GAIT KINEMATICS IN THOSE WITH CHRONIC ANKLE INSTABILITY

A Dissertation

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by

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ABSTRACT

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The purpose of this dissertation was to compare lower extremity kinematics in those with and without chronic ankle instability (CAI) and to determine if: 1) there are knee or hip kinematic differences between groups; 2) there are differences in movement variability between groups; 3) any kinematic changes occur at the ankle or knee while wearing tape; and 4) any clinical measures are able to predict maximum inversion during the swing phase of gait.

A total of thirty-nine physically active participants volunteered for the first study, fifteen with self-reported CAI, 11 individuals with a history of one ankle sprain, and 13 healthy controls. The first study, conducted in a motion analysis laboratory, found that while jogging, compared to controls, subjects with CAI had greater knee flexion during the mid to late phase of swing. This study also found that during unloading and swing subjects with CAI presented with more movement variability than controls.

Fifteen physically active subjects with self-reported chronic ankle instability volunteered for the second study. Subjects reported to a motion analysis laboratory where they were fitted for shoes and randomly assigned a testing order of two conditions, un-taped and taped. Subjects walked then jogged on a treadmill while kinematic data was collected. CAI subjects exhibited different ankle sagittal and frontal plane kinematics during multiple aspects of the gait cycle while taped compared to the un-taped condition. No changes were noted at the knee.

Twenty-six subjects with a history of ankle sprain completed two visits for study three. The first consisted of measuring various clinical measures. The second visit occurred in a motion analysis system. Subjects jogged in shoes on a treadmill while maximum inversion during swing was recorded. Regression analyses were conducted to determine which clinical measures could

best predict maximum inversion. While jogging, self-reported function and instrumented ligament laxity in the anterior direction were predictors of maximum inversion.

In conclusion, this study found that CAI subjects have different gait patterns compared to controls while in shoes. Identifying differences is the first step in establishing rehabilitation programs that may best prevent future ankle sprains.

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APPROVAL OF THE DISSERTATION

This dissertation, "Gait kinematics in those with chronic ankle instability," has been approved by the Graduate Faculty of the Curry School of Education in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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CHAPTER 1

INTRODUCTION

Background of the problem:

Lateral ankle sprains are very common in the general population, military personnel, and athletes.[1-4] Some individuals, termed copers, have a history of an ankle sprain, but fully recover and return to their previous level of activity with no residual problems.[5,6] Others that sprain their ankle, however, with a history of at least one previous ankle sprain go on suffer multiple sprains.[7-9] The occurrence of repetitive bouts of lateral ankle instability resulting in numerous ankle sprains is termed chronic ankle instability (CAI).[10] Those with a history of ankle sprains, copers and CAI, have been reported to have alterations in simple proprioceptive[11-14] and mechanical tasks.[15-18]

Several researchers have theorized that alterations in movement kinematics may occur in those with CAI which may predispose them to future injuries. Studies evaluating movement kinematics between those with a history of ankle sprains compared to healthy controls, during landing, cutting, and gait, have been conducted.[19-29] Although studies have found that individuals with CAI have a more inverted ankle position just prior to heel strike compared to healthy controls,[19,25] there is inconsistencies regarding sagittal plane kinematics.[19,23,25] Although differences have been found, several limitations should be noted. First, the studies were either performed with subjects barefoot or with motion analysis markers attached on the outside of shoes. Barefoot tasks are novel to majority of people and often uncomfortable, thus, differences found between groups may be related to differences in movement strategies to accomplish the required task. Secondly, attaching motion analysis markers to the outside of a shoe may not accurately reproduce the movement of foot and ankle. Research needs to be conducted with subjects shod and motion analysis markers evaluating foot/ankle movements to accurately describe alterations that may occur in those with CAI.

The aforementioned research has focused on ankle and foot kinematics during dynamic tasks. Another notable limitation is the lack of literature reporting proximal joint kinematics. Previous research has reported that subjects with CAI have altered proximal kinematics and neuromuscular stimulation during a variety of tasks.[30-35] Individuals with CAI may utilize different movement strategies at proximal joints to adapt to their pathology. However, there are limited studies evaluating proximal joint kinematics in subjects with CAI while walking and jogging in shoes.

Although research reports kinematic differences in the foot and ankle during dynamic tasks, few studies have been published evaluating typical interventions to correct the kinematic differences. McKeon et al[28] reported gait alterations in those with CAI following a long-term balançe training rehabilitation. Ankle prophylactics, such as ankle taping, are commonly used as a short term intervention to prevent lateral ankle sprains. Although literature has shown that ankle prophylactics reduce the incidence of ankle sprains,[36,37] the specific mechanism behind this reduction is unknown. Lastly, it is unknown if there are no known research investigating the relationship between clinically measured variables with altered gait mechanics. Finding clinical-measured risk factors that predict altered gait patterns may help with the care and rehabilitation of individuals with a history of ankle sprain.

Alterations in gait kinematics may predispose individuals with a history of ankle sprain to further injuries. More applicable research, conducted with methods typical to everyday activities, such as wearing shoes, is needed in order to find effective rehabilitation and improve quality of life in those with a history of ankle sprain.

Research purposes:

Manuscript 1

- The primary purpose of this manuscript was to evaluate hip and knee frontal and sagittal plane ankle kinematics between subjects with CAI and copers and CAI subjects and healthy controls while walking and jogging on a treadmill in shoes.
- The secondary purpose of this manuscript was to evaluate the movement variability in the sagittal and frontal plane kinematics at the ankle, knee and hip between the groups.

Manuscript 2

- The purpose of this manuscript was to evaluate frontal and sagittal plane ankle kinematics in subjects with CAI while walking and jogging shod on a treadmill with and without wearing a traditional ankle tape procedure.
- The secondary purpose was to evaluate sagittal plane knee kinematics to determine kinematic alterations up the kinetic chain.

Manuscript 3

- The purpose of this study was to determine which clinically measured variables (ROM, static balance, dynamic balance, laxity, and subjective function) best predict maximum inversion during the swing phase of gait while jogging in those with a history of ankle sprain.

Research hypotheses:

Manuscript 1

- Individuals with chronic ankle instability will demonstrate more frontal plane adduction at the hip throughout the gait cycle compared to the coper and healthy control groups while walking and jogging.
- Individuals with chronic ankle instability will demonstrate more knee flexion throughout the gait cycle compared to the coper and control groups while walking and jogging.
- The chronic ankle instability group will have more sagittal plane kinematic variability at the hip and knee compared to the coper and healthy control groups while walking and jogging.

Manuscript 2

- In subjects with chronic ankle instability, ankle taping will limit the amount the inversion and plantar flexion compared to a no-tape condition while walking and jogging in shoes on a treadmill.
- In the taped condition, the knee will present with altered sagittal plane kinematics compared to the un-taped condition.

Manuscript 3

- Self-reported function, inversion laxity and dynamic balance will best predict individuals who will be most inverted during the swing phase of gait in those with a history of ankle sprain. Specifically, we believe that the FAAM-S, instrumented inversion laxity, and the Star Excursion Balance Test in the posteriolateral direction will be strong predictors of maximum inversion.

Assumptions:

1. Participants did not alter gait while on treadmill

2. The shoes did not influence the markers during collection

3. The cut outs of the shoes did not disrupt the integrity of the shoes

Delimitations:

1. Participants were physically active between the ages of 18-50 years of age

2. Participants all wore the same brand and style of shoe during data collection

3. Treadmill speed was set at 3.0mph and 6.0mph

4. CAI subjects will have self-reported chronic ankle instability qualified as <90% on FAAM and <80% on FAAM-Sport

5. All subjects were free from ankle sprain for at least six weeks prior to data collection

Limitations:

There are no known limitations at this time.

Operational definitions:

1. Ankle Tape: Prophylactic bracing commonly used to prevent lateral ankle sprains. The taping method includes anchors, stirrups, horseshoes, heel locks and figure-of-eights.
2. Anterior Drawer Test: A clinical test used to determine the laxity of the anterior talofibular ligament. The subject is in a seated position, the clinician stabilizes the distal part of the shank with one hand, with the other an anterior force is applied to the calcaneus. The clinician grades the movement on a scale of 0 to 4 based on the amount of movement (subluxation of the talus from the tibia).
3. Chronic Ankle Instability (CAI): Individuals with a history of recurrent ankle sprains, with the first sprain occurring longer than 12 months ago with lingering

symptoms and disability. Subjects in the CAI group score below an 85% on the Foot and Ankle Ability Measure-Sport scale.

4. Coper: Individuals with a history of one ankle sprain longer than 12 months ago but no recurrent sprains and no lingering symptoms or disability.
5. Dorsiflexion Range of Motion: Osteokinematic movement that occurs at the talocrural joint. This motion occurs in the sagittal plane and results in a decreased angle between the foot and shank.
6. Dynamic Postural Control: Maintenance of the center of mass within the base of support during a function activity This was measured using the Star Excursion Balance Test performed in three directions, anterior, posteriolateral, and posteriomedial.
7. Eversion of the Rearfoot: Osteokinematic movement that occurs at the subtalar joint. This motion occurs in the frontal plane and results in the calcaneus moving away from the midline.
8. Gait Cycle: The period of time for two steps to occur. One gait cycle is measured from initial contact of one foot to the successive initial contact of the same foot. It encompasses stance phase and swing phase.
9. Healthy Control: Individuals with no history of ankle sprain ever.
10. Hip Abduction Range of Motion: Osteokinematic movement that occurs at the hip joint. This motion occurs in the frontal plane and results moving the thigh away from the midline.

11. Hip Adduction Range of Motion: Osteokinematic movement that occurs at the hip joint. This motion occurs in the frontal plane and results moving the thigh towards the midline.

12. Hip Extension Range of Motion: Osteokinematic movement that occurs at the hip joint. This motion occurs in the sagittal plane and results in an increased angle between the thigh and torso.

13. Hip External Rotation Range of Motion: Osteokinematic movement that occurs at the hip joint. This motion occurs in the transverse plane and results in a turning of the thigh outward.

14. Hip Flexion Range of Motion: Osteokinematic movement that occurs at the hip joint. This motion occurs in the sagittal plane and results in a decreased angle between the thigh and torso.

15. Hip Internal Rotation Range of Motion: Osteokinematic movement that occurs at the hip joint. This motion occurs in the transverse plane and results in a turning of the thigh inward.

16. Inversion of the Rearfoot: Osteokinematic movement that occurs at the subtalar joint. This motion occurs in the frontal plane and results in the calcaneus moving toward the midline.

17. Knee Extension Range of Motion: Osteokinematic movement that occurs at the knee joint. This motion occurs in the sagittal plane and results in straightening of the knee.

18. Knee Flexion Range of Motion: Osteokinematic movement that occurs at the knee joint. This motion occurs in the sagittal plane and results in the bending of the knee.
19. Movement Variability: The amount of variability, determined by standard deviation from an individual's mean, in a single plane of motion at a joint.
20. Plantar Flexion Range of Motion: Osteokinematic movement that occurs at the talocrural joint. This motion occurs in the sagittal plane and results in an increased angle between the foot and shank.
21. Pronation Range of Motion: Osteokinematic movement that occurs at the subtalar joint. This motion is a triplanar motion that results in eversion, abduction, and dorsiflexion.
22. Stance Phase of Gait: The weight bearing aspect of the gait cycle. Starts when the foot makes initial contact and ends at toe off.
23. Static Postural Control: Maintenance of the center of mass within the base of support during quiet standing. This was measured using the Balance Error Scoring System in two conditions, single-limb balance on a firm surface and single-limb balance on an unstable surface.
24. Supination Range of Motion: Osteokinematic movement that occurs at the subtalar joint. This motion is a triplanar motion that results in inversion, adduction, and plantar flexion.
25. Swing Phase of Gait: The non-weight bearing aspect of the gait cycle. Starts when at toe off and ends at terminal swing, just prior to initial contact.

26. Talar Tilt Test: A clinical test used to determine the laxity of both the anterior talofibular and the calcaneofibular ligaments. The subject is in a seated position, the clinician stabilizes the medial aspect of the shank with one hand, with the other an inversion force is applied to the calcaneus moving the foot/ankle into inversion. The clinician grades the movement on a scale of 0 to 4 based on the amount of movement and talar tilting.
27. Tibial Rotation Range of Motion: Osteokinematic movement that occurs at the tibiofemoral joint. This motion occurs in the transverse plane and occurs involuntarily during gait.

Significance of the study

This study aims to describe kinematics during gait and find clinical measures that best predict altered kinematics between those with a history of ankle sprains and healthy controls while shod. Evaluating joint kinematics, with and without prophylactics, in those with a history of ankle sprain may elucidate movement strategies adapted in order to accomplish movement tasks. Also, revealing common clinically measured variables that relate to altered gait kinematics can be easily implemented in to ankle sprain evaluations. By exposing different movement strategies and factors related to the movement strategies, researchers and clinicians may better understand how best to care for and rehabilitation lateral ankle sprains.

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CHAPTER 2

REVIEW OF LITERATURE

Introduction

The purpose of this literature review is to: 1) briefly describe the ankle complex, 2) review the spectrum of ankle instability, 3) describe pertinent literature on chronic ankle instability and present two chronic ankle instability models, 4) provide an overview of typical gait kinematics in healthy individuals, 5) review the literature on differences between barefoot and shod kinematics, 6) synthesize published literature on kinematics in individuals with chronic ankle instability, and, 7) discuss current findings on affect of tape.

The Ankle

The ankle complex is comprised of the distal tibiofibular joint, talocrural joint, and subtalar joint, function together to allow a large range of motion. The syndesmotic distal tibiofibular joint is integral to the stability of the ankle complex. Movement between the tibia and fibula at this articulation allow the ankle to adequately perform dorsiflexion and plantar flexion.[1] The talocrural joint is formed by articulations between the trochlea of the talus with the distal tibia and distal fibula. Dorsiflexion and plantar flexion, occurring in the sagittal plane, are the principle motions that occur at the talocrural joint, however some transverse and frontal plane motions also occur.[2] The articulation between the talus and the calcaneus comprise the subtalar joint. Because there are three separate articulations, complex motions occur at the subtalar joint. The subtalar joint has an oblique axis that runs downward, posteriorly in the sagittal plane and laterally in the transverse plane.[3] In the transverse plane, the joint axis is oriented approximately 23° medial to the long axis of the foot. In the sagittal plane the joint axis is approximately 42° relative to the sole of the foot.[3,4] It is important to note that the subtalar joint axis orientation can differ greatly across individuals. At the subtalar joint, the tri-planar motions of supination and pronation occur. Supination is the combined motions of foot adduction, plantar flexion, and inversion. In weight-bearing supination occurs in conjuction with tibial external rotation. Pronation is the combined motions of foot abduction, dorsiflexion, and eversion of the foot. In weight-bearing, pronation occurs in conjuction with tibial internal rotation.

Ligamentous support around the medial and lateral aspects of the ankle complex help provide stability to the region. Medially, the deltoid ligament helps restrict excessive eversion. The ligaments that support the lateral aspect of the ankle are the anterior talofibular ligament (ATFL), the posterior talofibular ligament (PTFL), and the calcaneofibular ligament (CLF). The primary function of the lateral ligaments is to prevent excessive inversion, however the ATFL also help prevent internal rotation of the talus. The boney articulations, joint capsule and lateral ligaments combine to create the stability of the ankle and resist excessive motion. Injury occurs when the ankle, which bears more weight per unit than any other joint in the body,[5] is overloaded.

The muscles that cross the ankle can be divided into four compartments. The anterior compartment is made up of the tibialis anterior, extensor digitorum longus, extensor hallicus longus, and the peroneal terius. The anterior compartment muscles act together to produce dorsiflexion. The lateral compartment, consists of the peroneal longus and peroneal brevis, contract to plantar flex and evert the foot. The deep posterior compartment includes three muscles. The posterior tibialis, flexor digitorum longus, and flexor hallicus longus work together to plantar flex the foot. Finally, the superficial posterior compartment consists of the gastrocnemius, soleus, and planteris. These three muscles also plantar flex the foot.

Spectrum of ankle instability

Lateral ankle sprains

Ankle sprains are very common in the general population, military personnel, and athletes. Based on all emergency room visits in the USA, the estimated incidence of ankle sprains is 2.15 per 1000 person-years.[6] Ankle sprains were reported to be the most common ankle injury in the United States Military Academy, accounting for 78% of all ankle injuries.[7] Of just sports-related emergency department visits, one in every five injuries is an ankle sprain.[8] Fong et al,[9] in a systematic review, found that the ankle was the most commonly injured joint among 70 different sports. It is also estimated that up to 55% of individuals who suffer from an ankle sprain do not seek professional treatment,[10,11] indicating that the actual incidence of ankle sprains may be higher than reported.

Lateral ankle sprains (LAS) comprise an estimated 85% of all ankle sprains.[12,13] Specifically, it has been reported that 45% of all basketball injuries and 31% of all soccer injures were LAS.[14] Although sports-related sprains are the most commonly reported, LAS have also been reported to occur from falls from stairs and stumbling on a ground-level surface.[6] The weakest lateral ligament is the ATFL and is usually the first ligament injured in a LAS.[15-18] The CFL is the second most common ligament involved in LAS followed by the PTFL.[15-17]

Many theories have been proposed as to the mechanism of injury for a LAS during dynamic tasks. The typically reported mechanism of injury is excessive inversion, plantar flexion, and internal rotation causing injuries to the lateral ligaments of the ankle.[14,15,19-21] Stormont and colleagues[22] hypothesized that ankle sprains occur during the loading or unloading phases of stance but not during full weight-bearing because of the boney restraints. Interestingly, Konradsen et al[23] conducted a cadaver study and reported that the foot/ankle complex could be placed in an extreme amount of inversion, plantar flexion and internal tibial rotation at initial contact and not sustain an ankle sprain. They reported that if contacted in this position, the foot and ankle would passively stabilize itself by everting.[23] In the same study, it was reported that misjudging the foot-floor clearance by 10° of inversion would cause the lateral aspect of the foot to collide with the ground causing a LAS, bringing into question the timing in the gait cycle of LASs.[23] In a computer-stimulated study,[21] results were reported questioning frontal plane kinematics at initial contact, but emphasized the importance of plantar flexion. Contradictory, in a recent case study in which a subject accidentally suffered a LAS while motion analysis data was collected, it was found that the injury occurred with the foot in more dorsiflexion than plantar flexion.[24] In the case study,[24] injury occurred during the unloading phase of stance, the individual's plantar pressure quickly shifted from the heel to the forefoot following heel strike, indicating a lift of the rear-foot. However, they also found a chaotic pattern for the center of pressure as it shifted forward signifying an unstable foot during unloading.[24] Perhaps the most interesting aspect of the case study is the fact that during the injury trial, kinematic and plantar pressure were extremely different compared to the non-injury trials from heel strike until almost toe off.[24]

Copers

Although a history of a previous LAS is a strong indicator for a future sprain,[25, 11,26-28] not everyone who suffers a LAS goes on to have any prolonged symptoms. In a systematic review, van Rijn concluded that 36-85% of LAS sufferers fully recovery within 3 years.[29] Willems et al[30] was the first group to study individuals who had a history of an ankle sprain with no complaints of instability. In their study, they formed 4 groups, individuals with no history of LAS, individuals with a history of more than 3 LAS with frequent giving-way episodes, individuals with a history of 3 or less LAS within 2 years of data collection and no complaints of instability, and individuals with a history of 3 or less ankle sprains, 3-5 years prior to data collection, and no complaints of instability.[30] The results of the study found that both groups of subjects with a history of ankle sprains but no feelings of instability were not statistically different than healthy subjects for ankle proprioception or invertor and evertor concentric and eccentric muscle strength.[30]

The term "coper" was first introduced in the ankle literature by Hertel and Kaminski in 2005[31]. The term, historically associated with anterior cruciate ligament literature,[32-34] was defined as an individual who had suffered an initial ankle sprain but no subsequent injuries.[31] Brown and colleagues[35] further defined coper to include individuals with a prior history of ankle sprain who had not suffered an ankle sprain within a year prior to data collection. Limiting the definition to those who are at least 12 months post-LAS reduces the risk of including individuals who still felt residual symptoms from initial injury.[36] Most researchers who use a coper group only included those who report little or no physical disability as scored on subjective questionnaires.[35,37-41] Wikstrom et al[39] have also defined their copers as individuals who have returned to pre-injury activity level without limitation to ensure that copers have not modified lifestyle to avoid chance of recurrent instability. Although the definition of coper is still evolving, researchers believe the use of a coper comparison group may best establish appropriate rehabilitation strategies following a LAS to likelihood of developing chronic ankle instability.[30,31,35,37-41]

Chronic Ankle Instability

Although an estimated 36-85% of those who suffer a LAS will fully recover, becoming a coper,[29] some of the population will suffer from multiple sprains, lingering symptoms including pain and/or disability. Up to an estimated 80% of athletes who sprain their ankle had previously suffered an ankle sprain.[42-44] Residual symptoms following a LAS have been reported to last up to 7 years post injury.[42-45] Chronic ankle instability (CAI) has been defined as the occurrence of repetitive bouts of lateral ankle instability resulting in numerous ankle sprains.[46] Those with CAI most often complain of pain, instability, or feelings of "giving way", with many complaining of more than one symptom.[42-45] Long-term consequences of CAI include interference with occupational and athletic participation[44,45] and increased risk of osteoarthritis and degenerative joint disease.[47-50] Historically, CAI has been attributed to two causes: mechanical instability (MI) or functional instability (FI).[51-53] Hertel[46] proposed a model in which MI and FI can occur separately or conjunction with each other.

<u>Chronic Ankle Instability</u>

Mechanical instability

MI results from anatomic changes,[46] and most often results in abnormal joint mechanics. MI is most often determined by abnormal joint range of motion, involving osteokinematics, arthrokinematics, or both. The most commonly reported MI alteration is pathological laxity. [51,54-56] Following ligamentous disruption to the ATFL and or the CFL, motion between the subtalar joint and the talocural joint can increase. Cadaver studies have shown that sectioning of the ATFL can lead to increased motion and the lack of the ATFL in combination with the CFL further increases the laxity.[56-58] Hubbard at el,[59] in a systematic review of the literature, concluded that following an acute LAS approximately 30% of individuals had objective mechanical laxity up to a year later. Although a definite link could not be made, the researchers believe that the increased laxity can be attributed to improper or incomplete healing of the lateral ligaments.

Although increased laxity is the most commonly reported, hypomobility, and arthrokinematic restrictions, can also contribute to MI.[60,61] Following an acute LAS, there is often a loss of range of motion, most typically dorsiflexion.[62,63] This can be due to edema, muscle tightness or from arthrokinematic changes. Many rehabilitation protocols focus on stretching of the triceps surae complex to regain full range of motion.[8,64,65]. Although tightness in the triceps surae complex probably affects the ankle joint range of motion, disruption of the required accessory motions at the talocrural and distal tibial-fibular joints probably contribute more in the reduced dorsiflexion. In order to dorsiflex at the talocrural joint, the distal fibula must glide posteriorly and rotate laterally. This movement opens up the anterior portion of the ankle mortise to allow the talus to glide posteriorly . Following a LAS, the talus has been found to be in an abnormally anterior position,[66] shifting the talocrural joint axis and thus causing restrictions in posterior glide have been found.[62,67]

Laxity tests

Ligament laxity can be measured by manual exam or by instrumented measures. The anterior drawer and talar tilt tests are both manual stress tests frequently used during clinical examinations by sports medicine practitioners. Manual muscle tests were traditionally scored on a 4-point grading scale[68] with zero representing "no laxity" and three representing "gross laxity". Recently, with the insight of hypomobility potentially occurring, Denegar et al[62] expanded the laxity scoring system. In their study, zero "represented hypomobility" and four to represent "gross laxity."

