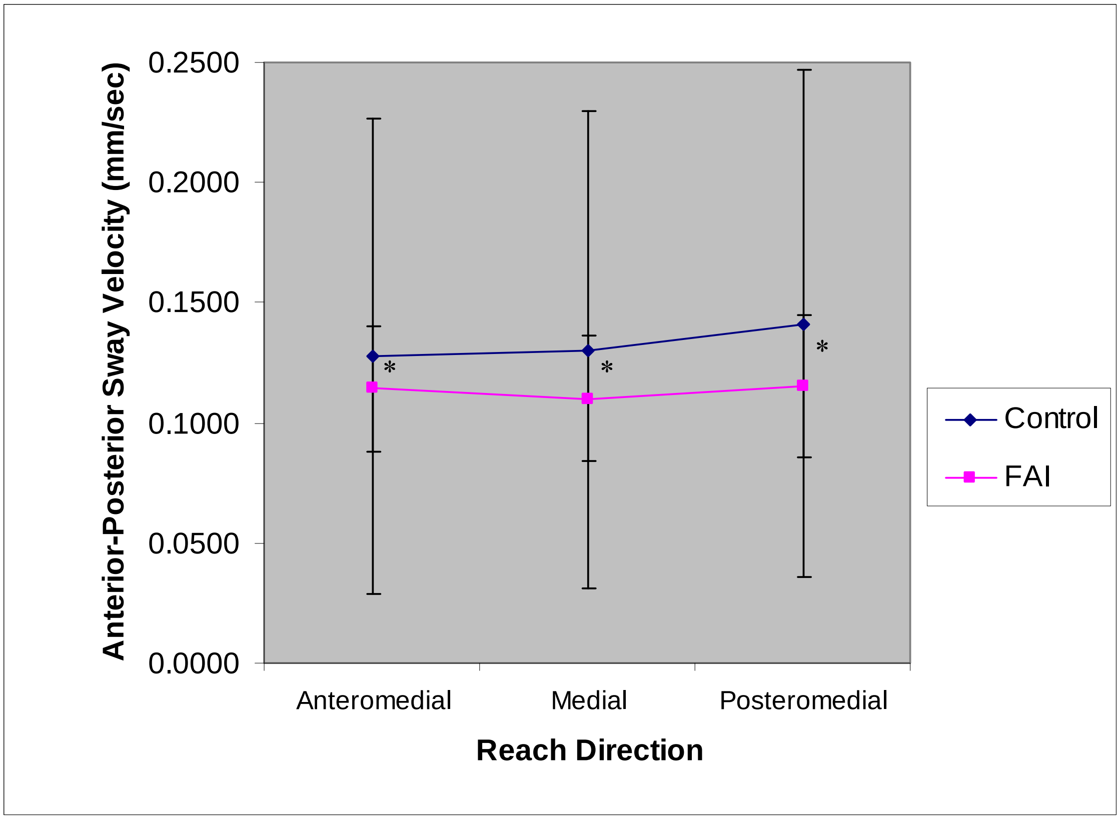

Figure 26. Method-by-direction-by-group interaction for anterior-posterior sway velocity using the Lateral Method during reach on the Star Excursion Balance Test. *Indicates significant difference between groups.

Table 26. Method-by-direction-by-group interaction for anterior-posterior sway velocity using the Lateral Method during reach on the Star Excursion Balance Test.

	Lateral Method		
	Anteromedial Reach	Medial Reach	Posteromedial Reach
Control	.1278±.0991	.1304±.0992	.1411±.1055
FAI	.1142±.0259*	.1102.0259*	.1152±.0294*

*Indicates significant difference between groups.

Subjective Taping Questionnaire

Means and standard deviations for the subjective questionnaire results can be found in Tables 27-30. For the question regarding tape interference, there was a significant difference between groups for the Kinesio tape/Kinesio method combination ($F_{1,38}$ = 5.109, P = .03). On the question about how comfortable each tape/method combination was during performance, there was a significant group main effect for the white tape/Kinesio method combination ($F_{1,38}$ = 7.047, P = .01). The ANOVA on the ankle stability with tape question showed a group main effect for the Kinesio tape/Kinesio method condition ($F_{1,38}$ = 4.101, P = .05). Lastly, the question regarding confidence during performance under the tape/method combinations also revealed a group main effect for the Kinesio tape/Kinesio method condition ($F_{1,38}$ = 4.58, P = .04).

Table 27. Means ± SDs for subjective questionnaire question regarding tapes' negative effect (diminished performance) or positive effect (enhanced performance). Higher numbers indicate more favorable responses.

Diminish to enhance performance	White tape/ Kinesio method	Kinesio tape/ Kinesio method	White tape/ Lateral method	Kinesio tape/ Lateral method
Control	3.85±1.81	5.65±1.79	4.85±1.14	4.90±1.33
FAI	4.75±2.27	6.85±1.57*	4.65±1.63	5.35±1.18

*Indicates significant main effect for group.

Table 28. Means ± SDs for subjective questionnaire question regarding tape comfort. Higher numbers indicate more favorable responses.

Uncomfortable to comfortable during performance				
	White tape/ Kinesio method	Kinesio tape/ Kinesio method	White tape/ Lateral method	Kinesio tape/ Lateral method
Control	2.70±1.34	5.65±1.79	4.85±1.14	4.90±1.33
FAI	4.45±2.63*	6.85±1.57	4.65±1.63	5.35±1.18

*Indicates significant main effect for group.

Table 29. Means ± SDs for subjective questionnaire question regarding ankle stability with tape. Higher numbers indicate more favorable responses.