The anterior drawer test assesses for anterior displacement of the talus within the mortise.[68] During the anterior drawer test the shank is supported while the clinician grips the calcaneous and produces an anterior force causing the talus to glide forward. Clinicians then try to score the amount of anterior movement. The talar tilt test is used to assess for excessive inversion of the talus within the motise.[68] To conduct the talar tilt test, clinicians support the shank while inverting the calcaneous. Again, clinicians subjectively score the amount of rotation that occurs at the subtalar joint. Fujii et al[69] conducted a study evaluating the sensitivity of the anterior drawer and talar tilt tests. In this study,[69] five clinicians performed manual muscle tests to the lower limbs of cadavers while a motion analysis system measured calcaneal movement. Although the clinicians did not score the amount of laxity during each test, they did evaluate the differences between examiners. Overall, the researchers found a good deal of variation between examiners and concluded that manual muscle tests were not sensitive enough to detect specific ligament involvement in an injury.[69] Although differentiating which ligament is injured may not be possible, Denegar et al[62] reported significant differences in clinician scoring between injured and uninjured ankles for both the anterior drawer and talar tilt tests.

A second method for measuring ankle laxity is measuring displacement using an instrumented arthrometer. A 6-degrees-of-freedom, spatial kinematic linkage system was introduced by Kovaleski et al[55] to quantify anteroposterior load displacement and inversion-eversion rotational laxity. The ankle arthrometer measures the relative motion between its footplate and a tibial reference pad while force and torque loads are applied to the ankle-subtalar joint. High intratester reliability coefficients have been found using uninjured subjects.[55] Kovaleski and colleagues[56] also reported that between 74% and 77% of the variation in arthrometer measurements was due to the variation in the bone-to-bone motion. Sectioning off lateral ligaments in cadavers caused increased arthrometric measurements, establishing the ability of the instrumented ankle arthrometer to detect injury, thus establishing the validity of the instrument.[56]

Studies have been conducted using the ankle arthrometer on subjects with acute lateral ankle sprains and self reported instability.[54,70,71] Overall, increased joint laxity in injured compared to uninjured ankles as measured by the instrumented arthrometer was reported.

Functional instability

FI was originally defined as the tendency for the foot to give way.[52] Freeman[53,72,73] explained the feelings of "giving way" in his theory of articular deafferenation. In his theory, Freeman hypothesized that following a LAS, the nerve fibers, specifically the sensory mechanoreceptors, in the lateral ankle ligaments are stretched and disrupted. Mechanoreceptors, which are responsible for sensing stretch, tension, postural information, and joint movement, have all been found to be located within the lateral ankle ligaments.[74] It is believed that these damaged afferent nerves ultimately affect the individual's proprioception. A downfall of the Freeman theory is the belief that proprioceptive control is a feedback-only model. Hertel[75] has refined this theory to include both feedback and feedforward aspects of sensorimotor control. The new model incorporates the afferent somatosensory aspect from Freeman and adds spinal reflexes and supraspinal efferent motor control aspects. Because the underlying pathological process for FI is not understood, researchers have investigated many different neuromuscular and sensorimotor functions to try to elucidate this complex condition.[76] Besides subjective feelings of giving way, many different alterations in function have been contributed to FI such as deficits in proprioception, postural, and gait.

Proprioception

Assessment of proprioception is most often measuring two ways: kinesthesia and joint position sense. Kinesthesia is the ability to detect passive joint motion. Studies have evaluated the ability for subjects with CAI to detect movement in both the sagittal plane[77-80] and frontal plane.[81,82] Overall, three studies[77,78,81] found subjects with CAI had difficulty perceiving passive movement and three studies[79,80,82] found no significant differences. There is an inconsistency with methods which makes conclusions difficult to draw.

Joint position sense is the ability to accurately reproduce, either actively or passively, joint positions. In a recent systematic review, Hiller et al[83] pooled the results of

11 different studies in a meta-analysis to evaluate joint position sense in those with CAI. This study only included studies with a CAI group (defined as two or more ankle sprains) and a non-injured control group. Overall, they did not find group differences for active or passive inversion, or passive mixed inversion/eversion joint position sense. No differences were found between groups for active mixed joint position sense either. Hiller et al[83] included three studies that evaluated dorsiflexion-plantar flexion, but found conflicting results. They equate the lack of group differences in proprioception to poor methods, stating that more studies need to be conducted that adhere to psychophysical principles (when testing thresholds, movement stimuli should be presented multiple times) for measuring proprioception. Interestingly, in a landmark study that Hiller and colleagues did not include in their systematic review, Glencross and Thornton[84] found that individuals with a history of ankle sprain had an error in active joint re-positioning. Interestingly, they found that the most severe ankle sprainers had a larger absolute degree of error. Glencross and Thornton[84] used individuals with a history of minimum one ankle sprain, although they do not report the total number of ankle sprains for each individual, this study indicates that individuals who disrupt their lateral ligaments may have proprioceptive deficits. Other studies not included in Hillers systematic review, reported significant active[30] and passive[85] joint position sense errors in those with instability. Yokoyama et al[85] recorded error during mixed plantar flexion and inversion and found that a group with FI estimated their involved ankle to be less plantar flexed than it actually was.

Overall, the results of proprioception testing in individuals with CAI are mixed. More research needs to be done with consistent kinesthesia methods should be done.

Along with more consistent and psychophysically acceptable methods to test joint position sense, more multi-planar movements should be conducted.

Postural control

Postural control can be measured statically or dynamically. Many researchers have demonstrated deficits in postural control in subjects with CAI.[39,51,75,86-94] Postural control has measured using instrumented and non-instrumented ways. McKeon and Hertel[95] performed a systematic review to determine if postural control was adversely affected in those with CAI. Including only studies using a force plate, it was determined that compared to healthy controls, those with CAI had poorer postural control.[95] However, force plates are not always practical in clinics, thus non-instrumented means to measure postural control are needed.

The balance error scoring system (BESS) is a valid and reliable measure of static postural control traditionally used in the assessment of concussions.[96] Docherty, McLeod, and Shultz[97] conducted a study measure postural control in those with FI incorporating the BESS. Thirty subjects with self-reported instability and thirty healthy control subjects performed the BESS under all six traditional conditions. Differences were found between groups for three conditions, tandem form surface, single-leg firm surface and single-leg form surface.

Similar to static postural control, there are many methods to assess dynamic postural control including the star excursion balance test (SEBT). The SEBT requires individuals to maintain a steady base of support on one limb while reaching as far as possible in various directions with the other. Normalized reach distances are analyzed to determine postural control deficits.[98] The SEBT has been thoroughly researched on subjects with CAI.[86,87,90,99] The SEBT, which originally involved balance measurements in eight directions was simplified in a study conducted by Hertel et al.[99] In this study, subjects with and without CAI performed the SEBT in all eight directions, significant differences were found between groups for three directions; anteromedial, medial, and posteriomedial.[99] In all three directions CAI subjects reached significantly less than healthy controls.[99]

CAI Models

Although, CAI had formerly been believed to be caused by either MI or FI, in 2002 Hertel[46] proposed a model of CAI that did not completely separate MI and FI completely, but instead placed them on a continuum with an overlapping group in which both MI and FI components exist. This model, with the two separate subgroups which can overlap to make a third combined subgroup, is widely accepted. Recently, Hiller et al[100] refined the Hertel CAI model to expand the number of separate subgroups to 3 (MI, perceived instability, and recurrent sprain). These three subgroups can exist independently or in combination with one or more of the other subgroups, making a possible 7 subgroups. In the Hiller model, the MI subgroup is characterized similarly to the Hertel model. Instead of using the traditional FI, Hiller proposed the term "perceived instability." The researchers classified individuals into this group based on their subjective feelings with no association to if there is actual objective functional limitation. The last independent subgroup is recurrent sprain, defined as a history of 3 or more sprains to the same ankle. Although this model shows promise, more research needs to be conducted to evaluate its feasibility.

Typical walking gait in healthy individuals

Walking is the most fundamental mode of human transportation. The gait cycle is defined as the period of time for two steps and is measured from the initial contact of one foot until the subsequent initial contact of the same foot. The gait cycle can be separated into two distinct phases: stance and swing. Stance phase occurs when the foot is in contact with the supporting surface. The two purposes of stance are to bear weight and provide body stability.[101] Stance phase consists of five sub-phases: heel strike, foot flat, mid-stance, heel rise, and toe off. Swing phase occurs when the limb is swinging forward and is not in contact with the supporting surface. The purpose of swing phase is to propel the limb/body forward. During swing the limb must prepare and align itself for heel strike and must also ensure of foot-floor clearance.[101]

Describing typical gait can be separated into kinematics and kinetics. Kinematics is the study of the position of the limb segments as well as the linear and angular displacements, velocities, and accelerations.[102] Kinetics is the study of the internal and external forces that produce movement. The internal forces are primarily muscular, external forces are ground reaction forces and gravitational.[102] Multiple studies have been published reviewing both the kinematics and kinetics of the foot and ankle during walking and running.[101-104] Here, I will provide an overview of typical walking gait in healthy individuals. Kinematics of the lower extremity joints (hip, knee, and ankle) will be described separately. Then overall kinematics will be discussed.

Hip-kinematics

While walking the majority of hip motion occurs in the sagittal plane, although some motion occurs in both the frontal and transverse planes. At heel strike the hip is flexed, adducted, and internally rotated. During stance, the hip extends until peak extension just before toe off; the average maximum extension is between 5- 15°.[104,105] As the hip extends, it continues to adduct in order to absorb shock.[104] Maximal adduction (average 5°)[104,105] is reached at mid stance, then the hip begins to abduct and continues through toe off. In the transverse plane, the hip maintains steady internal rotation (about 2-4°)[104,105] until late stance (heel rise) when it starts to externally rotate. Following toe off, the hip flexes until maximum flexion at mid to terminal swing (average 37°).[104,105] Abduction continues until just after toe off (maximum average 7°)[105] then starts adduction. During the majority of swing phase, the hip is externally rotated, just prior to heel strike, the hip internally rotates.

Knee-kinematics

Similar to the hip, the majority of knee motion occurs in the sagittal plane. Lafortune et al[106] used Steinmann traction pins inserted in the femur, tibia, and patella of healthy subjects to collect knee kinematic data while they walked down a walkway. They described the sagittal plane motion as biphasic; during both stance and swing the knee goes into flexion and extension. Specifically, at heel strike the knee is slightly flexed and reaches its stance phase peak (average 20°) about 190ms following contact.[106] Concurrently, at heel strike and the beginning of stance, the tibiofemoral joint is internally rotated about 5° and abducted approximately 1.2°.[106] Just prior to foot flat until heel rise, the knee extends, rotates to neutral, and remains slightly abducted.[106] Following heel off, the knee begins to flex and internally rotate again. At toe off the tibia is rotated internally with respect to the femur as joint continues to flex. The lack of external rotation during stance is contrary to previous reports[101]. The authors refer to the differences in methods as the reason for the discrepancy in the literature.[106] Older literature described kinematics by placing markers on the skin, whereas Lafortune et al[106] drilled markers into bone. They believe that previously reported external rotation is due to the combined action of muscles and ligamentous structures. A more recent study conducted by Benoit and colleagues[107] reported an absolute errors during stance between skin markers and pin markers to be from 2.5-4.4° in the frontal plane and 2.2-2.8° in transverse plane. Agreeing with the theory that surface markers may not represent the movements of boney structures.

During early swing phase the knee reaches peak flexion (around 60°) then quickly moves into extension to prepare for heel strike.[104,106] In a systematic review of gait data, Rodgers[101] reports that although there is contradictory research of the knee during swing, the majority of researchers report that the tibia rotates medially (estimated about 18°). However, according to Lafortune et al,[106] during the swing phase, the knee moves from an internal position to external rotation until just prior to heel strike. 75ms before heel strike, the knee begins to internally rotate to prepare for heel strike. In terms of the frontal plane during swing, Lafortune et al[106] reported that the knee was in constant abduction.

Kinematics-ankle

Kinematics of the foot and ankle have been researched in depth.[103,108-112] Dugan and Bhat[103] performed a thorough review on the ankle biomechanics throughout the gait cycle; whereas others have focused specifically on stance phase kinematics.[108-112] As motion analysis systems have advanced, ankle joint models have progressed from a hinge joint[109] to a multi-segmental models.[112,113]

At initial contact, typically the foot makes contact with the ground at the posteriolateral aspect of the heel.[102] At heel strike, the calcaneus is plantar flexed on average 5° and inverted about 5°.[108] Following heel strike, the calcaneus and talus move together into further plantar flexion. As the talocrural joint plantar flexes, the subtalar joint pronates and the for the first 20% of stance to absorb shock.[103] From just prior to foot flat until after heel rise the talocrural joint dorsiflexes.[103] Because the foot is fixed on the ground, dorsiflexion occurs from the tibia moving forward on the talus. Maximum dorsiflexion (around 14°) occurs when the body center of gravity is anterior to the base of support. Simultaneously with dorsiflexion, from just prior to foot flat the subtalar pronates and the hindfoot everts. Maximum pronation occurs just prior to maximum dorsiflexion. Maximum pronation denotes the end of absorption and the beginning of propulsion. Starting at heel rise the ankle begins to plantar flex and supinates. With ankle plantar flexion and supination the plantar fascia becomes tense which provides stability of the transverse tarsal joint through the windlass mechanism. To prepare for toe off, the foot becomes rigid in order to generate the force required for propulsion.

During swing phase, the ankle dorsiflexes and pronates in order for foot clearance as the limb advances forward.[102,103] At terminal swing, the foot becomes stable as it prepares for heel strike.

Kinetics

Kinetics have been analyzed by muscular activity, ground reaction forces and center of pressure patterns. In his review, Novacheck[104] provides a good overview of kinetics during gait. Overall he reports that the hip extensors are the main sources of power generation from heel strike to mid stance. From mid stance until toe off power generation comes from the knee extensors, hip abductors, and ankle plantar flexors. The first half of stance the hip flexors generate power followed by the hip flexors.

In terms of ground reaction forces, force plates have been utilized to evaluate vertical ground reaction forces. Following heel strike, there is an initial peak, representing a passive force peak related with shock absorption. There is a second, usually larger peak due to active muscle forces and is centered about stance phase absorption. While walking the reported range of peak vertical ground reaction forces is from 1.1 to 1.3 times body weight[101] and as high as 2.5 times body weight during running.[103]

Force plates have been used to record center of pressure data during the stance phase of gait. Research has reported that at heel strike pressure is located on the lateral border of the heel.[104] It quickly moves medially and remains medial as it shifts to the forefoot ends at toe off between the first and second metatarsal heads.[102,104]

Walking versus jogging

There are many differences between walking and jogging.[103] Jogging is distinguished by an increase in velocity. Whereas walking has a period of double support, the increase in velocity eliminates the double stance and causes two periods of double float; when neither foot is in contact with the ground. The timing of toe off depends on speed, however as velocity increases toe off occurs earlier causing a shorter stance phase and a longer swing phase. Other changes that occur include a typical transition from initial contact occurring at the heel to occurring at the midfoot. With midfoot strike, the foot is in slight plantar flexion at impact, dorsiflexes immediately following impact however the heel does not touch the ground. Although kinematics are similar, jogging requires more range of motion, specifically hip flexion, knee flexion, and ankle dorsiflexion.

Barefoot versus shod gait

In healthy samples, shoes have been found to influence kinematic, kinetic, spatio-temporal and physiological variables.[114-120] Researchers concur that while barefoot, individuals modify their gait so that at initial contact, the ankle tends to be more plantar flexed and less pronated.[115,117-119] The more foot flat position at initial contact is associated with an "impact-reducing" gait style.[115] Divert et al[116] noted that shoes attenuate foot-ground impact by adding damping material, reducing the impact the foot must absorb. Because shoes absorb much of the impact, it has been reported that while shod subjects tend to have an increased initial peak vertical ground force reaction (passive force peak).[117,119] Compared to shod, during barefoot running it has been reported that with the contact of the metatarsals (foot flat phase) there is a fast weight transfer from rearfoot to the lateral side of the forefoot, showing a reduced amount of rearfoot eversion during the pronation/absorption aspect of gait.[121,122]

General consensus also exists that since running barefoot causes individuals to reach for the ground; stride length shortens which coincides with an increase in stride frequency.[114-117] Although researchers have agreed on alterations that occur at the ankle in the sagittal plane, mixed results have been reported with regards to knee sagittal plane changes. Some studies report changes in knee kinematics[114,115,119,120,122] other have not found differences.[117] The studies that have reported differences in knee kinematics are in disagreement regarding the changes footwear causes.

An important limitation in the shod literature is the practice of placing markers on shoes. Authors have noted that, by placing markers on shoes, motion analysis systems are only recording the movement of the shoes. So it cannot be confidently concluded that the motions being captured by the shoes are what occur by the feet. Researchers have used sandals in attempt to evaluate foot motion while in shoes.[123,124] Sandals have allowed researchers to develop multi-segmental foot models and observe movements of the rearfoot and forefoot. However, limitations to sandals are the applicability to athletes and the lack of support that sandals provide compared to athletic shoes. Recently, Davis and colleagues[125] introduced gait research in which aspects of athletic shoes are removed in order to place markers on skin. With more advanced motion analysis systems, this new model is able to actually collect foot motion within a shoe while not disrupting the integrity and structure of the shoe.

CAI and biomechanics

As previously mentioned, the actual mechanism of injury for a LAS is not entirely understood, however the mechanics of the foot and ankle play a role. Alterations in kinematics in those with CAI have been found.[35,37,38,41,83,126-129] Hiller et al[83] in their systematic review identified 18 studies that evaluated biomechanical variables during gait, landing from a jump, and other various dynamic tasks. The researchers conclude that during gait individuals with recurrent ankle sprains have a more inverted ankle position and decreased foot clearance compared to healthy controls.[83] Previous studies agreed that those with CAI took longer to stabilize after landing compared to controls.[83] Hiller et al also found that in landing studies there was a consistency in those with recurrent sprains literature landed with more inverted ankles and the hip was less externally rotated prior to landing. Knee joint displacement following landing were not consistent.

Studies not included in the Hiller et al systematic review[35,37,38,40,41,126,128-130] have looked at kinematics, joint coupling, plantar pressures and variability during various dynamic tasks. Similar to Hiller et al's[83] findings, Drewes and colleagues[128] found CAI subjects to be more inverted during gait. In the same study, it was reported that CAI subjects have altered rearfoot-shank joint coupling compared to healthy controls.[128] In another study, sagittal plane differences were found between those with CAI and healthy controls while jogging on a treadmill.[126] In this study, CAI subjects were less dorsiflexed from 9-25% of the gait cycle.[126] Brown et al[35,37,40,41] in a series of articles evaluated differences between those with FI, MI and copers. Overall they found differences in kinematics[35,41] and movement variability[37,40] between the groups.

Researchers have also noted a more lateral plantar pressure distribution in subjects with CAI while standing[131] walking[129,132,133] and jogging.[38] Nawata et al[129] and Morrison et al[38] used pressure ratios between medial and lateral aspects of the involved foot of unstable ankles during walking and jogging respectfully. Both groups of researchers found that individuals with a history of recurrent sprains had a larger medial-lateral ratio compared to healthy controls. Interestingly, whereas Morrison et al[38] overlapped all stance frames to include reduce entire stance into one frame, Nawata et al[129] separated stance phase of gait into foot contact, midstance, and toe off. No significant differences were found at foot contact or toe-off,[129] exposing a limitation in gait analyses that only evaluate a short increment of the gait cycle.

Although differences have been found between healthy controls, copers, and those with CAI, the mechanism behind these differences remain elusive. The plantar pressure data[38,129,131,132] theorize that those with CAI maintain a more supinated and rigid foot in attempts to reduce recurrent sprains. Drewes et al[126] link the lack of dorsiflexion in CAI subjects while jogging to restricted arthrokinematics of the talus. Others contribute kinematic differences to increased laxity, deficits in proprioception, or neuromuscular adaptations to their pathology.

Although gait data has been published, it should be noted that there are many limitations to these studies. Most notably, most studies on biomechanics were performed either barefoot or with motion analysis markers attached to the outside of shoes. As previously mentioned, differences have been found between the novel task of barefoot activities in healthy individuals bringing into question the affect shoes may have on pathological populations, specifically those with CAI. Additionally, few studies[126,128] have used an instrumented treadmill. Using an instrumented treadmill has two benefits. First, subjects do not have to attempt to hit a force plate exactly, instead running on a treadmill allows for a set pace and natural gait. Secondly, an instrumented treadmill synchronizes kinetic data with kinematic data. These methods may not accurately demonstrate gait alteration characteristics of those with CAI.

Affects of ankle tape

Ankle prophylactics are a common intervention athletes use to prevent lateral ankle sprains. Previous research has established the use of ankle bracing and taping on the prevention of lateral ankle sprains.[26,134-137] Additionally, systematic reviews have been conducted evaluating ankle taping and bracing on range of motion[138] and functional performance.[139] Although the effectiveness of ankle prophylactics has been reported in CAI subjects, the mechanism behind the effectiveness has been questioned.

One hypothesis believes that external bracing and taping may increase afferent nerve firing, increasing proprioception.[140] Refshauge and colleagues performed a series of studies evaluating the role tape and bracing has on proprioception.[79,141] Refshauge recorded the ability of individuals with CAI to detect ankle movement in sagittal plane[79] and frontal plane[141] while taped and in a control condition. In both studies, no significant differences were found between conditions in a pathological sample.

Another hypothesis believes that the use of ankle prophylactics decrease the amount of laxity allowed at the talocrural joint. Wilkerson et al [142] conducted a study to measure rotary stability of two different ankle tapings. A Gibney taping and a Gibney taping with an additional subtalar sling tape was applied to cadavers before and after an inversion torque was applied using an ankle arthrometer. This study reported that both the Gibney and the Gibney plus subtalar sling taping methods reduced inversion displacement, 6.32° and 11.99° respectfully. Statistical analysis indicated that the Gibney plus subtalar sling procedure provided significant restraint.[142] Hubbard and Cordova[143] also performed a study evaluating laxity following taping. In their study, CAI subjects and healthy controls were compared before an ankle taping procedure and following 30 minutes of exercise with the ankle taped. The ankle arthrometer was used to measure displacement. This study found that tape significantly decreased anterior, posterior, inversion and eversion displacement following the application of tape.[143] The results of these two studies lead to questions regarding the affects of ankle prophylactics on dynamic tasks.

Very few studies have been conducted evaluating the effects of taping and bracing on biomechanics. Stoffel et al[144] and Cordova et al[145] conducted research investigating mechanics in healthy volunteers with and without tape. Using elite athletes, researchers[144] performed a traditional ankle taping procedure before and after a straight run, a 45° sidestep, and a 45° crossover cut while a motion analysis system collected knee and ankle kinematics and kinetics. Kinetic differences between taped and untapped tasks were reported at both the ankle and knee. Kinematically, at the ankle, tape was found to decrease range of motion and decrease the degree of peak inversion.[144] Cordova and colleagues[145] evaluated a basket-weave taping condition, a semi-rigid ankle brace, and a no support condition on kinematic and kinetic variables during a single-legged drop landing. In their study, tape and bracing produced significant kinetic differences compared to the control condition. Wearing tape did not affect sagittal plane hip or knee range of motion, however, tape did significantly limit the amount of sagittal plane ankle range of motion.[145]

Although the above two research studies have shown differences in kinetics and kinematics in subjects with and without ankle tape, the research was conducted in healthy individuals. Spaulding et al[146] analyzed gait in subjects with and without CAI. Subjects walked on a level walkway, on a 5° incline ramp, and conducted an 18cm step up in three conditions: no brace, a soft brace, and a semi-rigid brace in shoes. Similar to the above articles, kinetic differences were found between conditions. Sagittal plane kinematics were also found to be different. In all conditions and tasks, CAI subjects presented with less motion at toe off. While in the semi-rigid brace CAI subjects had significantly less motion during level walk.[146] Limitations to this study include the lack frontal plane kinematic measures and the lack of a taping condition.