Unstable to stable during performance				
	White tape/ Kinesio method	Kinesio tape/ Kinesio method	White tape/ Lateral method	Kinesio tape/ Lateral method
Control	6.00±2.32	7.15±1.57	5.35±1.81	5.70±1.75
FAI	6.13±2.15	6.70±2.30	4.55±1.93	4.53±1.92*

*Indicates significant main effect for group.

Table 30. Means ± SDs for subjective questionnaire question regarding confidence during performance with tape. Higher numbers indicate more favorable responses.

Unconfident to confident during performance				
	White tape/ Kinesio method	Kinesio tape/ Kinesio method	White tape/ Lateral method	Kinesio tape/ Lateral method
Control	5.15±1.81	6.60±1.98	6.05±2.24	6.60±2.06
FAI	4.95±2.67	6.20±2.53	4.80±2.35	5.08±2.43*

*Indicates significant main effect for group.

DISCUSSION

Several studies have investigated the usefulness of the SEBT in detecting FAI[10, 68] and the effects of fatigue on SEBT performance.[5, 122] However, no study has included a kinematic and/or kinetic assessment in these non-sagittal planes with an FAI and control group, nor has any study reported center of pressure measures during SEBT performance. In order to address these gaps, this study set out to 1) identifying particular patterns, or reach strategies, as defined through 3-D kinematic and kinetic components, in FAI subjects on the SEBT, and 2) investigating the effects of type of tape and application method on SEBT performance.

Differences Between Groups

Reach Distance

No reach distance differences were detected in any direction, under any condition tested (including the no tape/control condition). This finding is contrary to previously published results,[5, 10, 68, 122] describing significantly decreased reach in FAI subjects when compared to their contralateral limb, as well as with the matched limb of the control group. However, numerous method and data analysis differences may explain this difference.

First, Olmsted et al.[10] did not normalize reach distance to limb length, nor did they report if the FAI and control groups were significantly different in height. It is essential to normalize reach distance to leg length because those with longer legs are able to naturally reach further.[77] Without normalizing, it cannot be determined if actual reach differences existed in these subjects.

Previous studies using the SEBT have used an average of three reaches, or analyzed only the maximum of three reaches in the sagittal plane, or all eight reach directions of the SEBT.[10, 68, 122, 123] The current study included the average of six reaches individually in the three reach directions, which were recorded after the recommended six practice trials.[119] However, a recent investigation has identified that reach distance tends to stabilize after 4-5 practice reaches.[124] They were able to show the average score did not significantly change after this many reaches. Based on this evidence, because this study used six test reaches instead of three, it is possible that more reaches lead to better stability of reach scores and kinematic variables.

Additionally, Hertel et al.[68] identified considerable redundancy in the eight reach directions, ultimately finding that the AM and M reach directions to be best at identifying reach distance differences in FAI subjects. Moreover, his study showed that the PM reach direction was decidedly representative of the performance of all 8 reach directions of the SEBT, regardless of injury status, advocating a hypothesis-driven investigation to confirm the exploratory nature of their study. The current study used these same reach directions (AM, M, PM) in order to minimize data collection time and maximize the possibility of identifying FAI reach strategy differences. No reach distance differences existed in the current study and cannot confirm those of Hertel.[68] Hertel's subjects were allowed to use arms for balance during SEBT performance, which may account for these differences. However, reach distance alone is inadequate at identifying potential differences between FAI and control subjects on SEBT performance because of the large amount of movement variability in the human system. There is a need to look at additional factors that influence reach distance, namely angular displacement in order to obtain a more complete picture of involved components.

Due to the large amount of kinematic redundancy and variability in the human movement system, the same performance (in this case, maximum reach) can be achieved with different angular displacement combinations. Robinson et al.[124] used twenty uninjured subjects to look at angular displacement data over a series of SEBT reaches in order to identify when movement patterns stabilized. Their results showed that knee and hip flexion exhibited significant increases across trials in the M and PM reach directions, but stabilized after approximately four practice trials. Subjects in this study performed six practice and six test trials, and therefore, should have had stabilized angles. Along with varying joint angular displacement, different amounts of stress can be placed at each of these joints during movement. Thus, it was only appropriate to also investigate joint torques for the entire lower extremity in an effort to provide a complete picture of reach performance.

Kinematics and Kinetics

Trunk movement

Overall, FAI subjects exhibited significantly greater spinal flexion than control subjects under both methods. Under the lateral method, this movement was significantly different in all three reach directions, and in the anteromedial and medial reach directions with the Kinesio method. Interestingly, control subjects showed spinal extension with anteromedial reach, while FAI subjects had spinal flexion. In FAI subjects, spinal flexion angles were significantly lower using the Kinesio method condition when compared to the lateral method when reaching in the posteromedial direction. Because no reach differences were exhibited, this difference must be exhibited elsewhere in the kinetic chain.

Hip joint

Hip Flexion Torque

Hip flexion torque was significantly different between FAI and control subjects under two tape/method combinations in the anteromedial reach direction (Figure 5). FAI subjects had significantly greater hip flexion torque means when compared with control subjects under the white tape/lateral method and the Kinesio tape/Kinesio method conditions. In the PM reach direction, though not statistically significant, FAI subjects exhibited lower hip flexion torque means than control subjects under the white tape/lateral method and Kinesio tape/Kinesio method conditions. Because FAI subjects were able to reach the same distance as control subjects in this direction under these conditions, the decreased torque at the ipsilateral hip appears to have been displaced to another joint when reaching in the PM direction.

Opposite to this, the increased hip torque in FAI subjects with reach in the AM directions was significantly higher than control subjects with the white tape /lateral method and Kinesio tape/Kinesio method conditions. The reasons for this are unclear but it is possible that the higher flexion torque seen at the hip with these conditions is a result of lower torques into other distal joints in the kinetic chain.

Hip Abduction

Hertel et al.[68] identified the posteromedial reach direction as being highly representative of the performance of all 8 reach directions of the SEBT, regardless of injury status. Thus, it is extremely interesting that the significant post-hoc tests involved the posteromedial reach direction. For the four-way tape x method x direction x group interaction for hip abduction/adduction angles, post-hoc testing showed that injured subjects' stance leg hip adduction (negative values) was significantly greater under the Kinesio tape/Kinesio Method condition than the white tape/Kinesio method for PM reach (-2.96 degrees versus -.59 degrees with the white tape/Kinesio method)(Figure 15). With this tape/method combination, injured subjects' hip adduction angles neared control subjects' angles, who had greater angles than FAI subjects under all conditions. Greater hip adduction (or less hip abduction) of the stance leg with reach using the Kinesio/Kinesio condition demonstrates that injured subjects were able to shift their hip more towards the midline of their body as their opposite leg was furthest away from their body for the reach, and brings them closer to the strategy employed by control subjects.

Stance leg hip abduction also appears to have been influenced in FAI subjects in the other reach directions. For the M reach direction, FAI subjects showed hip abduction (positive values) on their stance (FAI) leg with all tape/method combinations. This suggests that FAI subjects attempted to move the pelvis on the femur to position the hip towards the direction of the reach. Conversely, control subjects exhibited hip *adduction* with medial reach, bringing their stance leg hip away from the midline of the body for reach (Table 16). Similar to the M direction, FAI subjects had greater hip abduction than control subjects in the AM direction. This may also be an attempt to widen the base of support using the hip in order maintain balance without falling over.

In a study using a perturbation platform, Beckman et al.[91] described a similar pattern at the hip. They were able to show that subjects with ankle instability exhibited shorter gluteus medius EMG onsets after the perturbation on the ipsilateral side. Pelvic angle curves for one subject demonstrated a superior pelvis displacement on the ipsilateral side with ipsilateral perturbation, suggesting the ipsilateral gluteus medius is reacting to being placed on stretch. This motion is similar to that exhibited with the Star Excursion balance test, as the lower leg is also in a closed packed position and movement of the pelvis on the femur is occurring in the manner similar to what is observed with the Trendelenberg orthopedic special test. Whether this movement pattern is the result from a weak gluteus medius or an inherent movement pattern in FAI subjects is unknown. Hip strength was not assessed in this study, though it should potentially be investigated in the future.

Hip Rotation

For the tape by method by group interaction for hip internal rotation angles, FAI subjects showed greater internal rotation means than control subjects on all conditions. Though not statistically different with post-hoc testing, it is possible that this strategy took emphasis off ankle rotation in an effort to protect the most distal joint in the kinetic chain.

Knee joint

At the knee, a direction by group interaction was present for knee flexion angles. Based on the pattern of the interaction, FAI subjects showed greater knee flexion angles versus control subjects in all three reach directions (Figure 18), although these differences were not statistically significant with post-hoc testing. This result is similar to results reported by Caulfield[116] who found that FAI subjects exhibited greater knee flexion before and after a jump landing. Again, because there were no reach distance differences, this change in knee flexion angles must be apparent elsewhere in the kinetic chain.

Knee internal rotation torque also showed a significant direction by group interaction. Though not statistically different on post-hoc analysis, FAI subjects had *lower* rotational knee torque in the all three directions. Also, for the M direction, FAI subjects had internal rotation torque, while control subjects showed external rotation torque (6.4 Nm versus -3.61 Nm)(Figure 11), again highlighting a reach strategy difference.

Ankle joint

A direction by group interaction was found for ankle rotational torque. In the AM reach direction, FAI subjects exhibited significantly *lower* internal rotational torque than control subjects (83.3 Nm versus 153.45 Nm)(Figure 12). The other two reach directions showed the same pattern, though these were not significant with post-hoc testing. This decreased torque could be explained by the increased hip rotation seen in FAI subjects versus control subjects. It is possible that this is a protective mechanism for the ankle. A study by Brown et al[121] also found kinematic & kinetic differences on several dynamic tasks in ankle instability subjects. Overall, unstable subjects exhibited increased eversion and frontal plane displacement on the study tasks, which, similar to this study, may in fact be indicative of a movement pattern adaptation. It is possible that this strategy is an attempt to avoid the plantarflexion-inversion sprain mechanism. Because the foot is fixed in this closed kinetic chain exercise, it appears that instead subjects are avoiding rotation of the tibia on the talus during SEBT reach. The greater hip flexion torque seen in FAI subjects in these reach directions helps support this theory.

Foot center of pressure

Poorer balance, as identified as greater center of pressure sway during static single-leg balance, has been touted as a gold standard in functional ankle instability research. Greater postural sway during static balance has been identified as a risk for ankle injury and a component of functional ankle instability.[43, 75] However, because ankle sprains and complaints of functional ankle instability occur during dynamic movement, there is a need for the investigation of center of pressure measures during such tasks. Due to the lack of reach distance differences between FAI and control subjects, this variable is one explanation of an inherent reach strategy difference between groups at the hip, knee, and ankle. Unlike previous works [75], this study did not find differences in area of the 95% confidence ellipse or sway pattern. However, the speed at which FAI subjects controlled their postural sway (sway velocity) did differ in both the medial/lateral and anterior/posterior directions.

Medial-Lateral Sway Velocity

Time To Stabilization[71, 74] and force plate measurements after an ankle perturbation[11, 12] have identified differences between FAI and injured subjects, but postural sway has not been investigated during SEBT performance. The use of traditional COP measures for this dynamic balance task is feasible because the SEBT requires that the foot remain in contact with the force plate during SEBT performance. Contrary to static balance results,[75] FAI subjects exhibited *decreased* sway velocity during SEBT reach. In the medial-lateral sway direction, FAI subjects had slower sway velocity under a combination of conditions. A significant three-way tape by method by group interaction was present, with post-hoc testing showing that FAI sway velocity was significantly slower than control subjects for each of the four tape/method combinations (Figure 21). A tape x direction x group interaction also identified significantly lower medial-lateral sway velocity in FAI subjects for both tapes in all three directions (Figures 21-23).