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CHAPTER 3

MANUSCRIPT 1

PROXIMAL JOINT KINEMATICS AND MOVEMENT VARIABILITY DURING GAIT IN INDIVIDUALS WITH AND WITHOUT CHRONIC ANKLE INSTABILITY

Abstract

Context: During barefoot gait, ankle kinematic differences have been found between individuals with chronic ankle instability (CAI) compared to healthy controls and those with a history of ankle sprain but no recurrent instability (copers). Conflicting results have been reported while shod. Alterations in proximal joint kinematics and movement variability may be adaptations individuals with CAI make to function with their unstable ankle joint. **Objective:** To determine if there are knee or hip kinematic differences, in the sagittal and frontal planes, in subjects with CAI compared to copers and controls while walking and jogging on a treadmill in shoes. The secondary purpose was to compare movement variability at the ankle, knee and hip between groups. **Design:** Descriptive laboratory study **Setting:** Motion analysis laboratory **Patient or Participants:** Fifteen subjects with self-reported CAI, 11 copers, and 13 healthy controls participated. **Main Outcome Measures:** Sagittal and frontal kinematics were measured at the knee and hip throughout the entire gait cycle. Group means and 90% confidence intervals were calculated and plotted. Movement variability was analyzed by calculating the average kinematic standard deviation during a 15s trial. The gait cycle was divided into four phases, loading, mid-stance, unloading, and swing. Separate 3 x 4 mixed model ANOVAs with repeated measures were conducted for walking and jogging. Paired comparison post hoc testing was performed to determine differences between groups at each phase. Alpha was set at 0.05. **Results:** The CAI group presented with more knee flexion than controls from 85-95% of the gait cycle while jogging (mean difference=4.80±1.26°). Sagittal plane movement variability differences were found at the ankle while jogging between the CAI and control groups during the unloading and swing phases of gait. **Conclusions:** Knee kinematic alterations during swing and increased ankle variability may occur in subjects with CAI to prevent recurrent ankle sprain.

Keywords: Ankle sprain, dynamical systems, motion analysis

Introduction

Lateral ankle sprains are extremely common and an estimated 30 – 70% of those who suffer an ankle sprain will suffer subsequent sprains.[1-7] Chronic ankle instability (CAI) has been defined as suffering from an initial lateral ankle sprain with the recurrent bouts of lateral ankle instability coupled and residual symptoms.[8] Individuals with CAI report lingering pain and instability, however there is a population of individuals who have a history of lateral ankle sprain but do not complain of persistent pain or instability. This group has been termed "copers". A coper is defined as an individual who suffered an initial ankle sprain but does not experience subsequent injuries or residual symptoms.[9] Most of the previous research on CAI has focused on comparing individuals with CAI with healthy controls. However, because both CAI and copers have experienced an initial sprain, comparing these two groups may be more appropriate to investigate etiology of CAI.[10-12]

Ankle kinematic differences have been found between CAI and healthy controls while walking,[13-15] jogging,[13, 16] and landing.[17, 18] Overall, CAI subjects tend to be more inverted just prior to heel strike, at heel strike, and immediately following heel strike.[13-15, 17, 18] However, all of the previous research was conducting while subjects performed tasks while barefoot. Although barefoot activities are becoming more popular, walking; jogging and landing while barefoot tend to be novel tasks for most, potentially causing kinematic changes. Plus, gait changes are known to occur between barefoot and shod locomotion.[19-24] Specifically, while barefoot, individuals tend to be more plantar flexed just prior to initial contact and land more in the mid-foot.[19, 22-24] Subjects with CAI have been found to have improved postural control with plantar stimulation and orthoses.[25-27]

Although the exact affect shoes have on those with CAI has not been investigated, recent research evaluating ankle kinematics between individuals with CAI, copers and healthy controls while shod did not find any sagittal or frontal plane differences between groups.[28] The conflicting results of show a need for further research to be conducted evaluating gait differences while shod.

Proximal joint kinematic differences[18, 29-32] and altered proximal neuromuscular activity[18, 33-36]have been found between groups with and without CAI during functional tasks. Changes in proximal movements may be compensations injured individuals make in order to accomplish a desired task while minimizing distal changes. During a dynamic reach test, CAI subjects have reduced knee and hip flexion angles.[29, 32] Mixed results have been reported on knee kinematics during a drop landing.[18, 30] Caulfield and Garrett[18] reported an increase in knee flexion 20 ms pre landing until 40 ms post landing. However, Gribble and Robinson[30] reported decreased knee flexion at initial contact during a time to stabilization task.

Movement variability is present in all human movement, but there is debate regarding the optimal amount of variability.[37-39] Increased movement variability has been related to increase lower extremity acute and overuse injury.[40-43] During a stop jump, those with functional ankle instability presented with significantly larger coefficient of variation and standard deviation in the frontal plane at the ankle compared to copers and subjects with mechanical instability.[44] However, during a single leg jump landing, no significant differences were found at the ankle between those with and without CAI.[45] Mixed results have also been reported regarding movement variability at the hip and knee for subjects with CAI.[44, 45] For the purposes of this study, movement variability is operationally defined as the amount of variability, determined by standard deviation from an individual's mean during one 15 second trial, in a single plane of motion at a joint. While walking there were between 8-12 strides (heel strike to subsequent heel strike of same foot) in one trial, while jogging that increased to 15-20 strides per trial.

Evaluating proximal joint kinematics and movement variability may identify adaptations that individuals with CAI make in to adjust with their ankle instability. Since while walking and jogging shod, ankle sagittal and frontal plane kinematics were not found to differ between those with and without CAI,[28] proximal joint alterations should be investigated. Thus, the purpose of this study was to evaluate hip and knee frontal and sagittal plane ankle kinematics between subjects with CAI and copers and CAI subjects and healthy controls while walking and jogging on a treadmill in shoes. The second purpose of this study was to evaluate the movement variability in the sagittal and frontal plane kinematics at the ankle, knee and hip between the groups.

Methods

The independent variable was group (CAI, coper. control) and the dependent variables were knee and hip sagittal and frontal plane kinematics and movement variability at the hip, knee and ankle.

Subjects

A total of 39 subjects, 13 control, 11 copers and 15 subjects with CAI volunteered. Control subjects had no history of ankle sprains ever in either limb. Copers had a history of one substantial ankle sprain, occurring more than 12 months ago, with no lingering symptoms. CAI subjects had a history of at least one substantial ankle sprain with the first sprain occurring more than 12 months ago and multiple recurrent episodes of their ankle giving way during functional activities. Subjects in the CAI group were screen by using a scored below a 87% on the Foot and Ankle Ability Measure-Sport scale.[46, 47] Subjects who reported bilateral CAI, the self-perceived "worse" ankle was the test ankle. Control limbs were matched so that there were similar percentages of "involved" left and right limbs in both groups. All subjects participated in moderate or vigorous physical activity at least 3 times per week as determined by the Godin Leisure Time Exercise Questionnaire.[48, 49] Exclusion criteria for all groups were a history of ankle fracture, vestibular or neurological disorders, and any lower extremity or lumbosacral injuries within the past 3 months that could adversely affect their neuromuscular function. The university IRB approved the study methods. Subjects were recruited from a large public university and the surrounding community. Prior to data collection, all subjects provided written informed consent.

Instruments

Gait kinematics were computed from captured reflective marker locations sampled at 250 Hz using a 12 camera analysis system (Vicon MX t20, VICON Motion Systems, Inc., Lake Forest, CA). This system has been demonstrated to have a spatial error of 0.42mm and a mean error of angle reproduction of 0.16°. Synchronized ground reaction force data was collected by a multi-axis strain gauge force plate imbedded under a custom-built treadmill (AMTI OR 6-7, Watertown, MA). Vertical ground reaction forces were sampled at 1000 Hz with a threshold of 10-20% body weight to determine initial contact and toe-off during walking and running. 3-D joint kinematics were collected using Vicon PlugIn Gait (Oxford Metrics, London, UK).

Subject preparation

To capture lower extremity kinematics, retroreflective markers were placed directly on the skin using double-sided tape to previously established landmarks.[50] Markers were located bilaterally on the lateral mid-thigh, lateral tibiofemoral joint line, femoral head, tibial tuberosity, lateral mid-shank, and lateral malleolus. Virtual markers were established bilaterally for the anterior and posterior iliac spines. All subjects wore Brooks Defyance running shoes (Brooks Sports, Inc., Bothell, WA). After consultation with the shoe manufacturer, the heel counter and regions directly over the 1st and 5th metatarsal heads were removed. This did not affect the integrity of the shoe. The removal of these sections of the shoe allowed accurate marker placement directly onto the subjects' skin for the medial side of the first metatarsal-phalangeal and the lateral side of the fifth metatarsal-phalangeal joints. A custom heel marker was placed on the posterior calcaneous and virtual markers were established on the medial and lateral calcaneous.

Data collection

Following consent anthropometric data were collected including height, weight, leg length, and knee and ankle girth. Appropriate maker placement was applied then subjects walked on the treadmill at 1.34 m/s for a minimum 3 minutes as a warm-up. For data collection, subjects walked then jogged on the treadmill at speeds of 1.34 m/s and 2.68 m/s, respectively. Subjects were given a minimum of 3 minutes at each speed to adjust to the pace of the treadmill before data collection. Walking always preceded jogging and subjects were given the option of a 5 min rest before jogging. Data was collected continuously at each pace until three 15-sec trials were collected. After completion of one condition, subjects were given a minimum of 5 minutes rest before collection occurred in the other condition. All data was collected by the same investigator who was blinded to group assignment.

Data Processing

Three trials consisting of 15 seconds of gait cycles were collected for each subject. One 15 second trial at each speed was used for analysis. Kinetic and kinematic data for each limb were resampled through a custom program in MatLab 7.04 (Mathworks Inc, Natick, MA). The data was organized to 100 frames so that each frame represented one percent of the entire gait cycle (heel strike to heel strike). This was done individually for each subject based on the average stride-cycle time for the involved limb. Kinematic data ensembles were visually inspected to determine outliers.

Statistical analysis

For all analyses, walking and jogging, joint, and plane of motion were analyzed separately. For all outcome measures, two comparisons were made. The first was between CAI subjects and controls. This evaluation has been commonly performed in the CAI literature. A second comparison was made between groups of individuals with a history of ankle sprain with and without lingering symptoms.

The primary objective was to determine group differences in degrees of sagittal and frontal hip and knee motion throughout the entire gait cycle. For each plane of motion, group means and associated 90% confidence intervals were calculated throughout the gait cycle. The data was inspected for time increments in which the confidence intervals did not overlap for more than 3 consecutive percentages of the gait cycle. For the increments that the confidence intervals did not overlap, group mean differences and associated standard deviations were calculated for the entire increment.

The secondary outcome of interest was the amount of movement variability in the kinematics between groups. Movement variability was determined by calculating each subject's kinematic stride to stride variability as determined by the standard deviation throughout the gait cycle for the 15 second capture. Gait was divided into four phases, loading, mid-stance, unloading, and swing. Average stance for all subjects for walking (percent gait cycle = 65%) and jogging (percent gait cycle = 35%) were evenly divided into thirds to determine loading, mid-stance, and unloading. The fourth phase, swing was from toe-off to 100% of gait cycle. Separate 3 (group) x 4 (phase) mixed model ANOVA with repeated measures were computed for each joint and plane of motion. Our specific comparisons of interest were the interaction and main effects for group. Significant group main effects were followed up with one-way ANOVAs at each phase of gait. Significant findings were followed up with paired comparison post hoc testing was performed to determine differences between groups at each phase. Alpha was set at 0.05 for all statistical tests and a Bonferonni correction for multiple comparisons was conducted.

Results

Preliminary analyses revealed no differences between groups in age, height, and mass (Table 1). The CAI group had significantly lower self-reported disability than controls on the FAAM-activities of daily living and significantly lower than both controls and copers on the FAAM-S. For all outcome measures, copers did not present differently than CAI, thus only differences between CAI and healthy controls will be presented.

Kinematics

CAI subjects had greater knee flexion than controls from 76 – 91% of the gait cycle while jogging (mean difference = 9.05 ± 1.12°). There were no other differences in kinematics at the knee or hip between groups (Figures 1 and 2).

Movement variability

There was no significant interaction or group main effect for any joint while walking (Table 2). During jogging two significant group x time interactions were identified one at the ankle [$F(6, 105) = 2.84$, $P = 0.013$] and one at knee [$F(6, 105) = 2.48$, $P = .028$] in the sagittal plane. Post hoc tests revealed significant group differences between controls and CAI subjects only at the ankle (Table 3A). During unloading (mean difference = 2.65°, $F(2, 36) = 7.11$, $P = 0.01$) and swing (mean difference = 1.79°, $F(2, 36) = 4.98$, $P = 0.04$) CAI subjects presented with more variability compared to controls (Figure 3).

Discussion

Results from this study showed two novel findings between controls and CAI groups while jogging while shod. First, near the end of swing, CAI subjects presented with more knee flexion compared to controls. Alterations during swing through and toe off may occur in subjects with CAI to prevent recurrent ankle sprain. Also, from the last third of stance through swing, CAI subjects had more variability in the sagittal plane at the ankle. The increased variability may contribute to the feelings of instability in subjects with CAI. The findings of this study illustrate the need to evaluate the entire gait cycle and not just immediately prior to through immediately post initial contact.

Ankle sprains are reported to occur while the foot is planter flexed and inverted beyond normal physiologic range.[51-54] However, the pathogenesis of when the hypermobility occurs and sprain happens has only been theorized. Due to obvious ethical reasons, conducting laboratory research and inducing injury is not done. Cadaver research has shown that the ankle joint is extremely stable during weight bearing, thus assuming that ankle sprains primarily occur during loading and unloading phases of stance.[55, 56] Another cadaver study suggest that during normal gait, an individual could land in a substantial degree of inversion, plantar flexion, and tibial internal rotation and not sustain a lateral ankle sprain.[57] The passive stability of the foot and ankle greatly reduces the vulnerability of the ankle at heel strike.[57] However, the same cadaver study,[57] proposed ankle sprain susceptibility during the latter part of swing when the non-weight bearing limb propels from behind the body to in front. Misjudgment of inversion during this critical time can potentially cause a collision between the ground and the lateral aspect of the foot. A recent case report of an accidental ankle sprain that occurred during motion analysis capture reported that the ankle sprain occurred during the unloading, latter aspect of stance.[58] Interestingly, the present study found significant differences between those with and without CAI at both critical time points in the gait cycle; swing through of non-weight bearing and unloading of stance.

While jogging, previous investigation did not reveal any sagittal or frontal ankle kinematic differences between those with and without CAI while shod throughout the entire gait cycle.[28] In the current study, CAI subjects demonstrated more knee flexion during the latter aspect of swing. This kinematic adjustment may be performed to avoid unintended foot contact with the floor. Increasing flexion at the knee will naturally increase the distance between the foot and the ground. The lack of differences at terminal swing (95 – 100% of gait cycle) is most likely due to the need to extend the knee to prepare for initial contact. Subjects with CAI have been shown to have impaired joint position sense at the ankle compared to controls.[53, 59, 60] To counter the lack of knowing where their foot is in space, we believe that subjects with CAI may make proximal adjustments. While barefoot, Drewes et al[13] reported greater inversion in CAI subjects compared to controls from 78 – 100% of gait encompassing the same percentage of the gait cycle as in the present study. Other studies have found swing differences at the ankle while barefoot between those with and without CAI, looking specifically from 250 ms pre initial contact. There is limited research investigating shod gait mechanic related to CAI, further research should incorporate shoes as well as evaluate the entire gait cycle.

There is no consensus on the optimal measurement of kinematic variability during gait analysis. We chose to estimate kinematic variability by calculating the standard deviation of joint positioning at each percentage point of the gait cycle across multiple strides. Few studies have evaluated variability during dynamic tasks in subjects with CAI.[44, 45] Two previous studies investigating movement variability in subjects with CAI performing two different jump maneuvers reported conflicting results.[44, 45] In both studies, subjects were asked to move down a runway, jump and land with their involved limb on a force plate creating two major differences in methodology from the current study. First, asking subject to land on a target may inherently alter movement patterns due to the specificity of the task. Also, results from the two studies evaluated only the loading aspect of the task. In the current study, we asked subjects to move on a treadmill with in-ground synchronized force plates so that they did not have to aim their footing to a particular location. This method increases the likelihood of subjects performing a natural gait pattern during collection. Secondly, we collected and evaluated movement variability throughout the entire gait cycle. Dividing the gait cycle into four phases, three weight bearing phases (loading, mid-stance, and unloading), and swing allowed us to identify phase-specific alterations in subjects with CAI.

Overall, increased variability indicated that during repetitive cycles of gait, subjects with CAI exhibited more inconsistent movement patterns. Increased variability could indicate alterations in the neuromuscular system following CAI. Unpredictable movement patterns during rhythmic motions such as jogging, could be related to the self-reported feelings of instability in subjects with CAI because during each stride the system must develop new patterns to accomplish the same task. The different movement patterns could also potentially periodically place the ankle in precarious positions.[57]

Specifically, increased sagittal plane movement variability at the ankle during unloading and swing may contribute to CAI subjects' subjective feelings of instability. During unloading and toe off, the ankle is in plantar flexion and quickly continuing to plantar flex for propulsion. Increased or decreased plantar flexion could indicate a change in the size of the base of support during this phase of stance. Being more plantar flexed would mean subjects were more on their midfoot and toes during stance reduces the base of support, ultimately causing instability. Although being less plantar flexed should signify joint stability, in a motion-anlysis captured accidental ankle sprain, the sprain occurred during unloading with the ankle actually in 18° of dorsiflexion, bring into question the sagittal plane orientation of the ankle during injury.[58] Further research needs to be conducted to determine the most stable position of the ankle during unloading. However, as the current study shows, subjects with CAI demonstrated increased variability in sagittal plane movement during this phase of gait.

Sagittal plane movement variability was also noted in subjects with CAI during the non-weight bearing aspect of gait. During swing, the non-weight bearing limb must accomplish floor clearance and preparation for contact. More variability during this aspect of gait could be related to instability. More variability during floor clearance could be a factor in potentially causing a foot-floor collision resulting in a sprain. At the end of swing, when the foot must prepare for initial contact, increased variability indicated that the organism would need to make adjustments in order to properly strike the ground without causing harm. A limitation of this study is that the entire swing aspect of gait was grouped together. Further research should divide swing to determine whether more variability occurs in specific subsections of swing.

There are a few limitations to our study. We choose to use a set speed during data collection. The chosen speeds may not have been comfortable for all subjects, potentially causing changes to their natural gait. Also all subjects wore the same brand and style of shoe during data collection. This was needed because we had specific cutout locations in the shoe to allow accurate placement of markers on the foot without disrupting the integrity of the shoes. The provided shoes were chosen because of the ability to perform the cutouts as well as because of the neutral style of the shoe. However, placing subjects in new shoes could also potentially alter their natural gait. To reduce the likelihood of collecting data during unnatural gait we provided our subjects with ample time to adjust to the shoes and speed of the treadmill at each speed prior to collection.

To our knowledge, this is the first study to evaluate both kinematic and movement variability differences between groups of subjects with and without ankle instability throughout all of gait while shod. We found changes in proximal joint kinematics during swing, which could be alterations subjects with CAI may make to manage their unstable ankle. Movement variability at the ankle during unloading and swing may contribute to unstable feelings subjects with CAI report.

Conclusions

In conclusion this study found that knee sagittal plane kinematic differences and ankle movement variability differences between controls and subjects with CAI jogging while shod. Near the end of swing, CAI subjects presented with more knee flexion compared to controls. Alterations in gait may occur in subjects with CAI to prevent recurrent ankle sprain.

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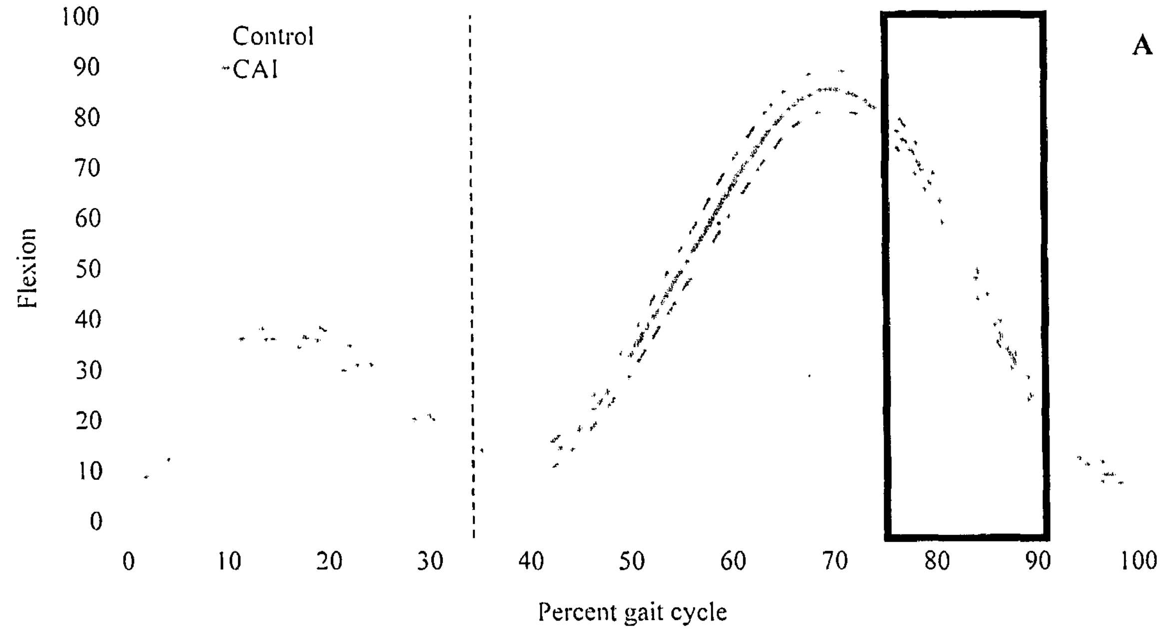


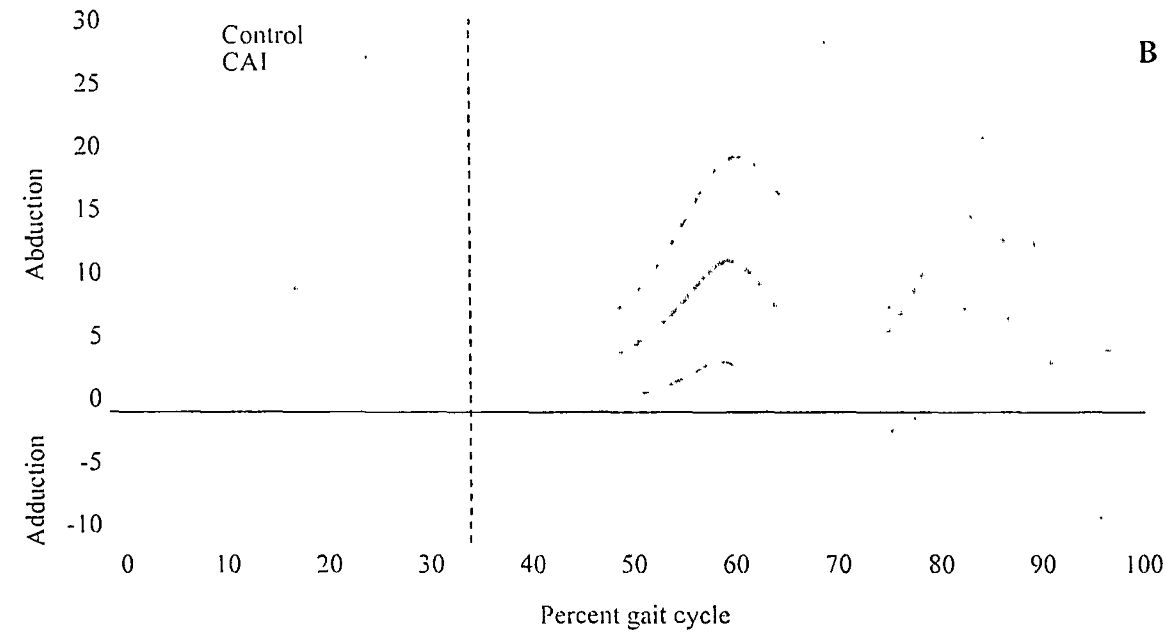
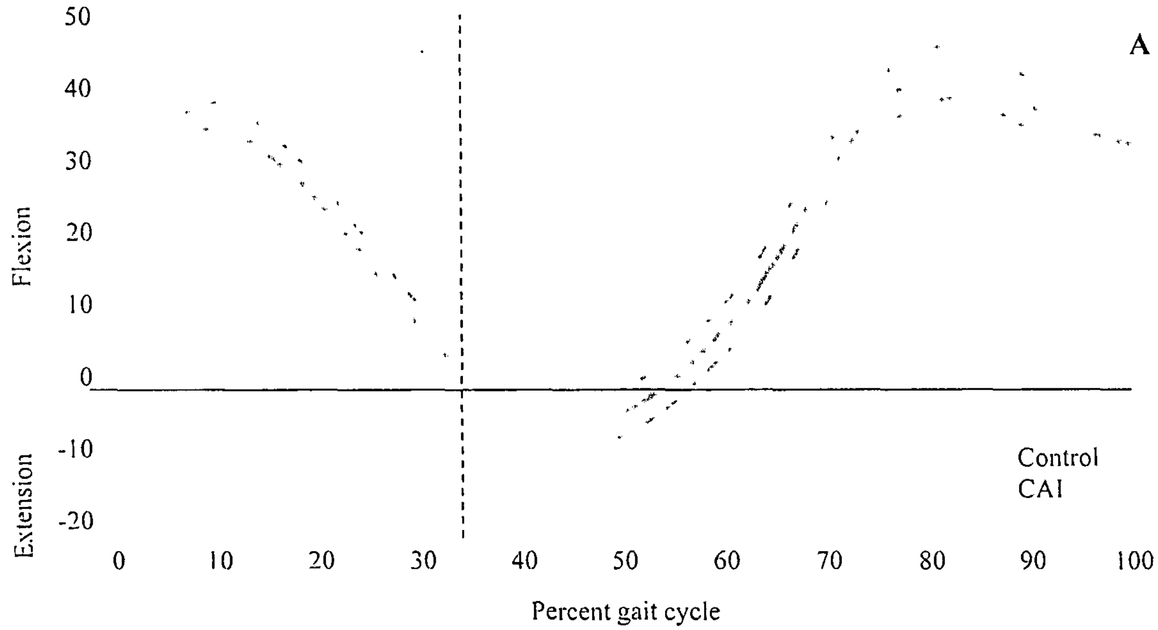


Figure 3.1: Knee sagittal plane kinematics while jogging. 0% of gait cycle represents initial contact; toe off occurred at 35%; 100% is terminal swing. Solid lines represent group means; dashed lines represent the 90% confidence interval. A) Sagittal plane kinematics. CAI subjects were more flexed from 76 – 91% of the gait cycle (mean difference = 9.05 ± 1.12°). B) Frontal plane kinematics.