Anterior-Posterior Sway Velocity

Similar results were found in the anterior-posterior direction. Post-hoc tests on a tape by method by group interaction showed that FAI subjects had decreased sway velocity under all tape/method combinations when compared with control subjects (Figure 24). There were no within group differences. A method x direction x group interaction showed that this effect was evident across all directions. FAI subjects had slower A-P sway velocity than control subjects in all three reach directions (Figures 25, 26).

Due to the lack of reach distance differences between FAI and control subjects, this variable is one explanation of an inherent reach strategy difference between groups at the hip and knee. These results are similar to Nakagawa et al.,[6]who also found no significant difference in SEBT scores, but did find differences in COP measures. They suggest SEBT was not sensitive enough to detect deficits in the overall function of the ankle joint. The results of this study show that is extremely difficult to isolate analysis to just the ankle joint when it is part of the entire lower extremity kinetic chain. It is evident through the results of this study that FAI subjects exhibit differences in the other joints of the lower extremity.

Tape

It is possible that there was a regional neuromuscular effect from the tape at the ankle. Baier et al.[125] found subjects had decreased sway velocity with the use of an ankle orthosis. Leanderson et al.[12, 126] found decreased mean sway and maximum sway post-tape application and then on difference after exercise with or without tape. These studies proposed that the tape and orthosis provided increased afferent input through the skin receptors, which enhanced, or "normalized" the movement, rather than provided a prophylactic effect. If this is the case, the use of Kinesio tape would be supported through this mechanism, as by design, Kinesio tape is inherently flexible and supposed to enhance afferent input through skin receptors. Evidence of published studies has yet to fully identify this mechanism.[118]

However, because the effect in the current study was seen with both taping conditions and both methods in FAI subjects, it appears that the *presence* of tape is what actually had an effect. Matsusaka et al.[13] had an FAI group perform rehabilitation exercises over a period of 10 weeks using a single strip of tape over the lateral peroneal tendons. The results showed that these subjects were able to achieve uninjured postural sway levels faster than a control FAI group who did not use the tape during rehabilitation. The lateral taping method used in this study was similar to that of Matsusaka, and interestingly was able to affect performance one a single task during a one day testing period. Thus, it may be the case that tape does not need to be applied continually in order to have an effect.

It is also possible that the decreased velocity is an attempt to remain more stable during reach by decreasing the variability of movement at the ankle and foot. In other words, FAI subjects were inherently more "cautious" during reach performance in order to ensure they performed the task within the confines of the task rules (reach as far as possible, don't lift the foot), and therefore self-constrained their movement in order to fully comply with the rules. However, it is not possible to detect this ex-post facto.

Subjective Taping Questionnaire

Subjects completed a questionnaire regarding their feelings about the tape's effect during testing. Using a 10-point Likert scale, subjects were asked to compare each taping condition to the no tape condition for four subjective aspects: performance ability, comfort, ankle stability, and confidence. Higher scores indicated more favorable ratings (Appendix 4). The results of one-way ANOVAs showed that subjects had significantly higher ratings for performance enhancement, tape comfort, ankle stability, and performance confidence under at least one tape/method combination when compared with control subjects. When rating comfort of the white tape/Kinesio method combination, FAI subjects scored this significantly higher when compared with control subjects. Many subjects, both FAI and control, complained that this tape/method combination was restrictive and painful during SEBT performance. However, it may be the case that FAI subjects are more used to employing an ankle brace and/or tape and therefore had an inherently different interpretation of the tape/method combination. The Kinesio tape/lateral method combination was significantly more effective for increasing feelings of ankle stability in FAI subjects compared to control subjects. Again, this may be the case of FAI subjects being accustomed to using tape as a prophylaxis.

Pre-existing vs. resultant mechanism

Whether the differences found in this study are due to a pre-existing neuromuscular mechanism or are a result of functional ankle instability still remains unclear. Plisky et al.[123] conducted a prospective study using the SEBT to determine if reach was a predictor of lower extremity injury in 235 high school basketball players. Reach distance on each leg, as well as reach distance difference between legs, and total combined reach was calculated for the anterior, posteromedial and posterolateral directions. A cutoff point of 4.0cm difference was used to identify those at risk, having identified this distance through an ROC analysis. In the posteromedial direction, decreased normalize reach, and composite reach was significantly associated with lower extremity injury. However, these results were not broken out across those with previous injuries or those who used taping or bracing during activity. Also, Plisky[123] used the theory of "limb imbalance", where a decreased reach on one leg was treated as a risk factor for injury on either limb, making it harder to identify which factors exactly were preexisting. There is a need for further prospective studies using movement analysis on functional performance tests in order to specifically identify pre-existing factors that appear to influence injury. If this is possible, specific strategies to avoid lateral ankle sprains may be developed and tested.

Clinical Relevance

The results of this study show that an ankle injury has an effect on the entire lower extremity on the injured side. Clinicians should be mindful of treating ankle injuries in isolation, as other aspects are clearly affected. Clinicians may also choose to employ tape at the ankle with rehabilitation exercises in order to influence proximal movement at the knee and hip, which should not be neglected when treating the ankle. Tape may also be effective in increasing FAI subjects' feelings of performance enhancement, confidence and stability.

Conclusions

The purpose of this research study was to identify particular reach strategies on the SEBT in FAI subjects using 3-D kinematic and kinetic components. A second purpose was to consider the effects of type of tape and application method on SEBT performance in FAI subjects. The most important findings of this study are as follows:

1) No reach distance differences were detected in any direction, under any condition tested.
2) FAI subjects exhibited *greater* spinal flexion than control subjects under both methods in all three reach directions.

3) FAI subjects had *greater* hip flexion torque means when compared with control subjects under all tape/method conditions in the AM and M reach directions.
4) In the PM reach direction, FAI subjects exhibited *lower* hip flexion torque means than control subjects under the white tape/lateral method and Kinesio tape/Kinesio method conditions.
5) FAI subjects showed *greater* knee flexion angles versus control subjects in all three reach directions.
6) FAI subjects had *lower* rotational knee torque in the all three directions.
7) FAI subjects exhibited significantly *lower* rotational ankle torque than control subjects.
8) FAI subjects exhibited *decreased* medial-lateral sway velocity during SEBT reach.
9) FAI subjects exhibited *decreased* anterior-posterior sway velocity during SEBT reach.

In conclusion, FAI subjects' functional performance, as defined through SEBT reach distance, does not differ from control subjects. However, the strategy used for the functional performance clearly differs. Adequate care was taken to ensure proper rest was given between each taping condition and reach direction so as not to fatigue subjects. Therefore the results show FAI subjects used more spinal flexion, hip abduction, and knee flexion, as well as had greater hip flexion torque, lower knee and ankle rotational torques, and decreased center of pressure sway velocity. The combination of these movements in FAI subjects appear to place each joint of the lower extremity in its most stable (closed-pack) position. Essentially, it appears that FAI subjects are "stacking" the joints in order to produce a stable base while the reach leg goes furthest away from the midline. The use of tape appears to influence these variables to a certain extent, and may be beneficial for rehabilitation.

Suggestions for Future Research

A prospective movement analysis study on lateral ankle sprains and any functional ankle instability that results from the initial injury should be conducted in order to help identify any pre-existing mechanisms. If these can be identified, an intervention may be planned and implemented with hopes of decreasing the injury rate, or at least decreasing the long lasting effects of functional ankle instability. Secondly, the use of EMG in conjunction with movement analysis in FAI and control subjects may help highlight any neuromuscular timing events that occur during SEBT performance. This may give further insight in to reach strategy differences. Thirdly, more studies using tape as a rehabilitation tool should be conducted to see if the kinematic and kinetic effects last over time. Fourth, there were no center of mass location differences in any plane at maximum reach, despite movement pattern differences. It is possible that the path the center of mass traveled from the initiation to the termination of reach differs between subjects, and therefore should also be investigated.

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APPENDIX 1

INJURY HISTORY SURVEY

Instructions:
This form will be used to categorize your injury history. Please fill out the form completely and give additional information as requested. If you have any questions, please ask the administrator of the survey. Thank you for your participation.

1. Have you ever had an injury to your hip or thigh? ❑Yes ❑No
   If yes, please explain. Include side, body part, injury, and date of injury (ex., right

   hamstring strain 7/00)

   Side (Right or Left) **Injury** **Date**

   ___________ _____________________________ _____________
   ___________ _____________________________ _____________

2. Have you ever had an injury to your knee? ❑Yes ❑No
   If yes, please explain. Include side, body part, injury, and date of injury.

   Side(Right or Left) **Injury** **Date**

   ___________ _____________________________ _____________
   ___________ _____________________________ _____________

3. Have you ever had an injury to your leg below the knee? ❑Yes ❑No
   If yes, please explain. Include side, body part, injury, and date of injury.

   Side(Right or Left) **Injury** **Date**

   ___________ _____________________________ _____________
   ___________ _____________________________ _____________

4. Have you ever had an injury to your ankle or foot? ❑Yes ❑No
   If yes, please explain. Include side, body part, injury, and date of injury.

   Side(Right or Left) **Injury** **Date**

   ___________ _____________________________ _____________
   ___________ _____________________________ _____________

5. Please indicate your gender: ❑Male ❑Female

6. Please circle the number that best describes your physical activity level:

Level	**Activity**
5	Competitive participation in sports that include jumping, turning, or twisting sports (ie. Volleyball, basketball, soccer) at least three (3) hours per week
4	Recreational participation in sports that include jumping, turning, twisting sports (ie. Volleyball, basketball, soccer) at least three (3) hours per week
3	Jog, bike, swim, with occasional participation in twisting sports like volleyball, basketball, or soccer at least three (3) hours per week
2	Regularly jog, bike, or swim at least three (3) hours per week
1	Occasionally jog, bike, or swim

APPENDIX 2

Cumberland Ankle Instability Tool

The CAIT Questionnaire

	Left	Right	Score
1. I have pain in my ankle			
Never			5
During Sport			4
Running on uneven surfaces			3
Running on level surfaces			2
Walking on uneven surfaces			1
Walking on level surfaces			0
2. My ankle feels UNSTABLE			
Never			4
Sometimes during sport (not every time)			3
Frequently during sport (every time)			2
Sometimes during daily activity			1
Frequently during daily activity			0
3. When I make SHARP turns, my ankle feels UNSTABLE			
Never			3
Sometimes when running			2
Often when running			1
When walking			0
4. When going down the stairs, my ankle feels UNSTABLE			
Never			3
If I go fast			2
Occasionally			1
Always			0
5. My ankle feels UNSTABLE when standing on ONE leg			
Never			2
On the ball of my foot			1
With my foot flat			0

6. My ankle feels UNSTABLE when

Never			3
I hop side to side			2
I hop on the spot			1
When I jump			0

7. My ankle feels UNSTABLE when

Never			4
I run on uneven surfaces			3
I jog on uneven surfaces			2
I walk on uneven surfaces			1
I walk on a flat surface			0

8. TYPICALLY, when I star to roll over (or "twist") on my ankle, I can stop it

Immediately			4
Often			3
Sometimes			2
Never			1
I have never rolled over on my ankle			0

9. After a TYPICAL incident of my ankle rolling over, my ankle returns to "normal"

Almost immediately			4
Less than one day			3
1-2 days			2
More than 2 days			1
I have never rolled over on my ankle			0

*NOTE: The scoring scale is on the right. The scoring system is not visible on the subject's version

APPENDIX 3

Functional Ankle Disability Index - Sport

Foot and Ankle Disability Index Sport

Please answer every question with one response that most closely describes your condition within the past week. If the activity in question is limited by something other than your foot or ankle, mark N/A.