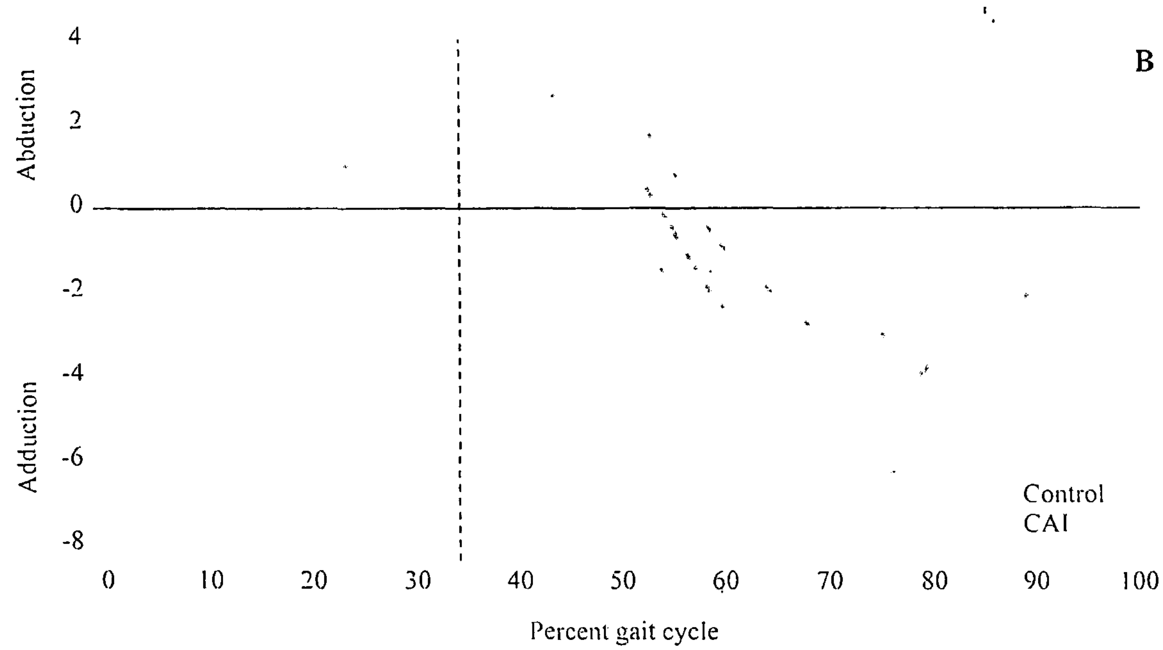


Figure 3.2: Hip kinematics while jogging. 0% of gait cycle represents initial contact; toe off occurred at 35%; 100% is terminal swing. Solid lines represent group means; dashed lines represent the 90% confidence interval. A)Sagittal plane kinematics. B) Frontal plane kinematics.

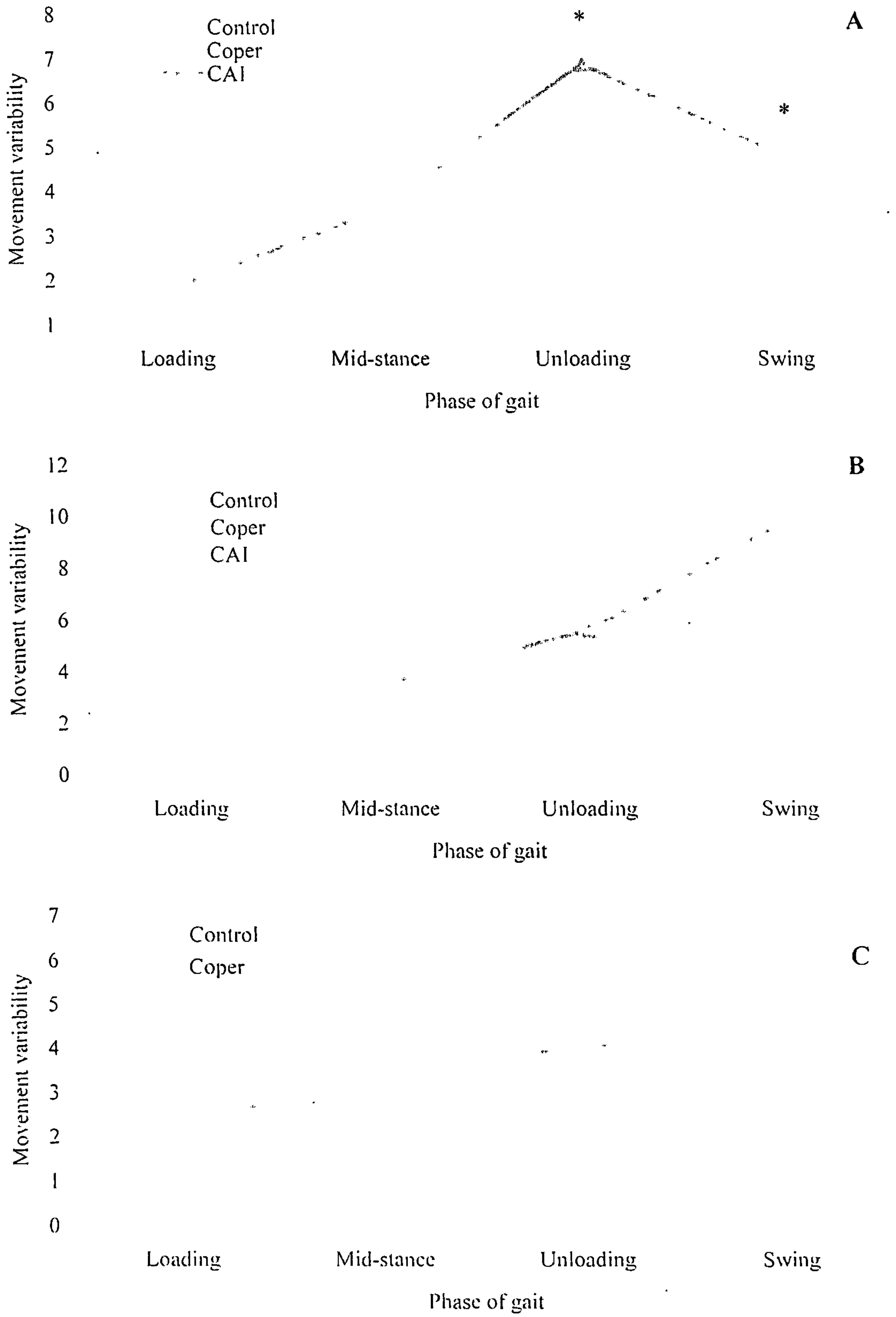


Figure 3.3: Estimated marginal means of movement variability while jogging. A) Ankle. B) Knee. C) Hip.
* = significant difference between controls and CAI

Table 3.1: Subject demographical information.

	Control n = 13	Coper n = 11	CAI n = 15
Gender (M:F)	6:7	5:6	8:7
Age (years)	23.3 ± 4.6	25.1 ± 9.3	26.9 ± 6.8
Height (cm)	169.7 ± 11.2	169.3 ±10.3	171.7 ± 6.3
Weight (kg)	67.1 ± 15.7	64.1 ± 14.6	73.5 ± 10.7
Godin	66.8 ± 35.3	64.4 ±29.1	54.5 ± 30.9
FAAM (%)	100 ± 0.0	100 ± 0.0	92.1 ± 5.8
FAAM-S (%)	100 ± 0.0	99.2 ± 2.0	75.8 ± 13.3
# sprains	N/A	1.0 ± 0.0	5.3 ± 3.1

CAI=chronic ankle instability

Table 3.2: Movement variability while walking. Mean (sd) measured in degrees.

	Control n = 13	Coper n = 11	CAI n = 15
Ankle sagittal plane			
Loading	1.03 (.29)	1.10 (.37)	.89 (.25)
Mid-stance	1.09 (.39)	1:13 (3.7)	1.13 (3.6)
Un-loading	1.56 (.58)	1.76 (.34)	1.66 (.65)
Swing	1.38 (.44)	1.46 (.66)	1.44 (.47)
Ankle frontal plane			
Loading	.83 (.24)	1.05 (.62)	.90 (.32)
Mid-stance	.60 (.19)	.74 (.23)	.64 (.14)
Unloading	.91 (.24)	.88 (32)	.81 (.29)
Swing	1.12 (.33)	1.11 (.31)	1.18 (.42)
Knee sagittal plane			
Loading	1.42 (.41)	1.43 (.51)	1.50 (.64)
Mid-stance	1.70 (.57)	1.55 (.29)	1.83 (.61)
Unloading	2.04 (.76)	2.19 (.57)	2.29 (.90)
Swing	2.33 (.69)	2.05 (.32)	2.30 (.85)
Knee frontal plane			
Loading	.52 (.18)	.57 (.18)	.64 (.46)
Mid-stance	.56 (.27)	.42 (.13)	.50 (.25)
Unloading	.74 (.33)	.54 (.15)	.64 (.35)
Swing	1.30 (.39)	1.23 (.22)	1.25 (.47)
Hip sagittal plane			
Loading	1.11 (.29)	1.11 (.39)	1.29 (.68)
Mid-stance	1.11 (.32)	1.28 (.56)	1.28 (.53)
Unloading	.98 (.31)	1.26 (.85)	1.10 (.39)
Swing	1.34 (.33)	1.48 (.57)	1.46 (.57)
Hip frontal plane			
Loading	.63 (.15)	.70 (.26)	.58 (.18)
Mid-stance	.55 (.20)	.65 (.24)	.51 (.15)
Unloading	.70 (.25)	.74 (.20)	.70 (.17)
Swing	.80 (.26)	.80 (.35)	.67 (.17)

CAI = chronic ankle instability

Table 3.3: Movement variability while jogging. Mean (sd) in degrees.

	Control n = 13	Coper n = 11	CAI n = 15
Ankle sagittal plane			
Loading	1.34 (.55)	1.88 (.44)	1.86 (.55)
Mid-stance	2.52 (2.09)	4.06 (2.04)	3.58 (1.76)
Un-loading	4.23 (1.81)	7.06 (1.57)	6.88 (2.09)*
Swing	2.97 (1.48)	4.74 (1.64)	4.76 (1.27)*
Ankle frontal plane			
Loading	1.06 (.44)	1.09 (.24)	1.22 (.42)
Mid-stance	1.30 (.70)	1.32 (.56)	1.36 (.47)
Unloading	1.88 (.98)	1.73 (.67)	2.35 (2.04)
Swing	2.12 (.99)	2.51 (.88)	2.81 (1.51)
Knee sagittal plane			
Loading	1.83 (.55)	2.15 (.46)	2.24 (.51)
Mid-stance	2.58 (1.31)	3.35 (1.33)	3.56 (1.05)
Unloading	4.16 (2.69)	6.68 (3.40)	5.59 (2.40)
Swing	7.83 (3.82)	10.94 (2.20)	9.93 (1.50)
Knee frontal plane			
Loading	1.11 (.46)	1.43 (.50)	1.30 (.47)
Mid-stance	1.54 (.88)	1.80 (.57)	1.71 (.52)
Unloading	1.35 (.85)	1.62 (.44)	1.91 (.75)
Swing	2.33 (1.04)	2.92 (.51)	3.25 (.94)
Hip sagittal plane			
Loading	1.61 (.58)	1.83 (.63)	1.94 (.68)
Mid-stance	2.72 (1.13)	4.14 (1.22)	4.06 (1.46)
Unloading	2.62 (.99)	4.12 (.46)	3.86 (1.17)
Swing	4.78 (2.47)	6.43 (1.67)	6.23 (1.57)
Hip frontal plane			
Loading	.81 (.18)	.97 (.29)	.86 (.19)
Mid-stance	.94 (.20)	1.11 (.26)	.95 (.22)
Unloading	1.03 (.33)	1.13 (.24)	1.12 (.40)
Swing	1.13 (.45)	1.45 (.29)	1.23 (3.35)

CAI = chronic ankle instability
* = significantly different between controls

CHAPTER 4

MANUSCRIPT 2

GAIT KINEMATICS AFTER TAPING IN SUBJECTS WITH CHRONIC ANKLE INSTABILITY

Abstract

Context: Chronic ankle instability (CAI) is characterized by repetitive lateral ankle sprains. The reported mechanism of injury for a lateral ankle sprain is combined plantar flexion and inversion. Previous literature has demonstrated that individuals with CAI tend to be more plantar flexed and inverted just prior and at initial contact of gait, which may predispose them to subsequent sprains. Ankle taping is a common intervention that has been found to prevent ankle sprains. However, little research has been conducted to look at the affect ankle taping has on gait kinematics. **Objective:** To determine ankle kinematic differences in subjects with CAI with their ankle taped compared to an un-taped condition. **Design:** Controlled laboratory study **Setting:** Motion analysis laboratory **Patients or Participants:** 15 young adults subjects (8 males, 7 females) with self-reported CAI volunteered. Subjects had an average of 5.3 ± 3.1 incidences of ankle sprain. **Main Outcome Measures:** Subjects walked and jogged in shoes on a treadmill in two conditions (un-taped, taped) while frontal and sagittal plane ankle kinematics were recorded throughout the entire gait cycle. The conditions were randomized. Group means and 90% confidence intervals were calculated, plotted, and inspected for time increments in which the confidence intervals did not overlap. **Results:** During walking, subjects were less plantar flexed from 64-69% of the gait cycle (mean difference=5.73±0.54°) and less inverted from 51-61% (mean difference=4.34±0.65°) and 76-81% (mean difference=5.55±0.54°) of the gait cycle when taped. During jogging, subjects were less dorsiflexed from 12-21% (mean difference=4.91±0.18°) and less inverted from 47-58% (mean difference=6.52±0.12°) of the gait cycle when taped. **Conclusions:** In subjects

with CAI, taping resulted in less plantar flexion and inversion during the swing phase of gait. These changes in foot positioning may explain the protective aspect of tape in preventing lateral ankle sprains.

Keywords: External ankle support, ankle prophylactics, recurrent ankle sprains

Introduction

Lateral ankle sprains are very common injures[1] comprising an estimated 85% of all ankle injuries.[2, 3] A history of ankle sprain has been found to be the number one risk factor in predicting future sprains.[4-7] Basketball players with history of ankle sprain were found to be 4.9 times more likely to sustain another ankle sprain.[8] Up to an estimated 70% of individuals who suffer an initial ankle sprain will develop chronic ankle instability (CAI).[9, 10] CAI is characterized by repetitive bouts of lateral ankle instability often with residual feelings of "giving way".[10-12] Although the high prevalence of CAI is known, very little is actually understood regarding the mechanism or prevention of lateral ankle sprains.

Gait kinematic alterations in those with a history of lateral ankle sprain have been hypothesized to contribute to CAI.[13-16] In an *in vivo* study[17] it was found that misjudging the foot-floor clearance by 10° of inversion would cause an ankle sprain. Individuals with CAI have been found to underestimated the combined motions of plantar flexion and inversion during passive joint position sense.[18] These alterations in joint position sense may lead to alterations in kinematics during gait which may contribute to ankle sprains and instability.[17, 19] Brown[20] reported that individuals with functional instability Recently, researchers have compared ankle kinematics of CAI subjects to healthy controls while walking,[21-23] and jogging.[14, 21] Just prior to heel strike, at heel strike, and immediately following heel strike while walking, CAI subjects were more inverted compared to controls.[21-23] While jogging, Drewes et al[21] also reported that compared to healthy controls, CAI subjects were more inverted immediately prior to heel strike, at heel strike, and immediately post heel strike. In another study, Drewes at al[14] reported that while jogging, subjects with CAI were less dorsiflexed at the point of peak dorsiflexion in the gait cycle during jogging.

External ankle support is very common means of preventing sprains. Ankle prophylactics have been found to reduce the risk of recurrent ankle sprains.[5, 24-29] The purpose of ankle taping is to restrict ankle inversion and plantar flexion.[30, 31] In healthy subjects, tape has been found to reduce sagittal plane range of motion compared to untapped conditions while running, cutting and landing from a drop.[32-34] Sagittal plane kinematics during walking has been reported in individuals with CAI at foot contact and toe off while wearing an ankle brace.[35] However, there is no known literature evaluating sagittal and frontal plane kinematics in subjects with CAI while taped.

Therefore, the purpose of this study was to evaluate frontal and sagittal plane ankle kinematics in subjects with CAI while walking and jogging shod on a treadmill with and without wearing a traditional ankle tape procedure. The secondary purpose was to evaluate sagittal plane knee kinematics to determine kinematic alterations up the kinetic chain.

Methods

A pre-post design was used in this study. The independent variable was condition (un-tape and tape) and the dependent variables were degrees of frontal and sagittal planes lower extremity motion at the ankle and knee. All subjects walked and jogged on a treadmill in both conditions while kinematic data were captured.

Subjects

A total 15 subjects with self-reported CAI volunteered. All subjects had a history of at least one ankle sprain with the first sprain occurring more than 12 months ago and multiple recurrent episodes of their ankle giving way during functional activities. Subjects were screen by using a scored below a 95% on the Foot and Ankle Ability Measure (FAAM) and below an 85% on the FAAM-Sport. In subjects who reported bilateral CAI, the self-perceived "worse" ankle was the test ankle. All subjects participated in moderate or vigorous physical activity at least 3 times per week as determined by the Godin Leisure Time Exercise Questionnaire.[36, 37] Exclusion criteria were a history of ankle fracture, vestibular or neurological disorders, and any lower extremity or lumbosacral injuries within the past 3 months that could adversely affect their neuromuscular function. The university IRB approved the study methods. Subjects were recruited from a large public university and the surrounding community. Prior to data collection, all subjects provided written informed consent.

Instruments

Gait kinematics were computed from captured reflective marker locations sampled at 250 Hz using a 12 camera analysis system (Vicon MX t20, VICON Motion Systems, Inc., Lake Forest, CA). This system has been demonstrated to have a spatial error of 0.42mm and a mean error of angle reproduction of 0.16°. Synchronized ground reaction force data was collected by a multi-axis strain gauge force plate imbedded under a custom-built treadmill (AMTI OR 6-7, Watertown, MA). Vertical ground reaction forces were sampled at 1000 Hz with a threshold of 10-20% body weight to determine initial contact and toe-off during walking and running. 3-D joint kinematics were collected using Vicon PlugIn Gait (Oxford Metrics, London, UK).

Subject preparation

To capture lower extremity kinematics, retroreflective markers were placed directly on the skin using double-sided tape to previously established bony landmarks.[38] Markers were located bilaterally on the lateral mid-thigh, lateral tibiofemoral joint line, femoral head, tibial tuberosity, lateral mid-shank, and lateral malleolus. A custom foot marker set was placed on the posterior calcaneus, over the second metatarsal head, the medial side of the first metatarsal-phalangeal joint, and the lateral side of the fifth metatarsal-phalangeal joint. Virtual markers were established bilaterally for the anterior and posterior iliac spines and on the medial and lateral calcaneous. All subjects wore Brooks Defyance running shoes (Brooks Sports, Inc., Bothell, WA). After consultation with the shoe manufacturer, the heel counter and regions directly over the 1st and 5th metatarsal heads were removed to allow accurate marker placement directly onto the subjects' skin. The removal of these regions did not affect the integrity of the shoe.

Data collection

Following anthropometric data collection subjects were randomly assigned to condition order. For the un-taped condition, marker placement was applied. For data collection, subjects walked then jogged on the treadmill at speeds of 1.34 m/s and 2.68 m/s, respectively. Subjects were given a minimum of 3 minutes at each speed to adjust to the pace of the treadmill before data collection. Walking always proceeded jogging and subjects were given the option of a 5 min rest before jogging. Data was collected continuously at each pace until three 15-sec trials were collected.

For the taped condition, a traditional ankle taping procedure was conducted bilaterally on all subjects by the same clinician (LC).[39] The clinician was a certified athletic trainer with over 9 years of experience. The clinician used non-adhesive under-wrap (Pre-wrap) and 1.5" athletic tape (Johnson & Johnson) to apply a common taping method which included base strips, stirrups, heel locks, and figure-of-eights. Following the ankle taping procedure, marker set-up and data collection methods were identical to the un-taped condition. All data was collected by the same investigator who was not blinded to condition.

Data Processing

Three trials consisting of 15 seconds of gait cycles were collected for each subject. Each trial was inspected to find one complete trial per subject with adequate data to process. Kinetic and kinematic data for each limb were resampled through a custom program in MatLab 7.04 (Mathworks Inc, Natick, MA). The data was organized to 100 frames so that each frame represented one percent of the entire gait cycle (heel strike to heel strike). This was done individually for each subject based on the average stride-cycle time for the involved limb. Kinematic data ensembles were visually inspected to determine outliers.