DIFFICULTY	4 = no difficulty at all	3 = slight difficulty	2 = moderate difficulty
	1 = extreme difficulty	0 = unable to do	N/A = not applicable
PAIN	4 = no pain	3 = mild pain	2 = moderate pain
	1 = severe pain	0 = unbearable	N/A = not applicable

		Left	**Right**
Running			
	Difficulty		
	Pain		
Jumping			
	Difficulty		
	Pain		
Landing			
	Difficulty		
	Pain		
Squatting and stopping quickly			
	Difficulty		
	Pain		

Cutting, lateral movements

Difficulty		
Pain		

Low-impact activities

Difficulty		
Pain		

Ability to perform activity with your normal technique

Difficulty		
Pain		

Ability to participate in your desired sport as long as you would like

Difficulty		
Pain		

**Scores are recorded as a percentage of 32 points

APPENDIX 4

Subjective Taping Questionnaire

Using the scales below, please rate the following questions based on your experience today.

1. Compared to no tape, how much did the taping affect your performance?

|____|____|____|____|____|____|____|____|____|____|
0 1 2 3 4 5 6 7 8 9 10
Extremely diminished ... **Extremely enhanced**

First leg	**Second leg**
Condition 1______________________	Condition 1________________________
Condition 2______________________	Condition 2________________________
Condition 3______________________	Condition 3________________________
Condition 4______________________	Condition 4________________________

2. How comfortable was the tape during your performance of each condition?

|____|____|____|____|____|____|____|____|____|____|
0 1 2 3 4 5 6 7 8 9 10
Extremely uncomfortable ... **Extremely comfortable**

First leg	**Second leg**
Condition 1______________________	Condition 1________________________
Condition 2______________________	Condition 2________________________

Condition 3______________________ Condition 3________________________

Condition 4______________________ Condition 4________________________

3. Compared to no tape, how stable did your ankle feel during your performance of each condition?

|____|____|____|____|____|____|____|____|____|____|

0 1 2 3 4 5 6 7 8 9 10

Extremely unstable — **Extremely stable**

<u>First leg</u> **<u>Second leg</u>**

Condition 1______________________ Condition 1________________________

Condition 2______________________ Condition 2________________________

Condition 3______________________ Condition 3________________________

Condition 4______________________ Condition 4________________________

4. Compared to no tape, how confident were you during your performance of each condition?

|____|____|____|____|____|____|____|____|____|____|

0 1 2 3 4 5 6 7 8 9 10

Extremely unconfident — **Extremely confident**

<u>First leg</u> **<u>Second leg</u>**

Condition 1______________________ Condition 1________________________

Condition 2______________________ Condition 2________________________

Condition 3______________________ Condition 3________________________

Condition 4______________________ Condition 4________________________

APPENDIX 5

Reach Distance RM ANOVA Significance

	Effect Tape		Method		Direction		Tape*Method		Tape*Direction		Method*Direction		Tape*Method *Direction	
	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
Reach Distance	.10	.76	3.49	.07	34.62	<.005	4.77	.04	.23	.79	1.65	.20	.54	.59

APPENDIX 6

Reach Distance Group Interaction Significance on RM ANOVA

	Effect													
	Tape*Group		Method*Group		Direction*Group		Tape*Method *Group		Tape*Direction *Group		Method*Direction*Group		Tape*Method* Direction*Group	
	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
Reach Distance	.68	.42	.61	.44	1.06	.35	.29	.59	.42	.66	.34	.71	.35	.71

APPENDIX 7

Kinetic Variables for RM ANOVA Significance

	Effect Tape		Method		Direction		Tape*Method		Tape*Direction		Method*Direction		Tape*Method *Direction	
Kinetic Variables	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
Hip Flexion Torque	.49	.49	8.98	.005	28.25	<.005	.08	.78	1.39	.25	.86	.43	.66	.52
Hip Abduction Torque	3.00	.96	.09	.77	44.00	<.005	5.65	.02	.38	.69	1.17	.32	1.75	.18
Hip Rotation Torque	.48	.50	.22	.65	31.44	<.005	.28	.60	.15	.87	1.27	.29	.33	.72
Knee Flexion Torque	.06	.81	3.32	.08	4.06	.02	2.67	.11	5.83	.004	2.61	.08	3.65	.03
Knee Valgus Torque	.53	.47	38.00	<.005	33.10	<.005	.11	.75	.21	.81	1.41	.25	.26	.77
Knee Rotation Torque	.24	.63	1.90	.18	13.83	<.005	.66	.42	1.73	.18	.15	.86	.71	.49
Ankle Dorsiflexion Torque	10.36	.003	54.39	<.005	277.68	<.005	1.21	.28	.75	.48	.71	.46	3.95	.02
Ankle Inversion Torque	3.73	.06	6.34	.02	12.67	<.005	.28	.6	.3	.74	3.06	.07	.50	.61
Ankle Rotation Torque	3.86	.06	14.39	.001	34.64	<.005	.05	.82	.44	.65	11.46	<.005	.78	.46

APPENDIX 8

Kinetic Variables for Group Interaction Significance on RM ANOVA

Kinetic Variables	Effect Tape*Group F-value	Tape*Group P-value	Method*Group F-value	Method*Group P-value	Direction*Group F-value	Direction*Group P-value	Tape*Method *Group F-value	Tape*Method *Group P-value	Tape*Direction *Group F-value	Tape*Direction *Group P-value	Method*Direction*Group F-value	Method*Direction*Group P-value	Tape*Method* Direction*Group F-value	Tape*Method* Direction*Group P-value
Hip Flexion Torque	.10	.75	.23	.64	.67	.51	.04	.84	.42	.66	.08	.92	3.26	.04
Hip Abduction Torque	.14	.71	.48	.5	1.28	.29	.58	.5	.49	.62	.76	.45	.11	.90
Hip Rotation Torque	.14	.71	.03	.86	1.23	.3	.24	.63	.3	.75	.79	.5	.26	.77
Knee Flexion Torque	1.63	.21	.54	.47	1.21	.3	.68	.41	1.11	.34	2.13	.13	.96	.39
Knee Valgus Torque	.68	.42	1.54	.22	1.44	.25	.21	.65	.02	.98	.43	.65	1.24	.30
Knee Rotation Torque	1.46	.23	.48	.49	3.65	.03	.16	.69	.83	.44	2.10	.13	.96	.39
Ankle Dorsiflexion Torque	3.04	.09	.04	.85	1.46	.24	.42	.52	.01	.99	.25	.78	2.09	.13
Ankle Inversion Torque	.41	.53	1.30	.26	.05	.95	.02	.90	.54	.59	.03	.97	.71	.49
Ankle Rotation Torque	1.29	.26	3.03	.09	3.81	.03	.08	.77	1.36	.26	2.54	.09	1.02	.37

APPENDIX 9

Kinematic Variables for RM ANOVA Significance

Kinematic Variables	Effect Tape		Method		Direction		Tape*Method		Tape*Direction		Method*Direction		Tape*Method *Direction	
	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
Center of Mass Sagittal Plane	.34	.56	.86	.36	.18	.84	.77	.39	.57	.57	.37	.69	.40	.67
Center of Mass Frontal Plane	.21	.65	.004	.948	38.73	<.005	.20	.66	.03	.97	.30	.74	.22	.81
Center of Mass Transverse Plane	.002	.96	1.72	.20	38.64	<.005	.73	.4	.48	.62	.32	.72	.17	.85
Thorax Flexion Angles	.21	.65	.09	.76	9.35	<.005	2.63	.11	.62	.54	.67	.62	.15	.86
Thorax Lateral Flexion Angles	.32	.58	.16	.69	25.48	<.005	.10	.76	.02	.98	1.01	.37	.05	.96
Thorax Rotation Angles	.57	.46	3.45	.07	3.70	.03	.19	.67	.53	.59	.35	.69	.86	.43
Spine Flexion Angles	.05	.82	4.22	.05	163.19	<.005	2.09	.16	.57	.57	.62	.54	.59	.56
Spine Lateral Flexion Angles	.14	.71	.20	.66	40.90	<.005	.35	.56	.98	.93	1.07	.35	.06	.94
Spine Rotation Angles	.33	.86	1.41	.24	9.73	<.005	.35	.56	.75	.48	.93	.40	.50	.61
Pelvic Anterior Tilt Angles	.01	.91	6.76	.01	144.87	<.005	.76	.47	.76	.47	.57	.57	1.54	.22
Pelvic Obliquity Angles	.35	.56	.001	.97	27543	<.005	.35	.56	1.31	.28	2.26	.11	.16	.85

Pelvic Rotation Angles	.13	.72	.95	.34	8.38	.001	.47	.50	.77	.50	.90	.41	.61	.55
Hip Flexion Angles	.09	.77	11.18	.002	206.09	<.005	.05	.82	.52	.60	1.42	.25	1.13	.33
Hip Abduction Angles	.11	.75	4.06	.05	32.3	<.005	.92	.34	4.27	.02	.03	.97	4.12	.02
Hip Rotation Angles	.83	.37	2.06	.16	60.78	<.005	1.26	.27	2.22	.17	1.13	.33	.20	.82
Knee Flexion Angles	1.82	.19	29.52	.05	24.65	<.005	4.24	.05	.62	.54	.59	.53	.07	.93
Knee Valgus Angles	1.45	.24	.02	.89	7.04	.002	8.97	.005	.94	.4	1.13	.33	.08	.92
Knee Rotation Angles	.88	.35	54.75	<.005	5.98	.004	.39	.54	1.15	.32	.64	.53	.96	.39
Ankle Dorsiflexion Angles	.64	.43	27.04	<.005	78.24	<.005	.01	.91	1.20	.31	1.54	.23	.18	.84
Ankle Inversion Angles	.003	.96	15.88	<.005	1.68	.19	.65	.43	.97	.39	1.22	.28	.79	.46
Ankle Rotation Angles	11.72	.002	23.94	<.005	1.86	.16	1.56	.22	.85	.43	.79	.46	1.60	.21