Statistical analysis

For all analyses, walking and jogging data was analyzed separately. Similarly, sagittal and frontal planes as well as ankle and knee joints were evaluated independently. For each plane of motion, group means and associated 90% confidence intervals were calculated throughout the gait cycle. The data was inspected for time increments in which the confidence intervals did not overlap for more than 3 consecutive percentages of the gait cycle. For the increments that the confidence intervals did not overlap, group mean differences and associated standard deviations were calculated.

Results

Fifteen subjects (8 males, 7 females; age = 26.9 ± 6.8 years; height = 171.7 ± 6.3 cm; mass = 73.5 ± 10.7 kg) with self-reported CAI (FAAM = 92.1 ± 5.8%, FAAM-Sport = 74.8 ± 13.3%) volunteered. Subjects had an average of 5.3 ± 3.1 incidences of ankle sprain occurring 28.0 ± 34.4 months ago.

Ankle kinematics

Figure 1 shows the ankle kinematics between un-taped and taped conditions while walking. While walking, stance occurred from 0 – 62% of the gait cycle. In the sagittal plane, while taped, subjects were less plantar flexed from 64 – 69% of the gait cycle (mean difference = 5.73 ± 0.54°). In the frontal plane, subjects were less inverted while taped from 51 – 61% (mean difference = 4.34 ± 0.65°) and 76 – 81% (mean difference = 5.55 ± 0.28°) of the gait cycle. Figure 2 shows the ankle kinematics while jogging, at this speed, average toe off occurred at 35% of the gait cycle. From 12 – 21% of the gait cycle, while taped, subjects were less dorsiflexed (mean difference 4.91 ± 0.18°). Tape also reduced the amount of inversion from 47 – 58% of the gait cycle (mean difference = 6.52 ± 0.12°).

Knee kinematics

At the knee, there were no differences between flexion and extension kinematics between the taped and untaped conditions (Figure 3).

Discussion

At the ankle, tape caused kinematic changes in both the sagittal and frontal planes while walking and jogging. In general while taped, CAI subjects tended to be less inverted at different increments in the gait cycle. Interestingly, the increments when these changes were observed varied with different treadmill speeds. We did not detect any kinematic changes just prior to or immediately following heel strike. Nor did we observe any sagittal plane kinematic changes at the knee between conditions.

Although the use of tape and other external support at the ankle has been documented to reduce the risk of lateral ankle sprains,[5, 24-29] the mechanism of protection is still debated. The application of tape has been found to restrict open-chain range of motion and laxity[31, 40-43] indicating mechanical benefits of support. However, the mechanical restraint of tape in reducing ankle sprains may only occur at the extreme ranges of motion and have no effect stabilizing the joint within the mid-range of motion.[44] Tape has also been suggested to provide neuromuscular benefits.[45-48] Tape is believed to provide cutaneous input that causes an increase in motoneuron pool excitability.[49] The increase in motoneuron pool excitability may aid in changes of joint position sense,[50] postural control,[47] and lower leg muscular activity.[42, 51] The firing of afferent signals at the ankle has been hypothesized to better position the lower extremity during function.[42, 50, 51] Because our kinematic alterations occurred during both the end and middle of the arc of motion our results support both theories of tape properties.

Immediately following the application of tape, CAI subject were less inverted from 51 – 61% of the gait cycle while walking. This represents the time from heel off to toe off during stance. It has been suggested that ankle sprains occur during initial loading or unloading.[52] A recent case report[53] captured video analysis data during an accidental lateral ankle sprain of a subject performing a lateral cut. The report noted that the ankle sprain occurred during unloading, with the forefoot in contact with the ground whilst the rearfoot drifted laterally and inverted. Our study showed that at this critical aspect of the gait cycle the use of tape positions an unstable ankle in a more neutral, less precarious position, potentially reducing the risk of incurring a lateral ankle sprain.

Following toe off while walking in tape, subjects went from being less plantar flexed almost immediately to being less inverted compared to the un-taped condition. The increment of these changes lasted from 64 – 81% of the gait cycle, representing initial swing and mid-swing including foot-floor clearance.[54] Individuals with CAI have been found to have a smaller foot-floor clearance during gait compared to individual with stable ankles.[20, 23] In a cadaver study conducted by Konradson and Voigt,[17] it was suggested that joint position sense error during foot-floor clearance leads to unintentional contact of the lateral aspect of the foot with the floor resulting in ankle sprains. Our study shows that the application of tape may stimulate the distal leg to better position itself to clear the floor and avoiding mid-swing contact.

As seen in Figure 2, while jogging the total amount of sagittal plane motion is greater compared to the slower speed. Unlike in the walking state, while taped, individuals with CAI were less dorsiflexed leading up to peak dorsiflexion during the stance phase. During this time in the gait cycle when dorsiflexion motion is highest, the lack of dorsflexion may be due to the mechanical properties of tape. However, because this restriction in range of motion occurs during full weight-bearing, the authors do not believe this finding positively or negatively affects ankle sprain risk. During full weight-bearing, the likelihood of ankle sprain is minimal due to the stability of the joint.[52, 55] Further research should be conducted to determine potential consequences of a lack of dorsiflexion during mid-stance.

Frontal plane motion during initial swing was observed while jogging. Again, preparing the foot to clear the ground is essential during this aspect of gait. Although not statistically significant, during foot-floor clearance, while taped, subjects were actually everted, ensuring adequate clearance. Similar to walking, tape may have stimulated the lower leg into better positioning to avoid contact with the ground. Previous research has reported increased muscular activation while taped during simulated inversion.[42, 51] Peroneus muscle reaction time to a simulated ankle sprain was significantly improved with the application of tape in subjects with ankle instability.[42]However there is a need to evaluate this relationship during functional activities such as walking and jogging.

Previous literature on the effect of ankle prophylactics on CAI subjects is extremely limited.[35] Spaulding et al[35] compared ankle sagittal plane kinematics in CAI subjects while wearing a flexible brace, a semi-rigid brace, and an un-braced condition. No sagittal differences were found between conditions while walking on a level surface at foot contact or toe off. The results of the current study found similar results in the sagittal plane. An advantage of the current study was our ability to evaluate two planes of motion throughout the entire gait cycle and not just at two discrete time points.

Altering and restricting range of motion at the ankle has been found to be detrimental to proximal knee joints such as the knee.[33, 34, 56, 57] Stoffel et al[33] investigated the effect of tape on knee biomechanics in healthy individuals while running and cutting. They reported reduced peak internal rotation moment and peak varus moment at the knee while taped. They concluded that the application of ankle tape provided protective benefits at the knee. At initial contact from a jump, ankle bracing was found to increase knee flexion.[34] However, the increase in knee flexion was not associated with an increase in knee injury risk.[34] Our study did not find sagittal plane kinematic differences at the knee. Although our knee results do not agree with previous research the differences in tasks may be the reason. Jumping and landing requires the lower extremity to absorb a significantly larger amount of force than walking or jogging.

One of the most common methods of preventing lateral ankle sprains is through the use of external support. Although ankle sprains often occur while landing awkwardly from a jump, those with CAI report feeling unstable while walking and jogging on a level surface. However, previous research on ankle prophylactics has mostly focused on healthy subjects and kinematic differences during a jumping task.[32-34, 58, 59] The only previous reported research evaluating subjects with CAI, ankle braces, and walking on a level surface was limited by only investigating two discrete points in the gait cycle.[35] Spaulding et al[35] found that controls were more plantar flexed at initial contact and toe off compared to braced conditions. The results of our study found similar results immediately following toe off, however we did not find any sagittal plane differences between groups at initial contact.

Conclusions

The current study presents data on a pathological sample performing common tasks in sports. Overall we found that in subjects with CAI, taping alters sagittal and frontal plane kinematics at the ankle while walking and jogging in shoes on a treadmill. The alterations seen in the taped condition may contribute to a reduced risk of ankle sprains. Tape may aid in the protective the ankle because of its mechanical properties during stance and its neuromuscular affect on ankle position just prior to critical aspects of gait such as toe off and foot-floor clearance.

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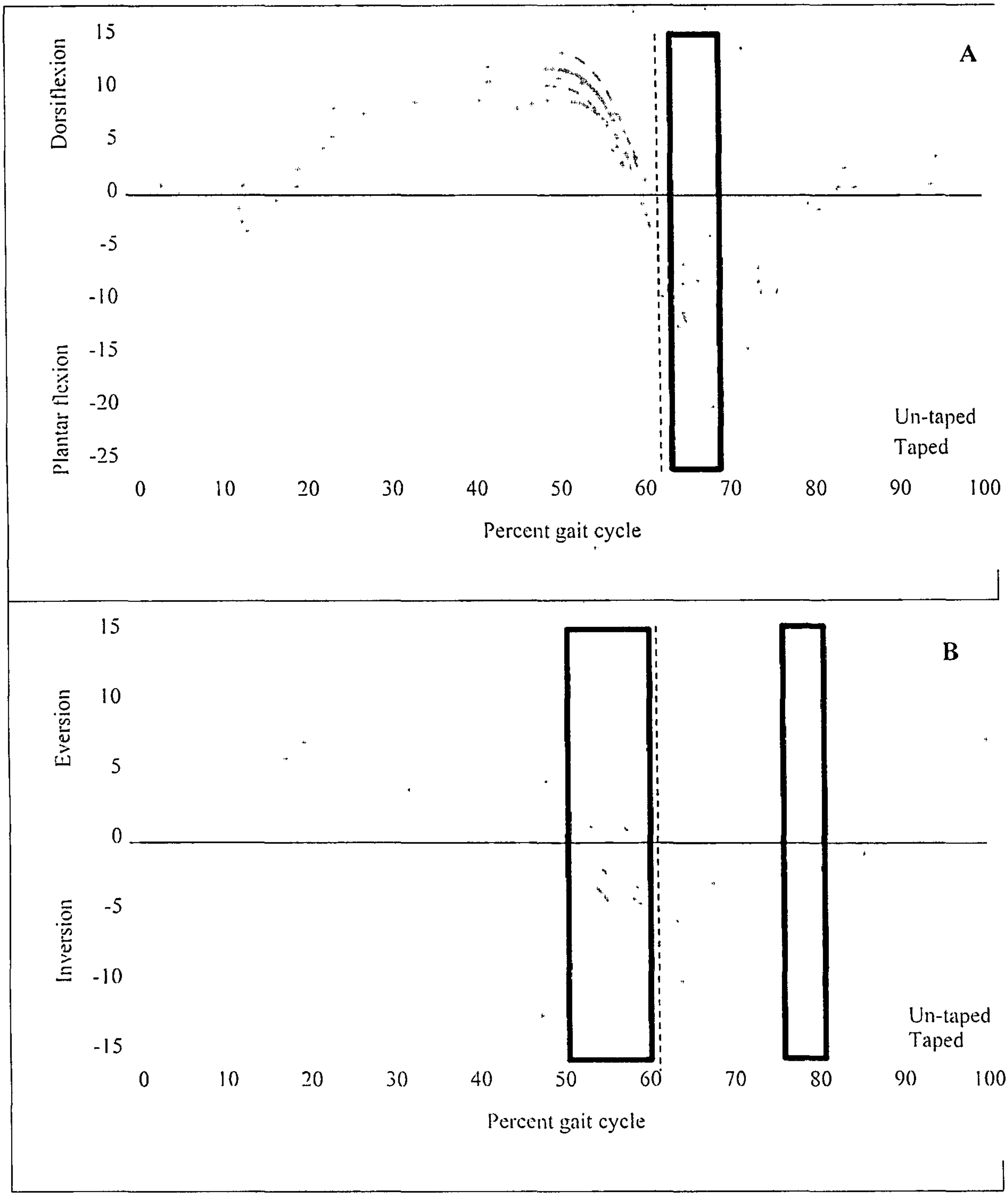

Figure 4.1: Ankle kinematics while walking. 0% represents initial contact; 62% is toe off; 100% is terminal swing. Solid lines represent group means, dashed lines represent the 90% confidence intervals. A) Sagittal plane kinematics. In the taped condition, subjects were less plantar flexed from 64 – 69% (mean difference = 5.73 ± 0.54°). B) Frontal plane kinematics. In the taped condition, subjects were less inverted from 51 – 61% (mean difference = 4.34 ± 0.65°) and from 76 – 81% (mean difference = 5.55 ± 0.28°).

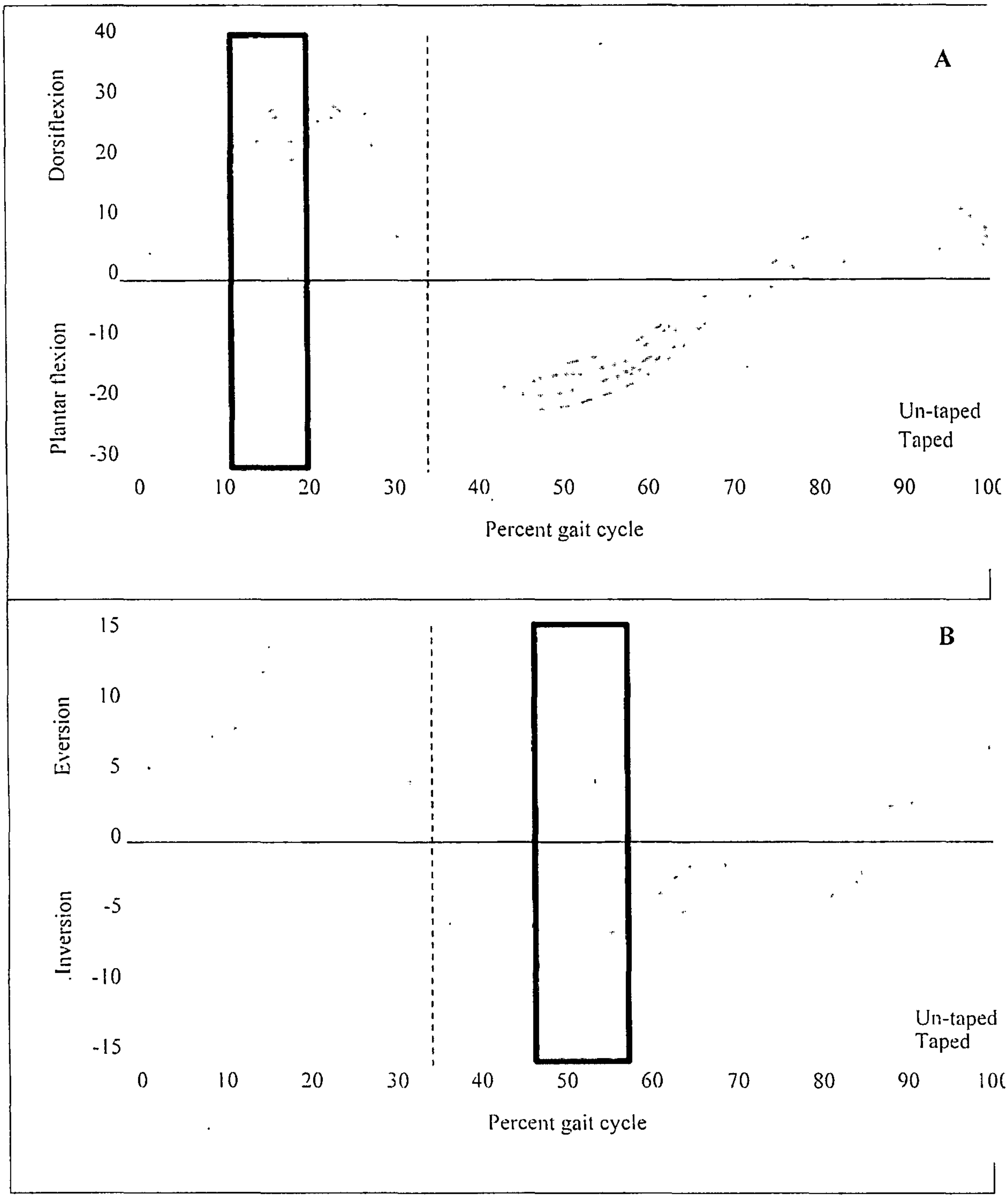

Figure 4.2: Ankle kinematics while jogging. 0% represents initial contact; 35% is toe off; 100% is terminal swing. Solid lines represent group means, dashed lines represent the 90% confidence intervals. A) Sagittal plane kinematics. In the taped condition, subjects were less plantar flexed from 12 – 21% (mean difference = 4.91 ± 0.18°). B) Frontal plane kinematics. In the taped condition, subjects were less inverted from 47 – 58% (mean difference = 6.52 ± 0.12°).

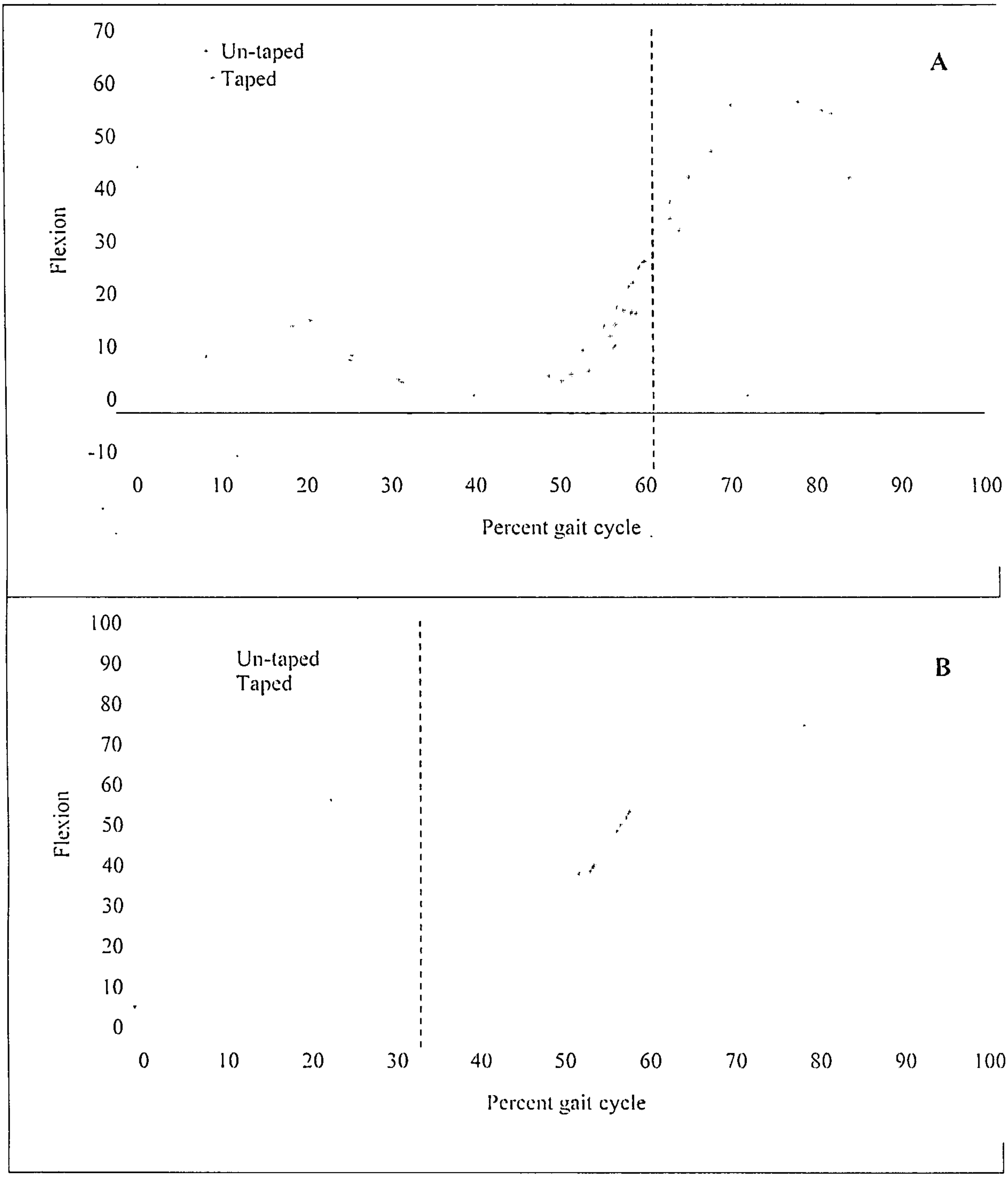

Figure 4.3: Knee sagittal plane kinematics while walking and jogging. 0% represents initial contact; 100% represents terminal swing. Solid lines represent group means, dashed lines represent the 90% confidence intervals. A) Walking. Toe off is 62% of gait cycle. B) Jogging. Toe off is 35% of gait cycle.

CHAPTER 5

MANUSCRIPT 3

CLINICAL MEASURES THAT PREDICT MAXIMUM INVERSION DURING GAIT IN SUBJECTS WITH A HISTORY OF ANKLE SPRAIN

Abstract

Context: Individuals with a history of an ankle sprain have been found to have alterations in clinically measured variables such as range of motion (ROM), postural control, laxity, and subjective function). Subjects with chronic ankle instability (CAI) have also been found to be more inverted during the swing phase of gait. Being more inverted during gait may lead to episodes of recurrent sprain. **Objective:** To determine which clinical measures best predict maximum inversion during the swing phase of gait in those with a history of ankle sprain. **Design:** Descriptive laboratory study **Setting:** Laboratory **Patient or Participants:** 26 active individuals with a history of at least one ankle sprain participated. **Main Outcome Measures:** Ankle ROM was assessed during weight bearing and non-weight bearing conditions. Static and dynamic balance was assessed by the Balance Error Scoring System and Star Excursion Balance Test, respectively. Ligament laxity was measured manually via the posterior talar glide, the anterior drawer test, and the talar tilt test. Ligament laxity was also measured in the anterior and inversion motions using an instrumented ankle arthrometer. Subjective function was measured using the Short Form-12, the Foot and Ankle Ability Measure (FAAM) and the FAAM-Sports scales. Maximum inversion during swing was determined during jogging by a 12-camera motion analysis system. Linear regression analyses using a stepwise method were used to determine which clinical measures were most predictive of the maximum inversion angle during swing phase in both walking and jogging. **Results:** While jogging, worse FAAM scores (r^2 = .488) and increased anterior laxity using an instrumented arthrometer (r^2 = .217) were significantly associated with greater maximum inversion during swing. **Conclusions:** Clinicians should know that

worse self-reported function and increased anterior laxity may be able to identify individuals with abnormal gait without the need of an expensive motion analysis system.

Keywords: Coper, chronic ankle instability, biomechanics, range of motion, laxity

Introduction

Chronic ankle instability (CAI) is characterized by repetitive bouts of lateral ankle instability.[1-3] CAI is estimated to occur in up to 70% of individuals who suffer an initial ankle sprain.[3,4] Individuals with CAI most often complain of pain, instability, or feelings of giving way, with many complaining of multiple symptoms.[2,3,5] Long-term consequences of CAI include interference with occupational and athletic participation[2,6] and increased risk of osteoarthritis and degenerative joint disease.[7-10]

Historically, CAI has been attributed to two causes: mechanical instability (MI) or functional instability (FI).[11-13] MI is defined as changes resulting from abnormal joint mechanics.[1] FI can be defined as the sensation of instability without joint laxity.[1] Researchers believe that an individual with CAI could suffer from one or both, MI and FI. Previous studies have found clinical differences in subjective function, strength, postural control, laxity, range of motion (ROM), and proprioception, between those with and without CAI. Even though CAI can be described simply using MI and FI, it is a multifaceted pathology that, although researched in depth, is not well understood.

One critical finding in the CAI literature is the altered gait kinematics between CAI and healthy controls during the swing phase of gait.[14-17] Specifically, subjects with CAI have been found to be more inverted just prior to heel strike,[15-17] as well as have a having a lower foot-ground clearance during swing through.[18] This altered positioning may lead to recurrent ankle sprains. Gait, which is a complex task incorporates and encompasses aspects of the clinical measures that have been found to differ between groups. Although previous research has reported differences in clinical measures as well as complex tasks such as gait, between CAI and healthy, to our knowledge, no research has tried to find a relationship between all the two.