APPENDIX 10

Kinematic Variables for Group Interaction Significance on RM ANOVA

	Effect Tape*Group		Method*Group		Direction*Group		Tape*Method *Group		Tape*Direction *Group		Method*Direction *Group		Tape*Method *Direction*Group	
Kinematic Variables	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
Center of Mass Sagittal Plane	.04	.84	.09	.77	.07	.93	.25	.62	.56	.56	2.92	.06	.26	.78
Center of Mass Frontal Plane	1.67	.20	.18	.68	1.62	.20	1.32	.26	1.15	.32	.34	.71	20.09	.80
Center of Mass Transverse Plane	.28	.60	.52	.47	.01	.99	.30	.59	.19	.83	.75	.47	1.98	.15
Thorax Flexion Angles	1.44	.24	.07	.80	.25	.78	.25	.62	1.07	.35	1.43	.25	1.92	.15
Thorax Lateral Flexion Angles	.47	.52	2.76	.11	.26	.78	2.94	.10	1.57	.22	.16	.85	.78	.46
Thorax Rotation Angles	.06	.80	2.06	.16	1.66	.20	.006	.94	.07	.94	.23	.79	.03	.97
Spine Flexion Angles	..99	.33	.65	.43	.30	.74	.69	.41	.32	.64	3.08	.05	1.44	.24
Spine Lateral Flexion Angles	.50	.83	1.47	.23	.55	.58	.96	.39	.08	.79	.14	.87	.55	.50
Spine Rotation Angles	.10	.75	.02	.90	.61	.55	.95	.34	.06	.94	1.78	.18	.23	.80
Pelvic Anterior Tilt Angles	.99	.33	.58	.45	.15	.86	.12	.89	.12	.89	2.96	.06	1.53	.23
Pelvic Obliquity Angles	.14	.71	.003	.96	.34	.71	1.31	.28	.34	.72	.65	.52	.66	.52

Pelvic Rotation Angles	.03	.86	.26	.61	.52	.60	.88	.35	.07	.94	1.53	.22	.29	.75
Hip Flexion Angles	.56	.46	.06	.80	1.93	.15	.05	.83	.04	.96	.71	.50	1.75	.18
Hip Abduction Angles	.003	.96	.87	.36	1.00	.91	.005	.94	.74	.48	.24	.79	3.87	.03
Hip Rotation Angles	.53	.47	.02	.90	.31	.74	4.48	.04	2.05	.14	.47	.63	.28	.69
Knee Flexion Angles	.22	.65	.92	.89	5.21	.09	.14	.71	.11	.90	1.87	.16	.65	.52
Knee Valgus Angles	2.48	.12	.33	.57	.89	.42	1.00	.32	.45	.64	2.16	.12	.51	.60
Knee Rotation Angles	1.00	.75	1.82	.19	.52	.59	.34	.56	1.25	.29	.13	.88	1.62	.21
Ankle Dorsiflexion Angles	.03	.86	.64	.43	.50	.61	.32	.58	.03	.97	.07	.93	.29	.75
Ankle Inversion Angles	.90	.35	2.64	.11	.27	.76	1.94	.17	.87	.42	1.00	.37	1.19	.31
Ankle Rotation Angles	.15	.70	.56	.46	3.84	.03	.02	.90	1.27	.29	.88	.42	.34	.71

APPENDIX 11

Force Plate Variables for RM ANOVA Significance

	Effect													
	Tape		Method		Direction		Tape*Method		Tape*Direction		Method*Direction		Tape*Method *Direction	
Force Plate Variables	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value	F-value	P-value
Area 95	.61	.44	2.27	.14	.89	.42	1.17	.29	1.59	.21	.77	.47	1.19	.31
Center of Pressure Sway Pattern – A/P	.77	.39	2.19	.15	.49	.62	2.75	.11	2.56	.08	.21	.77	2.28	.11
Center of Pressure Sway Pattern – M/L	1.00	.76	2.58	.12	.31	.74	.47	.50	.07	.93	.01	.92	.66	.52
Center of Pressure Sway Velocity – A/P	.13	.72	.12	.73	.82	.44	.38	.54	.48	.62	.52	.60	5.30	.01
Center of Pressure Sway Velocity – M/L	.21	.65	.70	.41	1.51	.23	.53	.47	1.41	.25	1.40	.25	3.05	.05

APPENDIX 12

Force Plate Variables for Group Interaction Significance on RM ANOVA

Force Plate Variables	Effect Tape*Group F-value	P-value	Method*Group F-value	P-value	Direction*Group F-value	P-value	Tape*Method *Group F-value	P-value	Tape*Direction *Group F-value	P-value	Method*Direction *Group F-value	P-value	Tape*Method *Direction*Group F-value	P-value
Area 95	1.55	.22	.13	.72	.83	.44	3.02	.09	.68	.51	.97	.38	.95	.40
Center of Pressure Sway Pattern – A/P	.28	.60	.09	.77	.62	.54	1.27	.27	.82	.44	.43	.65	1.38	.26
Center of Pressure Sway Pattern – M/L	1.34	.26	.23	.64	1.84	.17	1.31	.26	1.00	.91	1.72	.19	.50	.61
Center of Pressure Sway Velocity – A/P	.08	.76	.76	.39	1.54	.22	4.47	.04	3.39	.04	1.06	.35	1.30	.28
Center of Pressure Sway Velocity – M/L	.58	.45	.52	.48	.17	.85	4.17	.05	1.94	.17	3.07	.07	.47	.63

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Post Graduate Training

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Employment History

- August 2004-May 2008, Research Assistant

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- October 2003-June 2004, Certified Athletic Trainer

  Pacific Athletic and Industrial Rehabilitation

- August 2002-June 2003, Intern Certified Athletic Trainer

  University of the Pacific

- August 2000-June 2002, Graduate Assistant Certified Athletic Trainer,

  University of California, at San Diego

Professional Society Memberships

- June 1999-present, Member, National Athletic Trainer's Association
- March 2007-present, Member, German Society for Biomechanics

Honors and Awards

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  Poster Presentation Award

Publications

Peer-reviewed journal articles

1. Arnold BL, **de la Motte SJ**, Linens SW, Ross SE. Functional ankle instability is associated with balance impairments: a meta-analysis. *Med Sci Sports Exerc*. 2008; In press.

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1. **de la Motte SJ**, Arnold BL, Ross SE. Ankle rotational torque is significantly lower in FAI subjects on the Star Excursion Balance Test. American College of Sports Medicine Annual Meeting, May 27-30, 2009.
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