Therefore, the purpose of this study was to determine which clinically measured variables (ROM, static balance, dynamic balance, laxity, and subjective function) best predict maximum inversion angle during the swing phase of gait while jogging in those with a history of ankle sprain. The clinical measurements were self-reported questionnaires, non-weight bearing ROM in the four cardinal planes, weight bearing dorsiflexion with knee bent, weight bearing dorsiflexion with knee straight, balance error scoring system (BESS) on a firm surface and a unstable surface, the star excursion balance test in the anterior, posteriolateral and posteriomedial directions, the posterior talar glide (PTG), anterior drawer laxity, talar tilt laxity, and instrumented arthrometer laxity in the anterior and inversion directions. It is hypothesized that FAAM-S, instrumented inversion laxity, and the SEBT in the posteriolateral direction will best predict maximum inversion during swing.

Methods

This study required two visits from subjects. During the first visit, subjects reported to a sports medicine research lab where clinical measures were collected. The second visit was conducted in a motion analysis laboratory. While at the motion analysis laboratory, ankle inversion kinematics were recorded while subjects jogged on a treadmill in shoes. Data was collected during both visits by one researcher (LC) who was blinded to the involved and uninvolved limbs of each subject.

Subjects

A total of 26 subjects with a history of at least one ankle sprain volunteered. In subjects who reported a history of bilateral ankle sprains, the self-perceived "worse" ankle was the test ankle. All subjects participated in moderate or vigorous physical activity at least 3 times per week as determined by the Godin Leisure Activity Questionnaire.[19, 20] Exclusion criteria were a history of ankle fracture, vestibular or neurological disorders, and any lower extremity or lumbosacral injuries within the past 3 months that could adversely affect their neuromuscular function. The university IRB approved the study methods. Subjects were recruited from a large public university and the surrounding community. Prior to data collection, all subjects provided written informed consent.

Instruments

An instrumented ankle arthrometer (Blue Bay Research, Inc., Milton, FL) was used to measure anterior and inversion talar laxity.[21, 22] A fluid-filled bubble inclinometer (Fabrication Enterprises Inc, White Plains, NY) and a standard goniometer were used to measure active ROM and PTG.[23] The unstable condition for BESS was conducted using a closed-cell foam surface (AIREX Balance Pad).

Gait kinematics were computed from captured reflective marker locations sampled at 250 Hz using a 12 camera analysis system (Vicon MX t20, VICON Motion Systems, Inc., Lake Forest, CA). This system has been demonstrated to have a spatial error of 0.42mm and a mean error of angle reproduction of 0.16°. Synchronized ground reaction force data was collected by a multi-axis strain gauge force plate imbedded under a custom-built treadmill (AMTI OR 6-7, Watertown, MA). Vertical ground reaction forces were sampled at 1000 Hz with a threshold of 10-20% body weight to determine initial contact and toe-off during walking and running. 3-D joint kinematics were collected using Vicon PlugIn Gait (Oxford Metrics, London, UK).

Data collection

Clinical measures

Following informed consent, subjects completed the Foot and Ankle Ability Measure (FAAM) and the FAAM-Sport Scale questionnaires[24, 25], and the Short Form 12. Height, weight, sex, and age demographics were collected. The clinical measures were conducted in standard order; BESS-firm, BESS-foam, non-weight bearing ROM in four planes, weight bearing ROM, PTG, manual laxity tests, SEBT in anterior, posteriolateral, and posteriomedial directions, and lastly arthrometer testing.

Single limb firm and unstable conditions for the BESS test was performed. Docherty et al[26] reported that subjects with ankle instability performed significantly worse than healthy controls in the single limb conditions. Subjects performed 20 seconds of single limb stance with eyes closed while the researcher recorded the number of errors incurred. Subjects were instructed to stand with hands on their hips and remain as motionless as possible. If they lost their balance they were instructed to get right back into the starting position as quickly as possible. One error was recorded for each time a subject: 1) lifted hands off iliac crests; 2) opened eyes; 3) stepped, stumbled, or fell; 4) moved the hip into more than 30 degrees of flexion or abduction; 5) lifted the forefoot or heel; 6) remained out of the testing position for more than 5 seconds. The total number of errors was recorded for each condition; firm surface and foam surface. Each subject performed the BESS once for each condition and each limb.

ROM was recorded both weight bearing and non-weight bearing. Non-weight bearing ROM was conducted with the subjects sitting on a treatment table with knees straight and feet off the end of the table. Active dorsiflexion and plantar flexion were conducted using a bubble inclinometer.[23] Active inversion and eversion were measured using a short arm goniometer. Weight bearing ROM was conducted using a bubble inclinometer in to positions for dorsiflexion: knee straight and knee bent.[23,27,28] All ROM measurements were taken three times.

PTG as well as the anterior drawer and talar tilt tests were performed according to previously established methods.[23 29] PTG was conducted with the subject sitting with knees bent and shank hanging off the table. Using a bubble inclinometer strapped to the subject's shank, the subject's foot was placed into subtalar neutral. The knee was passively flexed while the ankle was passively dorsiflexed. Once a restriction was felt, the knee angle was recorded. PTG was performed three times. All manual laxity tests were performed by one researcher (LC) with 9 years of clinical experience. Both the anterior drawer and talar tilt tests were scored by the researcher on a scale from 0 to 4 (0 = hypomobility, 1 = normal, 2 = mile laxity, 3 = moderate laxity, 4 = gross laxity).[29]

Three directions of the SEBT were measured: anterior, posteriolateral, posteriomedial. The methods used for the SEBT have been described elsewhere.[30,31] In general, for each direction, subjects were instructed to reach as far as possible and lightly touch down along a tape measure. Trials were discarded and redone if a subject was unable to maintain single limb balance during task, put too much pressure down on reach leg, or was unable to return to starting position. For each direction, three trials were conducted and normalized to subject's leg length.

The instrumented arthrometer was used to measure anterior displacement and inversion rotation. Subjects rested supine on a treatment table with lower leg stabilized and midshank off the table. After application of the ankle arthrometer, three anterior loads of 125 Newtons were applied followed by three inversion loads of 4 N-m. Total anterior and inversion displacement between the calcaneus and talus were recorded.[21, 22, 32]

Ankle kinematic subject set-up

To capture lower extremity kinematics, retroreflective markers were placed directly on the skin using double-sided tape to previously established bony landmarks.[33] Markers were located bilaterally on the lateral mid-thigh, lateral tibiofemoral joint line, femoral head, tibial tuberosity, lateral mid-shank, and lateral malleolus. A custom foot marker set was placed on the posterior calcaneus, over the second metatarsal head, the medial side of the first metatarsal-phalangeal joint, and the lateral side of the fifth metatarsal-phalangeal joint. Virtual markers were established bilaterally for the anterior and posterior iliac spines and on the medial and lateral calcaneous. All subjects wore Brooks Defyance running shoes (Brooks Sports, Inc., Bothell, WA). After consultation with the shoe manufacturer, the heel counter and regions directly over the 1st and 5th metatarsal heads were removed to allow accurate marker placement directly onto the subjects' skin. The removal of these regions did not affect the integrity of the shoe.

Ankle kinematic data collection

Following marker placement, subjects jogged on the treadmill at speeds of 2.68 m/s. Subjects were given a minimum of 3 minutes to adjust to the pace of the treadmill before data collection. Data was collected continuously until three 15-sec trials were collected.

Data Processing

For the ROM, PTG, SEBT, and instrumented ankle laxity clinical measures, the mean of three trials was calculated and used for statistical analysis. The remaining clinical measures, BESS and manual laxity tests were conducted once and that number used for analysis.

Three trials consisting of 15 seconds of gait cycles were collected for each subject. Each trial was inspected to find one complete trial per subject with adequate data to process. Kinetic and kinematic data for each limb were resampled through a custom program in MatLab 7.04 (Mathworks Inc, Natick, MA). The data was organized to 100 frames so that each frame represented one percent of the entire gait cycle (heel strike to heel strike). This was done individually for each subject based on the average stride-cycle time for the involved limb. Kinematic data ensembles were visually inspected to determine outliers. After the data was processed, swing phase was determined for jogging (35% of gait cycle). Peak inversion angles for jogging during swing determined and used for analysis.

Statistical analysis

Overall, 22 predictor variables were measured. We first calculated bivariate correlations using Pearson product moment correlations between all clinical measures and the maximum inversion angle taken on the involved limbs of the subjects to reduce the number of potential predictors. All variables showing a moderate to strong relationship ($r > .35$) was retained for the regression analysis.[34] The retained variables were entered into a linear regression model using a stepwise method to determine their relationship with maximum inversion. A significance level of alpha < 0.05 was used for all linear regression analyses.

Results

Bivariate correlation of the clinical measures found seven variables that had a moderate or greater relationship with swing phase maximum inversion while jogging (Table 1). The variables were Short Form-12-physical scale, FAAM, FAAM-Sport scale, non-weight bearing inversion, SEBT in the anterior, posterolateral, and posteriomedial directions, and instrumented ankle laxity in the anterior direction. Linear regression revealed two significant clinical predictors of maximum inversion (total $r^2 = /705$). Variance in subjects; FAAM scores explained 48.8% and instrumented ankle laxity in the anterior direction explains an additional 21.7% of maximum inversion angle (predictive model $p = .009$). The predictive equation for maximum inversion is:

Maximum inversion = 93.87 – 0.95 (FAAM) + 1.02 (anterior laxity)

Discussion

The major finding of this study is that FAAM score and anterior laxity using an instrumented arthrometer are significant predictors of maximum inversion angle during the swing phase of jogging in individuals with a history of ankle sprain. The two clinical measures may potentially help clinicians identify individuals with abnormal gait without having to use a high-tech motion analysis system.

To our knowledge this is the first study to find a relationship with clinical measures and maximum inversion during swing. During the non-weight bearing aspect of gait the role of the limb is propel the body forward by advancing the limb from behind the body to in front of the body. The limb has two crucial responsibilities during the swing phase of gait, to clear the floor during limb advancement and to prepare the limb for initial contact.[35] Increased inversion of the ankle during floor clearance or at initial contact is thought to be a risk for ankle sprain.[15-18, 36] We choose to evaluated maximum inversion during swing because it encompasses both foot-floor clearance and pre-initial contact which have both been studied as critical times in the gait cycle.

We predicted that the FAAM-S, inversion laxity measured by the instrumented arthrometer and SEBT-posterolateral direction would all be strong predictors of maximum inversion. We chose the above variables due to specificity of function and motion involved. However, none of our hypotheses variables were correct. Although our hypothesized variables were not significant, a different self-reported questionnaire, the FAAM-ADL scale and instrumented laxity in a different direction, anterior were significant. These two variables point to the importance of obtaining both subjective and objective information when assessing a patient with a history of ankle sprain.

Self-reported function explained almost half of the maximum inversion during swing while jogging. For everyone percentage point that FAAM-ADL score is reduced, maximum inversion increases by 0.95°. Reporting more disability during activities of daily living was correlated with greater inversion. The FAAM questionnaire is an easily implemented instrument in the clinic. A simple validated[24] questionnaire may be a tool medical professionals can utilize when evaluating patients with a history of ankle sprain to potentially determine abnormalities during gait that may not be clearly evident through visual assessment. The FAAM-ADL and the FAAM-S scales are highly correlated (r =

.917), thus they have a considerable amount of shared variance and both scales would not be needed in the regression model.

Talocrural joint laxity in the anterior direction explained an additional 21.7% of maximum inversion while jogging. For every 1 millimeter increase in anterior displacement inversion increased 1.02 degrees. Increased inversion could potentially relate to increased risk for injury if the lower leg musculature has altered neuromuscular firing to support the foot.[37-40] Being capable of potentially identify patients objectively at higher risk for injury would be ideal to pro-actively treat the deficient.

The results of this study bring about more research questions. Research should be conducted separating foot-floor clearance from pre-initial contact to determine if there are more or different variables that better predict maximum inversion at each period of swing. Also, further research needs to be done following subjects with increased inversion during swing to determine if they are at an increased risk for ankle sprains.

Clinical implications

This study may ultimately help clinicians identify abnormal gait patterns in subjects with a history of ankle sprain. Being more inverted during swing potentially increase the risk of subsequent ankle sprains.[15-18, 36] Integrating easily administered assessments such as the FAAM and anterior laxity cause identify subjects who may benefit from gait rehabilitation programs.

Conclusion

Overall, this research study is explored the relationship between common clinical ankle measures to determine if any could significantly predict maximum inversion during gait in subjects with a history of ankle sprain., two variables did correlate with maximum inversion while jogging. Self-reported function of activities of daily living as measured by the FAAM, and instrumented anterior laxity as measured by an ankle arthrometer were both significant predicts. Both of these measures can be implemented into a clinic to identify patients who may be at greater risk for further ankle sprain.

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Table 5.1: Variable means (sd), correlation coefficients and P-values between clinical variables and maximum inversion while jogging

Variable	Mean (sd)	Correlation coefficient	P-value
Maximum inversion during swing (°)	9.55 (6.21)		
Height (cm)	170.89 (8.06)	-0.01	.96
Weight (kg)	68.87 (13.38)	-0.04	.90
Short Form 12 - physical scale (%)	54.80 (2.76)	-0.42	.10*
Short Form 12 – mental scale (%)	54.72 (3.64)	0.21	.44
FAAM – ADL scale (%)	95.63 (6.04)	-0.70	.003*
FAAM – Sport scale (%)	85.81 (15.96)	-0.55	.03*
BESS – firm surface (errors)	7.75 (6.30)	-0.22	.40
BESS – unstable surface (errors)	17.25 (3.77)	0.12	.66
NWB Dorsiflexion (°)	14.53 (9.59)	0.07	.80
NWB Plantar flexion (°)	61.56 (15.13)	-0.15	.59
NWB Inversion (°)	28.79 (7.03)	-0.35	.19*
NWB Eversion (°)	8.54 (4.12)	0.16	.57
WB Dorsiflexion with straight knee (°)	33.32 (6.92)	-0.20	.45
WB Dorsiflexion with bent knee (°)	36.96 (7.01)	0.15	.58
Posterior Talar Glide (°)	33.32 (6.92)	0.26	.33
SEBT – anterior (%)	62.59 (6.30)	-0.30	.25*
SEBT – posteriolateral (%)	76.43 (13.46)	-0.35	.18*
SEBT – posteriomedial (%)	83.90 (8.98)	-0.31	.25*
Instrumented anterior laxity (mm)	6.89 (2.88)	0.35	.19*
Instrumented inversion laxity	31.899 (7.43)	0.21	.44
Anterior drawer	2.29 (1.33)	0.05	.86
Talar tilt	2.21 (1.02)	-0.15	.58

FAAM = Foot and Ankle Ability Measure; ADL = activities of daily living; BESS = Balance Error Scoring System; NWB = non-weight bearing; WB = weight bearing; SEBT = Star Excursion Balance Test

* = variables entered into stepwise linear regression analysis

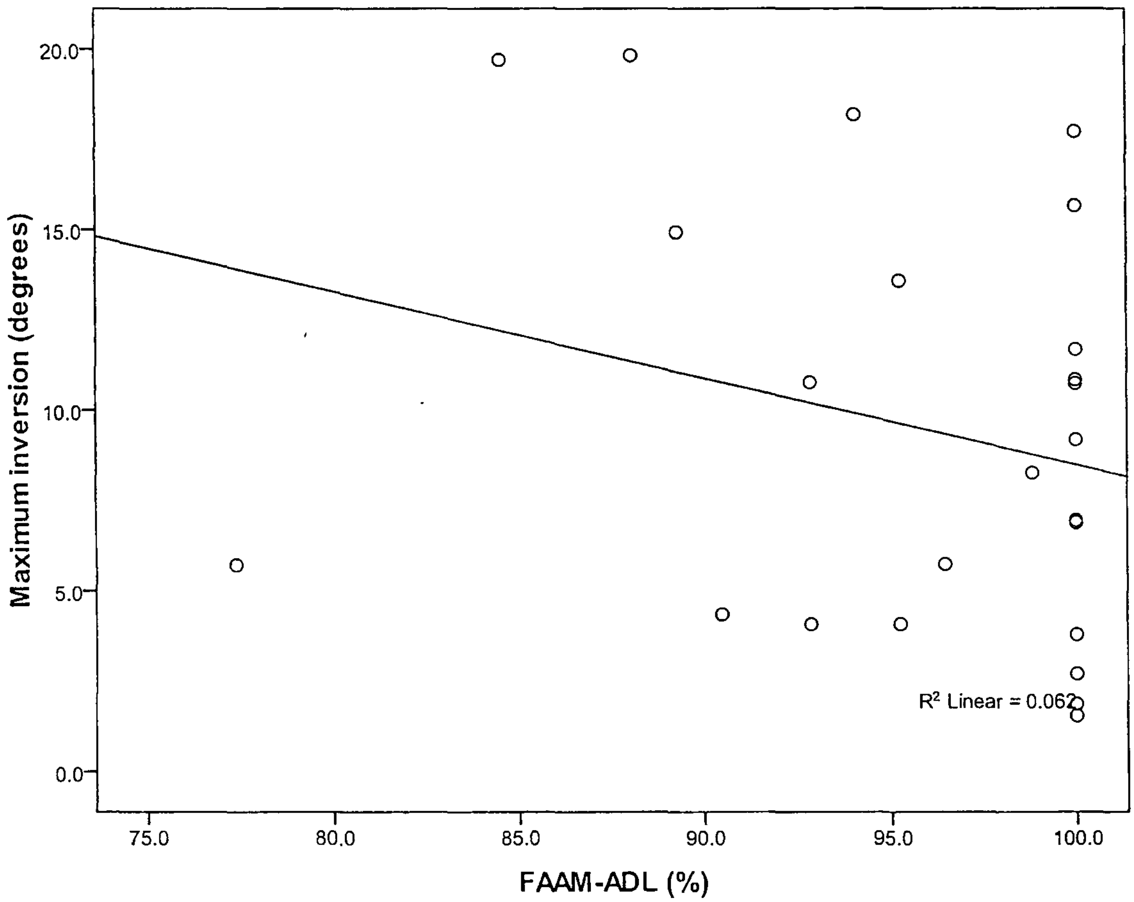


Figure 5.1: Scatter plot between maximum inversion and FAAM-ADL

FAAM-ADL = Foot and Ankle Ability Measure activities of daily living scale

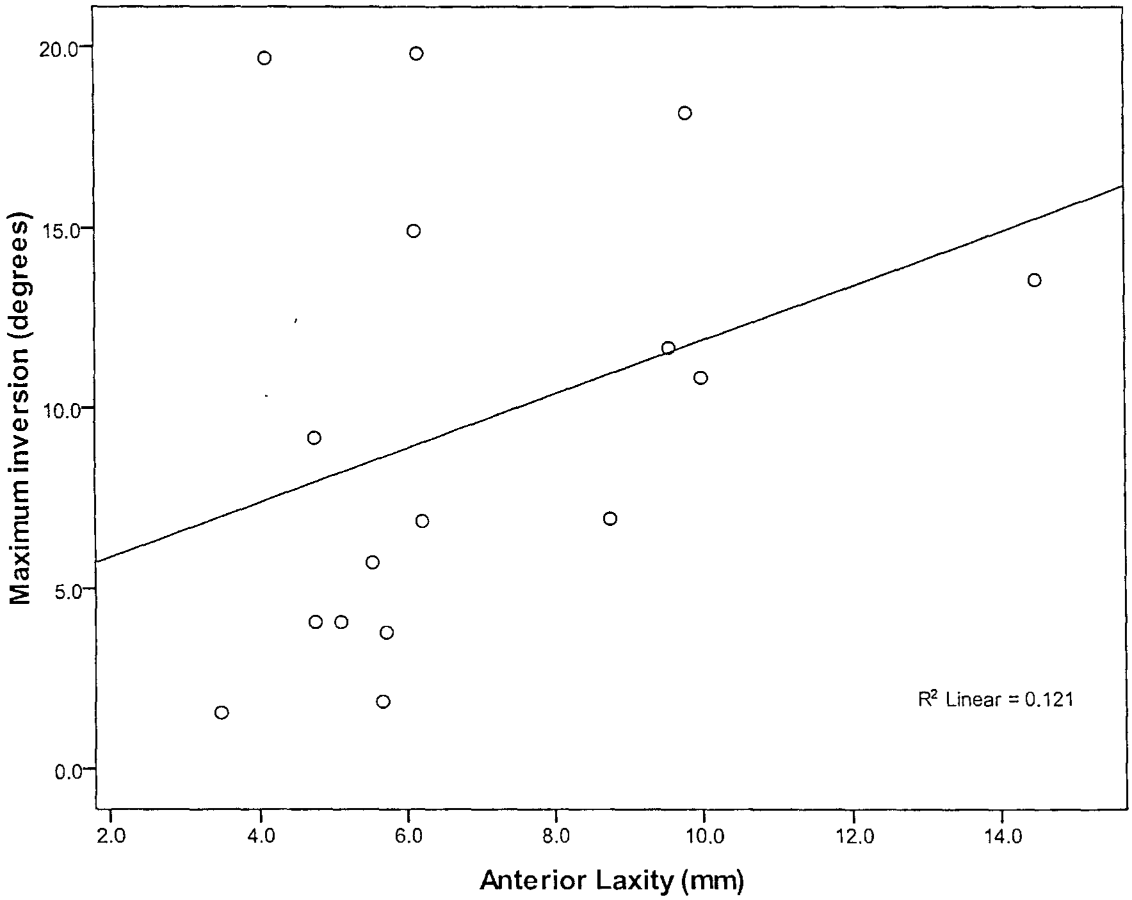


Figure 5.2: Scatter plot between maximum inversion and anterior laxity

CHAPTER 6

CONCLUSIONS

The purpose of this dissertation was to compare lower extremity kinematics in those with and without CAI. Specifically the aims were to: 1) evaluate hip and knee frontal and sagittal plane ankle kinematics between subjects with CAI and copers and CAI subjects and healthy controls while walking and jogging on a treadmill in shoes; 2) evaluate the movement variability in the sagittal and frontal plane kinematics at the ankle, knee and hip between the groups; 3) evaluate frontal and sagittal plane ankle kinematics in subjects with CAI while walking and jogging shod on a treadmill with and without wearing a traditional ankle tape procedure; 4) evaluate sagittal plane knee kinematics to determine kinematic alterations up the kinetic chain; 5) determine which clinically measured variables (ROM, static balance, dynamic balance, laxity, and subjective function) best predict maximum inversion during the swing phase of gait while walking and jogging in those with a history of ankle sprain. The following were research hypotheses investigated in this study.

Manuscript 1

- Individuals with chronic ankle instability will demonstrate more frontal plane adduction at the hip throughout the gait cycle compared to the coper and healthy control groups while walking and jogging.

Finding: This hypothesis was not confirmed. Subjects with CAI did not demonstrate altered kinematics at the hip compared to controls or copers while shod.

- Individuals with chronic ankle instability will demonstrate more knee flexion at the knee throughout the gait cycle compared to the coper and control groups while walking and jogging.

Finding: This hypothesis was partially accepted. We did find more knee flexion during swing in subjects with CAI compared to controls. However we did not find any differences between CAI subjects and copers. CAI subjects presented with more knee flexion during swing while jogging. This finding suggests that CAI subjects alter their gait at faster speeds in order to accomplish the required task.

- The chronic ankle instability group will have more sagittal plane kinematic variability at the hip and knee compared to the coper and healthy control groups while walking and jogging.

Finding: This hypothesis not confirmed. Findings from this study found that CAI subjects had greater movement variable at the ankle during unloading and swing compared to controls. There were no differences between CAI subjects and copers. While shod, CAI subjects did not present with different sagittal plane variability at the knee or hip compared to controls or copers. Having increased movement variability at the ankle may be a contributing source to the feelings of instability in subjects with CAI since they do not have a consistent movement pattern throughout gait.

Manuscript 2

- In subjects with chronic ankle instability, ankle taping will limit the amount the inversion and plantar flexion compared to a no-tape condition while walking and jogging in shoes on a treadmill.

Finding: This hypothesis was partially upheld. While taped, individuals did exhibit less inversion and plantar flexion as well as less dorsiflexion during various aspects of the gait cycle while both walking and jogging. Tape altered ankle kinematics in subjects with CAI while both walking and jogging. This study adds to the literature showing that taping unstable ankles alters motion but may also have a neuromuscular benefit while reducing the incidence of lateral ankle sprains.

- In the taped condition knee will present with altered sagittal plane kinematics compared to the un-taped condition.

Finding: This hypothesis was not confirmed. No sagittal plane kinematic differences were found between the taped and un-taped conditions in subjects with CAI. During walking and jogging, tape may only affect kinematics at the ankle joint.

Manuscript 3

- Self-reported function, inversion laxity and dynamic balance will best predict individuals who will be most inverted during the swing phase of gait in those with a history of ankle sprain. Specifically, we believe that the FAAM-S, instrumented inversion laxity, and the Star Excursion Balance Test in the posteriolateral direction will be strong predictors of maximum inversion.

Finding: This hypothesis was not confirmed. This study found that self-reported function and laxity were predictors of maximum inversion during swing, however the significant predictors were different from our hypothesized ones. FAAM-ADL and anterior laxity, together, accounted for about 71% of the variance seen in maximum inversion in subjects with a history of ankle sprain. These finding suggest that two clinical measures may be able to identify altered gait mechanics.

Synthesis and application of results

The most important finding of this study is that subjects with CAI have altered gait patterns while walking and jogging compared to healthy controls. Providing a taping intervention to subjects with CAI will again alter their lower extremity kinematics. The changes seen in CAI gait may be due to the recurrent sprains and the feelings of giving way.

Interesting a majority of the differences observed occurred during the latter part of stance and during the swing phase of gait. The etiology of lateral ankle sprains has been debated in the literature. Most believe that ankle sprains are the result of erroneous foot place during landing, however others have suggested that unloading and swing may be critical aspects of the gait cycle. Unfortunately, kinematics during unloading and swing has not been focused on in previous literature. The current study found changes throughout gait emphasizing the need for future research to further evaluate the entire gait cycle.

Additionally, the current study found that implementing a taping intervention alters motion patterns in subjects with CAI. Tape has been found to reduce the incidence of ankle sprains, however its mechanism is not fully understood. We found that tape may provide both a mechanical restriction as well as neuromuscular stimulation. While wearing tape, CAI subjects had a reduced range of motion, indicating a potential mechanical stability aspect to tape. Similarly, with the application of tape, CAI subjects may potentially activate lower limb muscular so as to have a more stable foot position throughout the gait cycle, thus reducing their risk of sustaining an ankle sprain.

CAI subjects and copers both presented with similar gait. Combining the two groups we evaluated various clinical measures to determine if we could find variables that could predict maximum inversion during swing. FAAM-ADL and instrumented anterior laxity accounted for over 70% of maximum inversion during swing while jogging. This finding may be utilized by clinicians to identify individuals who may present with abnormal gait patterns. Being proactive in finding subjects with altered gait may help reduce their chances of suffering further ankle sprains.

In conclusion, while shod subjects with CAI present with different gait compared to controls. To my knowledge this is the first study to evaluate CAI subjects kinematic differences while shod as well as taped and shod. Further research should be conducted to confirm the alterations found between groups. The changes seen in CAI subjects should be understood and corrected to help elucidate the pathology of CAI.

APPENDIX A

ADDITIONAL METHODS

Appendix A.1: Consent form

IRB #14893: Ankle kinematics of individuals with chronic ankle instability while treadmill running in two conditions.

Consent of an Adult to Be in a Research Study

In this form "you" means a person 18 years of age or older who is being asked to volunteer to participate in this study.

Participant's Name_______________________________

Principal Investigator:

Jay Hertel, PhD ATC
210 Emmet St South
Charlottesville, VA 22904
434-243-8673

What is the purpose of this form?

This form will help you decide if you want to be in the research study. You need to be informed about the study, before you can decide if you want to be in it. You do not have to be in the study if you do not want to. You should have all your questions answered before you give your permission or consent to be in the study.

Please read this form carefully. If you want to be in the study, you will need to sign this form. You will get a copy of this signed form.

Why is this research being done?

The primary purpose is to determine if there are ankle angle differences in subjects with chronic ankle instability while both barefoot and in shoes compared to copers (individuals who have only sprained their ankle once) and healthy controls. A secondary purpose is to assess for ankle laxity differences between groups.

You are being asked to be in this study, because you are physically active (participate in some form of physical activity for at least 20 minutes per day, three days per week) and can be placed into one of our categories. The classification scheme is as follows:

1. Healthy controls: no history of ankle sprain
2. Copers: history of a single ankle sprain more than 1 year ago but no recurrent or chronic problems
3. Chronic Ankle Instability (CAI): history of repetitive episodes of ankle sprains and/or feelings of giving way and prolonged symptoms.

Up to *80* people will be in this study at UVA.

How long will this study take?

Your participation in this study will require *2* of study visits over *2 weeks* period of time. The first visit will last about 1 hour and the second visit will last about 1.5 hours.

What will happen if you are in the study?

SCREENING and VISIT 1(will take approximately 30 minutes to complete):

If you agree to participate, you will sign this consent form before any study related procedures take place. Before you can start in the study, there will be a screening period. You will complete some questionnaires during this time to make sure you are eligible and it is safe for you to participate. These include the following:

- A questionnaire asking about your general medical history
- A questionnaire asking about your current physical activity level
- A questionnaire asking about your ankle function

If these questionnaires show you are eligible, you will start the study immediately. You will be asked to return to the clinic (within 2 weeks) to complete the study.

STUDY TREATMENT and RANDOMIZATION (2 visits each visit will last between *1 hour* and *1.5 hours*):

During the first visit, you will be asked to...

- Perform two different balance tests.
- Be measured by three different methods for ankle range of motion.
- Be measured by an ankle apparatus to determine your ankle ligament tautness.
- Stand in a normal/neutral position while the researchers measure your foot arch height.

During your second visit you will be asked to...

Walk and then jog on a treadmill in two different conditions. The two conditions are barefoot and with shoes on. You will be asked to walk (3.0 m/h: 20 min mile) and jog (6.0 m/h: 10 min mile) for about 5 minutes at a time for each condition. You will also be asked to repeat the procedures while following an intervention such as wearing a commercial ankle brace or getting your ankle taped. While walking and jogging a 12-camera analysis system will capture data from reflective markers placed on your legs and feet.

You will be randomly assigned (like the flip of a coin) into which condition (barefoot or in shoes) you will perform first. You have an equal chance of being assigned to each group first. You will complete both conditions.

During this study, you will be asked to fill out some questionnaires. These questionnaires ask about:

- *how you are feeling*
- *daily activities*
- *ankle pain and disability while performing functional activities*

These questionnaires will take about 10 minutes to complete.

If you want to know about the results before the study is done:

The study leader will tell you, during the study, of any results that are important to your health. That information is important for you to know, because it may help you decide whether you want to continue being in this study. We cannot tell you any other information until the results have been studied. At that time you can ask for more information.

What are the risks of being in this study?

This study poses little risks for physically activity individuals. In the event that an injury occurs, a certified athletic trainer will be onsite for evaluation and care.

Risks and side effects related to the procedures include:

<u>Likely</u>

- <u>Mild discomfort</u> from the ankle arthrometer

<u>Less Likely</u>

- Soreness from balancing and/or range of motion measures
- <u>Skin irritation from adhesives</u>

<u>Rare but serious</u>

- Falling while on the treadmill

<u>Other unexpected risks:</u>

You may have side effects that we do not expect or know to watch for now. Call the study leader if you have any symptoms or problems.

Could you be helped by being in this study?

You will not benefit from being in this study. However the information researchers get from this study may help others in the future.

What are your other choices if you do not join this study?

You do not have to be in this study to be treated for your illness or condition. You can get the usual treatment even if you choose not to be in this study.

Will you be paid for being in this study?

You will not get any money for being in this study.

Will being in this study cost you any money?

Being in this study will not cost you any money. Your insurance company will also not be billed.

You and/or your insurance company must pay for any tests or care given beyond what is required in this study. In addition, you and/or your health insurance may also have to pay for other drugs or treatments that are given to help you control any side effects. You will have to pay for any costs not covered by your health plan. You may be responsible for any co-payments or deductibles. You may wish to ask for an estimate of your financial costs. You may also wish to check with your insurance company before the study starts. Ask what they will cover and if they require you to get their permission before you decide to be in the study.

What if you are hurt in this study?

There is a small chance you could get hurt by this study in a way we did not expect. If you are hurt as a result of being in this study, we have no plans to pay you for lost wages, disability, or discomfort. If you are hurt in the study in a way that is unexpected your insurance company may pay for your treatment. If they do not pay, you will be treated free of charge at the University of Virginia. If you have questions about what will be covered if you are hurt in the study, talk to the study leader. You do not give up any legal rights by signing this form.

What happens if you leave the study early?

You can change your mind about being in the study any time. You can agree to be in the study now and change your mind later. If you decide to stop, please tell us right away. You do not have to be in this study to get services you can normally get at the University of Virginia.

Even if you do not change your mind, the study leader can take you out of the study.

How will your personal information be shared?

The UVa researchers are asking for your permission to gather, use and share information about you for this study. If you decide not to give your permission, you cannot be in this study, but you can continue to receive regular medical care at UVA.

If you sign this form, we may collect any or all of the following information about you:

- Personal information such as name, address, date of birth, social security number
- Your medical records and test results from before, during and after the study from any of your doctors or health care providers (including mental health care and substance abuse records, and HIV/AIDS records)
- Information needed to bill others for your care

Who will see your private information?

- The researchers to make sure they observe the effects of the study and understand its results
- People or committees that oversee the study to make sure it is conducted correctly
- Tax reporting offices (if you are paid for being in the study)
- People who evaluate study results, which can include sponsors that make the drug or device being studied, researchers at other sites conducting the same study, and government agencies that provide oversight such as the Food and Drug Administration (FDA)

The information collected from you might be published in a medical journal. This would be done in a way that protects your privacy. No one will be able to find out from the article that you were in the study.

What if you sign the form but then decide you don't want your private information shared? You can change your mind at any time. Your permission does not end unless you cancel it. To cancel it, please send a letter to the researchers listed on this form. Then you will no longer be in the study. The researchers will still use information about you that was collected before you ended your participation. UVa researchers will do everything possible to protect your privacy.

However, they will need to share your information with people who may not have to follow the rules described above. Some of those people may be allowed to share/release your information without your permission.

The information collected about you will be kept confidential by UVa as required by the federal Privacy Rule. Your information will not be released outside of UVa unless it is permitted by law.

A copy of this consent form will be put in your medical record. (This is not the same as the record of this research study.) This means that everyone who is allowed to see your records will be able to find out that you are in this study.

Please contact the researchers listed below to:

- Obtain more information about the study
- Ask a question about the study procedures or treatments
- Report an illness, injury, or other problem (you may also need to tell your regular doctors)
- Leave the study before it is finished
- Express a concern about the study

Jay Hertel, PhD ATC
210 Emmet St South
Charlottesville, VA 22904
434-243-8673

What if you have a concern about a study?

You may also report a concern about a study or ask questions about your rights as a research subject by contacting the Institutional Review Board listed below.

University of Virginia Institutional Review Board for Health Sciences Research
PO Box 800483
Charlottesville, Virginia 22908
Telephone: 434-924-2620
Fax: 434-924-2932

When you call or write about a concern, please give as much information as you can. Include the name of the study leader, the IRB-HSR Number (at the top of this form), and details about the problem. This will help officials look into your concern. When reporting a concern, you do not have to give your name.

Signatures

What does your signature mean?

Before you sign this form, please ask questions about any part of this study that is not clear to you. Your signature below means that you understand the information given to you about the study and in this form. If you sign the form it means that you agree to join the study.

Consent From Adult

PARTICIPANT (SIGNATURE)	PARTICIPANT (PRINT)	DATE

To be completed by participant if 18 years of age or older.

IRB #14893: Ankle kinematics of individuals with chronic ankle instability while treadmill running in two conditions

Person Obtaining Consent

By signing below you confirm that you have fully explained this study to the potential subject, allowed them time to read the consent or have the consent read to them, and have answered all their questions.

PERSON OBTAINING CONSENT (SIGNATURE)	PERSON OBTAINING CONSENT (PRINT)	DATE

Appendix A.2: Godin Leisure Time Exercise Questionnaire

Godin Leisure-Time Exercise Questionnaire

During a typical **7-day period** (a week), how many times on the average do you do the following kinds of exercise for **more than 15 minutes** during your free time (write on each line **ONE** number)

	Times per week
Strenuous exercise (heart beats rapidly) (running, jogging, hockey, football, soccer, squash, basketball, cross country skiing, judo, roller skating, vigorous swimming, vigorous long distance bicycling)	
Moderate exercise (not exhausting) (fast walking, baseball, tennis, easy bicycling, volleyball, badminton, easy swimming, alpine skiing, popular and folk dancing)	
Mild exercise (Minimal effort) (yoga, archery, fishing from river bank, bowling, horseshoes, golf, snow-mobiling, easy walking)	

Appendix A.3: Modified Ankle Instability Instrument

Modified Ankle Instability Instrument

	Yes	No
Have you ever sprained an ankle?		
Have you sprained your right ankle?		
Have you sprained your left ankle?		
Have you ever seen a doctor for an ankle sprain?		
Did you ever use a device (such as crutches) because you could not bear weight due to an ankle sprain?		
Does you ankle ever feel unstable while walking on a flat surface?		
Does your ankle ever feel unstable while walking on uneven ground?		
Does your ankle ever feel unstable during recreational or sport activity?		
Does your ankle ever feel unstable while going **up** stairs?		
Does your ankle eve feel unstable while going **down** stairs?		
Have you ever had rehabilitation on your ankle due to a sprain?		

Have you ever had an injury to either knee?

If yes, please explain, side (right or left), injury, and date

Have you ever had an injury to either leg below the knee?

If yes, please explain, side (right or left), injury, and date

Number of previous ankle sprains?

Left:

Right:

How long since your last ankle sprain?

Left:

Right:

Appendix A.4: Foot and Ankle Ability Measure (FAAM) and FAAM-Sport

Foot and Ankle Ability Measure

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 not applicable (N/A).

Which ankle is your worst ankle?

	No difficulty	Slight difficulty	Moderate difficulty	Extreme difficulty	Unable to do	N/A
Standing						
Walking on even ground						
Walking on even ground without shoes						
Walking up hills						
Walking down hills						
Going up stairs						
Going down stairs						
Walking on uneven ground						
Stepping up and down curbs						

Squatting						
Coming up on your toes						
Walking initially						
Walking 5 minutes or less						
Walking approximately 10 minutes						
Walking 15 minutes or greater						

Because of your **foot and ankle** how much difficulty do you have with:

	No difficulty at all	Slight difficulty	Moderate difficulty	Extreme difficulty	Unable to do	N/A
Home responsibilities						
Activities of daily living						
Personal care						
Light to moderate work (standing, walking)						
Heavy work (push/pulling, climbing, carrying)						
Recreational activities						

How would you rate your current level of function during your usual activities of daily living from 0 to 100 with 100 being your level of function **prior to** your foot or ankle problem and 0 being the inability to perform any of your usual daily activities?

Foot and Ankle Ability Measure

Sport Scale

Because of your **foot and ankle** how much difficulty do you have with:

	No difficulty at all	Slight difficulty	Moderate difficulty	Extreme difficulty	Unable to do	N/A
Running						
Jumping						
Landing						
Starting and stopping quickly						
Cutting/lateral movements						
Low impact activities						
Ability to perform activity with your normal technique						
Ability to participate in your desired sport as long as you would like						

How would you rate your current level of function during your sports related activities from 0 to 100 with 100 being your level of function **prior to** your foot or ankle problem and 0 being the inability to perform any of your usual daily activities?

Appendix A.5: Short Form 12 Questionnaire

The SF-12™ Health Survey

Completing the Questionnaire

Your Health in General

Strongly agree | Agree

Your Health in General

... of the following ... physical health?

YES NO

... other activities

... past 4 weeks ... emotional problems ...

YES NO

Accomplished less ...

... carefully ...

... past 4 weeks ... interfere ...

... A little bit Moderately ...

... how things have ... the past 4 weeks

	All of the Time	Most of the Time	...	...	...	... the ...

... your physical ...

Most of the ... Some of the time A little of the time ...

... COMPLETING THIS QUESTIONNAIRE

Appendix A.6: Plug-in Gait Marker Placement

The following Plug-in Gait marker placements were utilized in this study: SACR, LKNE, RKNE, LTHI, RTHI, LANK, RANK, LTIB, RTIB, LTOE, RTOE, LHEE, RHEE. All markers except SACR were affixed to the skin 3M 1522 tape by True Tape, LLC. SACR was securely fastened to the sacram via PowerFlex® self-adherent wrap.

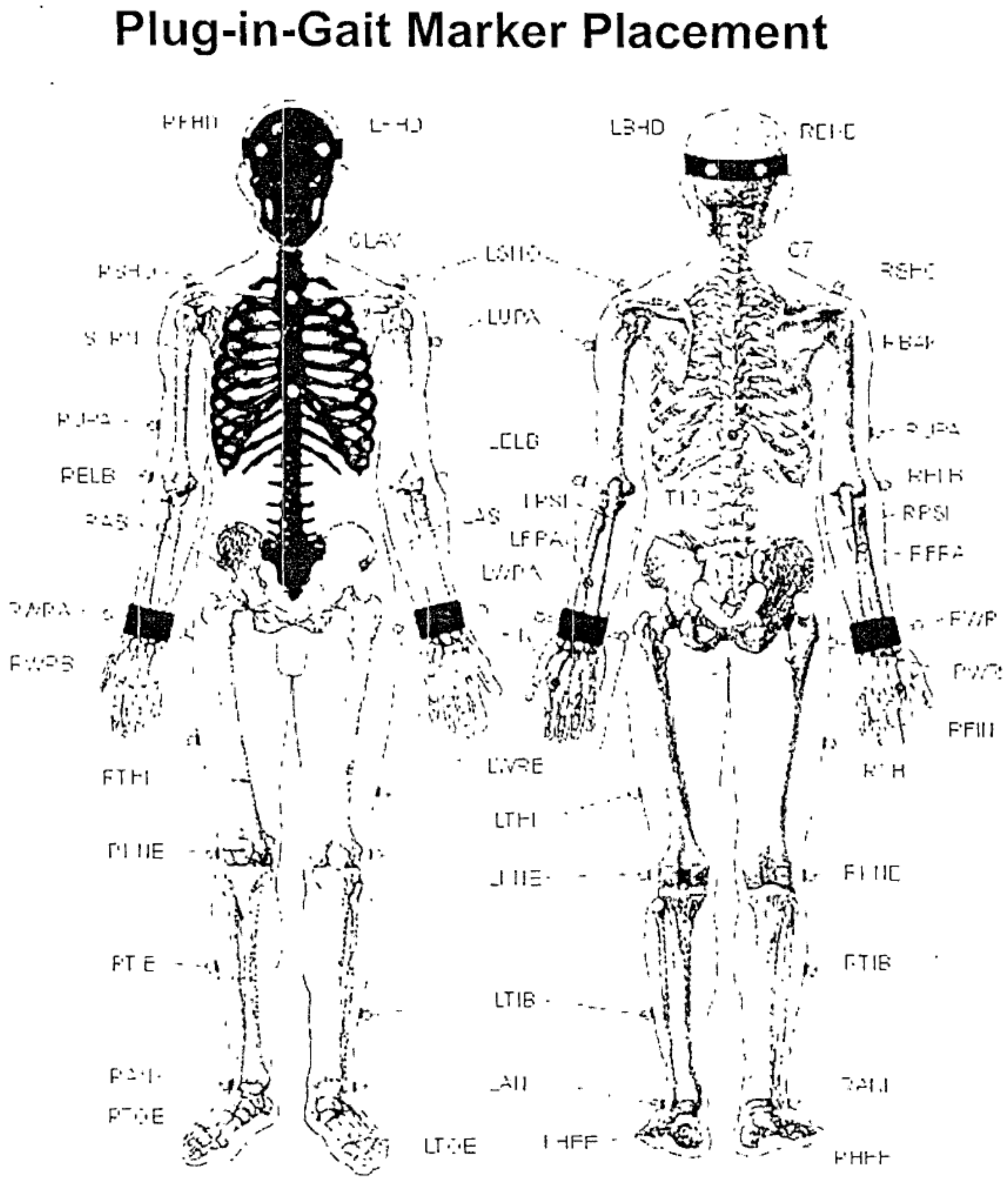


Figure C1 Plug-in-Gait Marker Placement

The following describes in detail where the Plug-in-Gait markers should be placed on the subject. Where left side markers only are listed, the positioning is identical for the right side.

Lower Body

Pelvis

LASI	Left ASIS	Placed directly over the left anterior superior iliac spine
RASI	Right ASIS	Placed directly over the right anterior superior iliac spine

The above markers may need to be placed medially to the ASIS to get the marker to the correct position due to the curvature of the abdomen. In some patients, especially those who are obese, the markers either can't be placed exactly anterior to the ASIS, or are invisible in this position to cameras. In these cases, move each marker laterally by an equal amount, along the ASIS-ASIS axis. The true inter-ASIS Distance must then be recorded and entered on the subject parameters form. These markers, together with the sacral marker or LPSI and RPSI markers, define the pelvic axes.

LPSI	Left PSIS	Placed directly over the left posterior superior iliac spine
RPSI	Right PSIS	Placed directly over the right posterior superior iliac spine

LPSI and RPSI markers are placed on the slight bony prominences that can be felt immediately below the dimples (sacro-iliac joints), at the point where the spine joins the pelvis.

SACR	Sacral Wand Marker	Placed on the skin mid-way between the posterior superior iliac spines (PSIS). An alternative to the LSPI and RPSI.

SACR may be used as an alternative to the LPSI and RPSI markers to overcome the problem of losing visibility of the sacral marker (if this occurs), the standard marker kit contains a base plate and a selection of short "sticks" or "wands" to allow the marker to be extended away from the body, if necessary. In this case it must be positioned to lie in the plane formed by the ASIS and PSIS points.

Leg Markers

LKNE	Left Knee	Placed on the lateral epicondyle of the left knee

To locate the "precise" point for the knee marker placement, passively flex and extend the knee a little while watching the skin surface on the lateral aspect of the knee joint. Identify where knee joint axis passes through the lateral side of the knee by finding the lateral skin surface that comes closest to remaining fixed in the thigh. This landmark should also be the point about which the lower leg appears to rotate. Mark this point with a pen. With an adult patient standing, this pen mark should be about 1.5 cm above the joint line, mid-way between the front and the back of the joint. Attach the marker at this point.

LTHI	Left Thigh	Place the marker over the lower lateral 1/3 surface of the thigh, just below the swing of the hand, although the height is not critical.

The thigh markers are used to calculate the knee flexion axis location and orientation. Place the marker over the lower lateral 1/3 surface of the thigh, just below the swing of the hand, although the height is not critical. The antero-posterior placement of the marker is critical for correct alignment of the knee flexion axis. Try to keep the thigh marker off the bellow of the muscle, but place the thigh marker at least two marker diameters proximal of the knee marker. Adjust the position of the marker so that it is aligned in the plane that contains the hip and knee joint centers and the knee flexion/extension axis. There is also another method that uses a mirror to align this marker, allowing the operator to better judge the positioning.

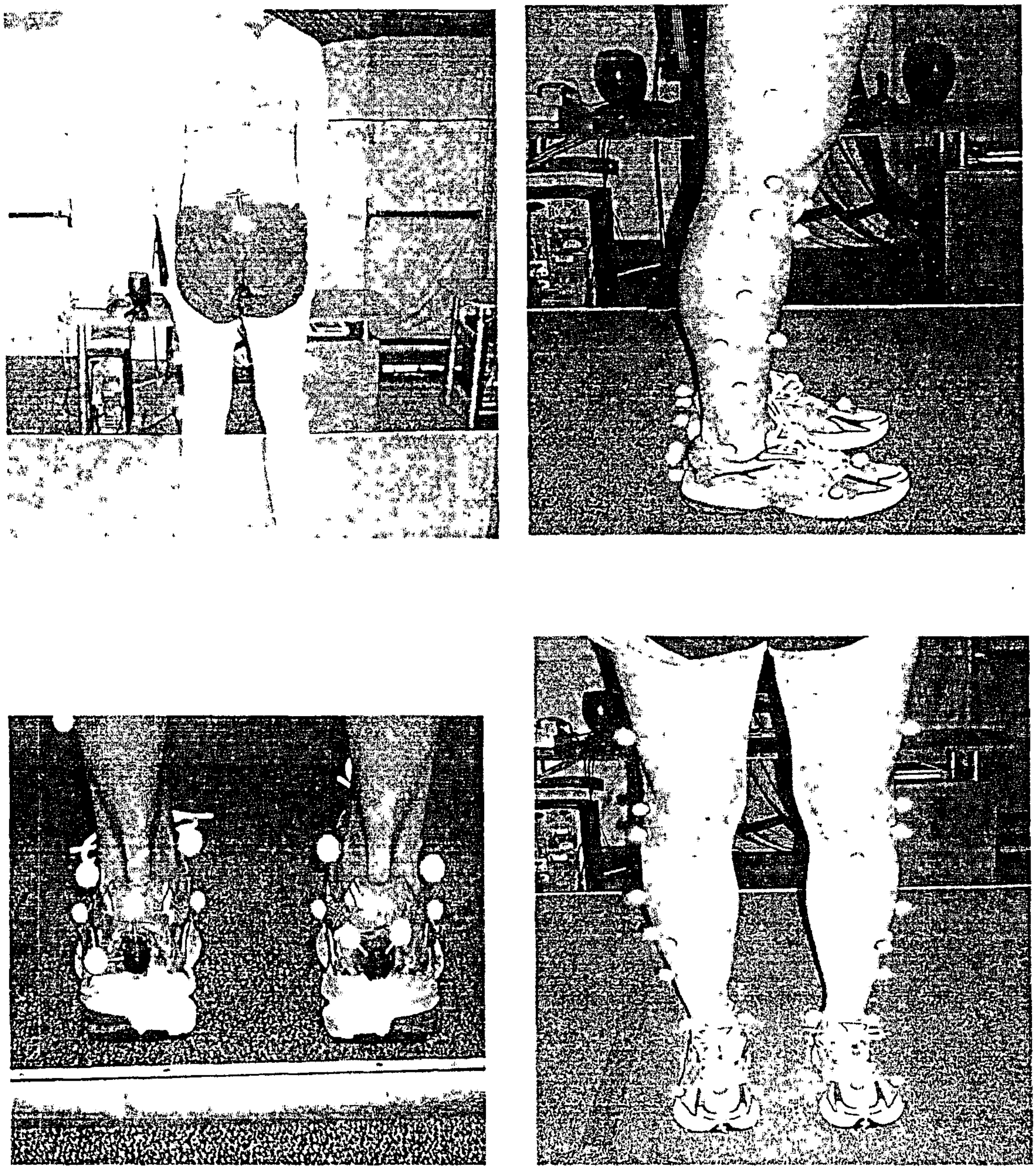
LANK	Left Ankle	Placed on the lateral malleolus along an imaginary line that passes through the transmalleolar axis
LTIB	Left Tibial Wand Marker	Similar to the thigh markers, these are placed over the lower 1/3 of the shank to determine the alignment of the ankle flexion axis

The tibial marker should lie in the plane that contains the knee and ankle joint centers and the ankle flexion/extension axis. In a normal subject the ankle joint axis, between the medial and lateral malleoli, is externally rotated by between 5 and 15 degrees with respect to the knee flexion axis. The placements of the shank markers should reflect this.

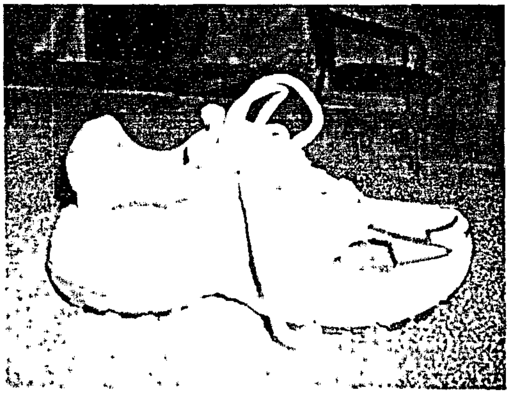
Foot Markers

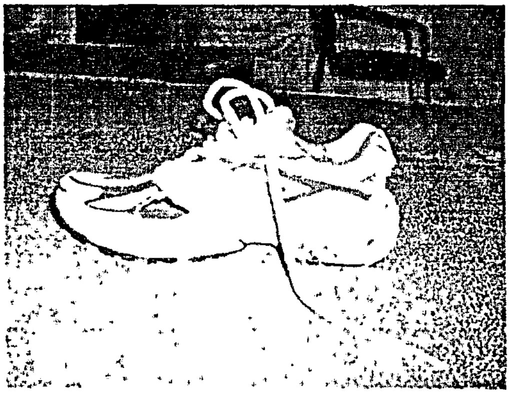
LTOE	Left Toe	Placed over the second metatarsal head, on the mid-foot side of the equines break between the fore-foot and mid-foot
LHEE	Left Heel	Placed on the calcaneous at the same height above the plantar surface of the foot as the toe marker.

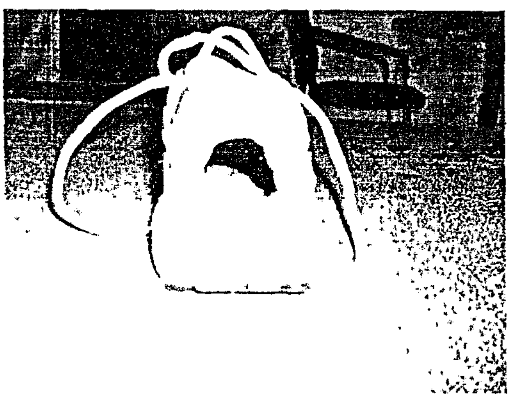
Appendix A.7: Modified Plug-In Gait marker placement used for motion analysis



Appendix A.8: Shoe cut-outs







Appendix A.9: Vicon Nexus data collection and processing procedures

1) Make sure camera view is 3d Prospective and you are "Live"
2) Static calibration trial
   - -capture ~2sec trial
   - -load and reconstruct trial (reconstruct button on top left of screen)
   - -manually label from "Label/Edit" tab on the right panel
   - -save
3) Calibrate Labeling Model
   - -In Pipeline
   - -run "Calibrate Labeling Model"
   - -save
4) Capture all pointing trials
   - -capture ~2sec trial for each
   - -open one trial
   - -under "Subject" tab in left pane, right click on subject and "Revert to Uncalibrated"
   - -label pointer and clusters; erase unlabeled
   - -save
   - -open each trial and label
   - -save
5) Batch process iliac spine pointing trials
   - -in Pipeline
   - -highlight iliac spine pointing trials; right click "Mark nodes"
   - -run "Pelvis Cluster Calibration"
   - -unmark nodes
6) Batch process heel pointing trials
   - -in Pipeline
   - -highlight heel pointing trials; right click "Mark nodes"
   - -run "Heel Calibration"
7) Process static trial
   - -run "Calibrate Labeling Model"
   - -run "Pelvis Cluster CalRec"
   - - run "Heel CalRec"
   - - run "Static Plug-In Gait Model"
   - -run "Static 3D ankle"
   - -run "Shank foot Calibration"
   - -run "Static Patrick foot model v3"
   - -save
7) Open dynamic trial
   - -Label markers
   - -go through entire trial and make sure markers are labeled
   - -run "Dynamic Plug-in gait" (only have "Fill gaps" checked)
   - -run "Pelvis Cluster CalRec"
   - -run "Heel CalRec"
   - -save
8) LabView: Treadmill Manager (See Treadmill Forceplates Manager Users Manual)
   - -click on the treadmill(s) of interest
   - -open .c3d file of interest
   - -run
   - -save
9) Open new .ezf file
   - -run "Dynamic Plug-in gait" (first 3 and last 3 boxes checked)
   - -run "Dynamic Patrick foot model v3"
   - -run "Dynamic 3D ankle"

Appendix A.10: Treadmill Forceplate Manager user's manual

Treadmill Foreceplates Manager Users Manual

Processing Input
Processing file path: Select .c3d file to process

FPTs Tab
-Highlight (green) the forceplate(s) utilized in the .c3d of interest

Actions Tab
-Custom event detector (**Default checked**): Labels gait cycle events, heel strikes and toe-offs
-Forceplate zeroing during swing (**Default checked**): Deletes swing phase error (Fx, Fy, Fz channels) from the subsequent stance phase measures. Accounts for signal drift.
-Zero Moments (**Default unchecked**): Deletes swing phase error (Mx, My, Mz channels) from the subsequent stance phase measures. Moment drift is *not* linear, and should not be removed.
-Filter GRF (**Default before event detection**): Determines the order in which the filtering occurs, or can be turned off so that no filtering is performed.
-Cut off frequency (**Default 30Hz**): Low-pass cutoff frequency
-Leave first % of stance unfiltered (**Default 6%**): Allows for Impact forces to be better examined. Does not apply if event detection has not already been performed.
-Make Copy of .tvd file (**Default unchecked**): never used.

Processing Settings Tab
-Fz threshold (**Default 60N**): The threshold of the vertical force used to detect gait cycle events.
-Below threshold signal to average (**Default 50%**): Determines when during swing the offset is calculated to remove drift from the signal
-Minimum contact duration (**Default 10 Frames**): Accounts for significant noise to verify that a stance phase is actually occurring for event detection
-Reinitialize to frame (**Default unchecked**)
-Use VICON offset (**Default unchecked**): Either uses the analog offsets in vicon, or overwrites them with 32768 (binary zero)
-Markers for detecting events (**Default Ankle**): Marker used to correlate force plate signals (right vs. left event)

Setup Settings Tab
-Make no changes

Program Usage:
1. Verify appropriate settings
2. Open .c3d file to process
3. Click [run]
4. Visually examine FP right and FP left plots for symmetry and lack of noise
   -If visual inspection yields unwanted result:
      (1) Check .c3d file in workstation:
         -If ankle markers are not visible at beginning of trial, crop initial frames

-Rerun

(2) Increase Fz threshold to 70N

-Rerun

-Repeat if necessary

Appendix A.11: Vicon and Treadmill Manager Extractor user's manual

Vicon & TM Parameter Extractor User's Manual

**Need .txt file indicating which trials you wish to process
**Need defaultpars.prc indicating which parameters you are interested in
*.prc file must be in the same directory as the .text file

.txt format (tab delimited)

Path	trialname	mass(kg)	height(m)	velocity(mph)
Neutral	Male20 Barefootrun01ezf30	80	1.825	6.0
Neutral	Male24 Barefootrun01ez30	87.4	1.843	6.0

.prc format (tab delimited)

Variable	Component	Derivative	Parameter	%From	%To
RHipAngles	0	0	1	0	100
RHipAngles	0	0	0	0	100
RHipAngles	1	0	1	0	100
RHipAngles	1	0	0	0	100
RHipAngles	2	0	1	0	100
RHipAngles	2	0	0	0	100

*Component: 0=x (sagittal); 1=y (frontal); 2=z (transverse)
*Derivative: Always 0
*Parameter: 1=min; 2=max

Processing Input
-Processing File Name: Select .txt file to process
-Vicon Data Files Common Path: Short path to locate data (ends where .txt file begins)

Trial Settings Tab
-TM speed (set at 3.0 or 6.0)
-Uncheck variable beginning cycle
-Start from cycle number: 0 is the first cycle available
-Average cycles: Number of cycles to average beginning with starting cycle

Processing Tab
-Always edit parameters
-Always include temporal and spatial parameters
-Add average of left and right parameters: NO

Output Settings Tab
-Moment unit: Nm/kgm
-Power unit: W/kg
-Generate files:
.crv file: group mean average and standard deviations
.ac file: individual curves for each trial included in group mean
.ap file: max/min from individual average curves
.pr file: individual average max/min

Appendix A.12: Using Plug-In Gait Ankle_Shoe

Using Plugin Gait Ankle and Plugin Gait Ankle Shoe

Kinematic Model Outputs

R3DAnkleAnglesXn	L3DAnkleAnglesXn
R3DAnkleAnglesYn	L3DAnkleAnglesYn
R3DAnkleAnglesZn	L3DAnkleAnglesZn
RAbsAnkleAngleXn	LAbsAnkleAngleXn
RAbsAnkleAngleYn	LAbsAnkleAngleYn
RAbsAnkleAngleZn	LAbsAnkleAngleZn
RAnkleAnglesXn	LAnkleAnglesXn
RAnkleAnglesYn	LAnkleAnglesYn
RAnkleAnglesZn	LAnkleAnglesZn
RSubTalangleRadXn	LSubTalangleRadXn
RSubTalangleRadYn	LSubTalangleRadYn
RSubTalangleRadZn	LSubTalangleRadZn
RSubTalAngleXn	LSubTalAngleXn
RSubTalAngleYn	LSubTalAngleYn
RSubTalAngleZn	LSubTalAngleZn
RHipAnglesXn	LHipAnglesXn
RHipAnglesYn	LHipAnglesYn
RHipAnglesZn	LHipAnglesZn
RKneeAnglesXn	LKneeAnglesXn
RKneeAnglesYn	LKneeAnglesYn
RKneeAnglesZn	LKneeAnglesZn
RPelvisAnglesXn	LPelvisAnglesXn
RPelvisAnglesYn	LPelvisAnglesYn
RPelvisAnglesZn	LPelvisAnglesZn
RHipMomentXn	LHipMomentXn
RHipMomentYn	LHipMomentYn
RHipMomentZn	LHipMomentZn
RKneeMomentXn	LKneeMomentXn
RKneeMomentYn	LKneeMomentYn
RKneeMomentZn	LKneeMomentZn
RAnkleMomentXn	LAnkleMomentXn
RAnkleMomentYn	LAnkleMomentYn
RAnkleMomentZn	LAnkleMomentZn
RHipPowerZn	LHipPowerZn
RKneePowerZn	LKneePowerZn
RAnklePowerZn	LAnklePowerZn
RNormalisedGRFXn	LNormalisedGRFXn
RNormalisedGRFYn	LNormalisedGRFYn
RNormalisedGRFZn	LNormalisedGRFZn

*Ankle motion = R3DAnkleAngles
Xn
+: dorsiflexion
-: plantarflexion

*Rearfoot motion = SubTalAngle
Yn
+: eversion
-: inversion

*Tibial rotation = AngleAngle
Zn
+: external rotation
-: internal rotation

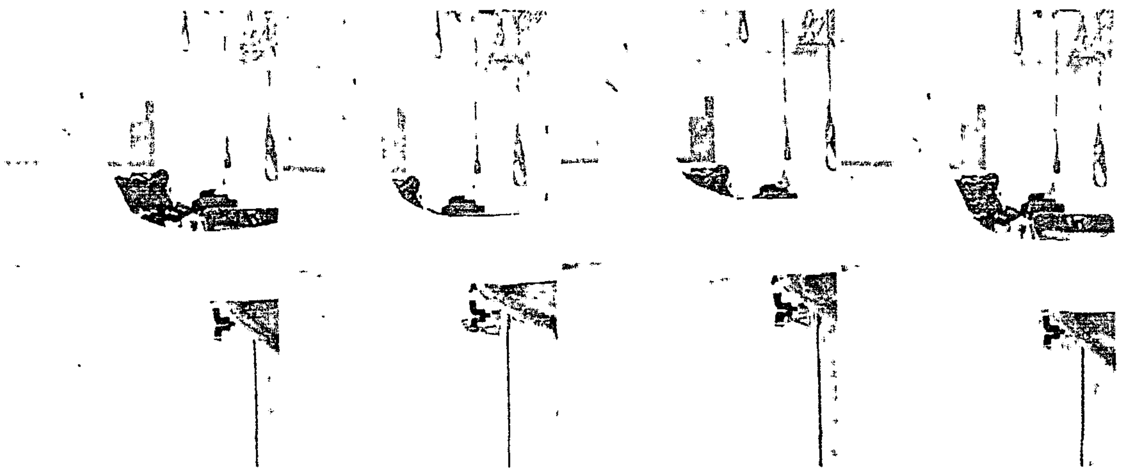
* Knee motion = KneeAngles
Xn
+: flexion
-: extension
Yn
+: abduction
-: adduction

* Hip motion = HipAngles
Xn
+: flexion
-: extension
Yn
+: abduction
-: adduction

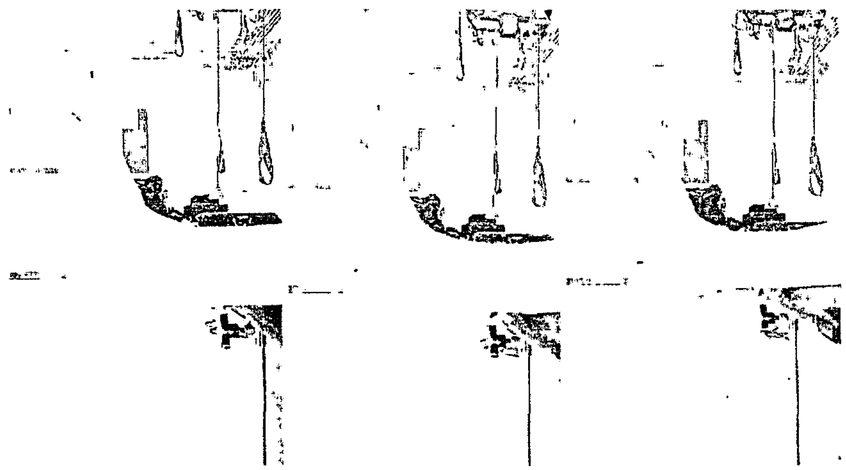
Processing File:
C:\Documents and Settings\ESIL\Desktop\Chinn_comps\02_jogging.txt
Vicon Data File:
C:\Documents and Settings\ESIL\Desktop\Chinn_comps

Appendix A.13: Taping procedure

A. Covered area with Pre-wrap
B. 3 anchor strips at top of pre-wrap
C. 3 stir-ups starting on the inside of the leg and finishing on the outside, partially overlapping each strip
D. Horse-shoes to cover ankle down to metatarsal heads
E. 1 heel locks beginning at inside of foot, goes behind the heel and finishes over the top of the ankle
F. 1 heel locking beginning on the outside of foot, goes behind the heel, and finishes over the top of the ankle
G. 2 figure-of-eights: starts at above medial malleolus, goes over foot, across the bottom of foot, up and over the foot and finishes around the lower leg
H. Closing strip.

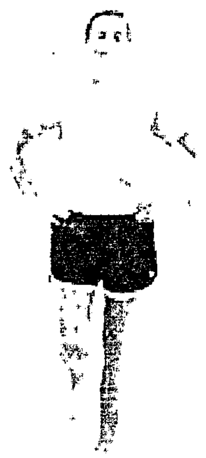


A. B. C. D.

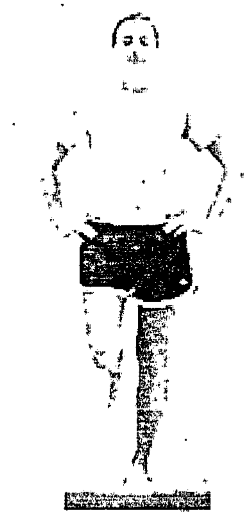


E. G. H.

Appendix A.14: Testing positions for Balance Error Scoring System

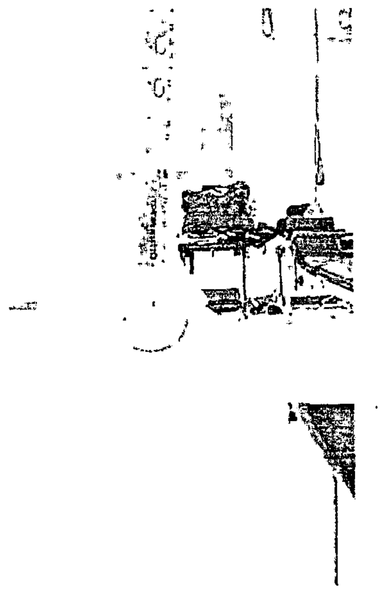


A. Firm surface

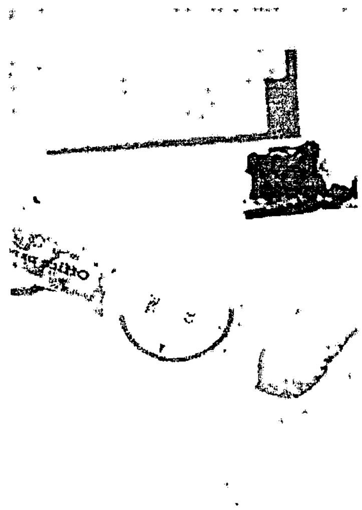


B. Unstable surface

Appendix A.15: Testing positions for non-weight bearing range of motion

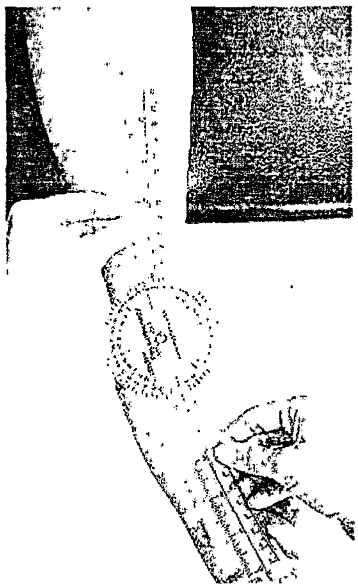


Dorsiflexion



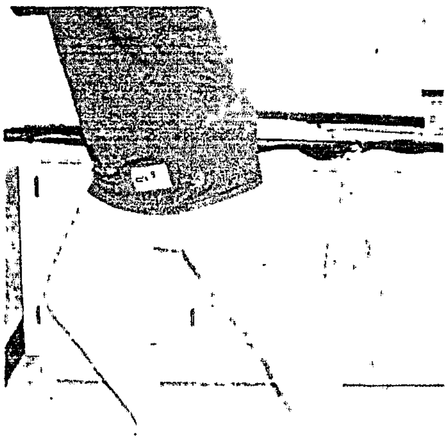
Plantar flexion

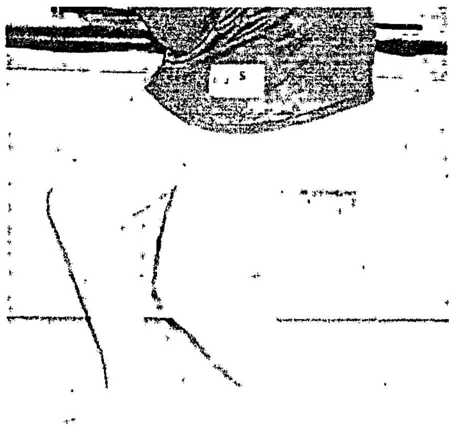
Inversion



Eversion

Appendix A.16: Testing positions for weight bearing dorsiflexion

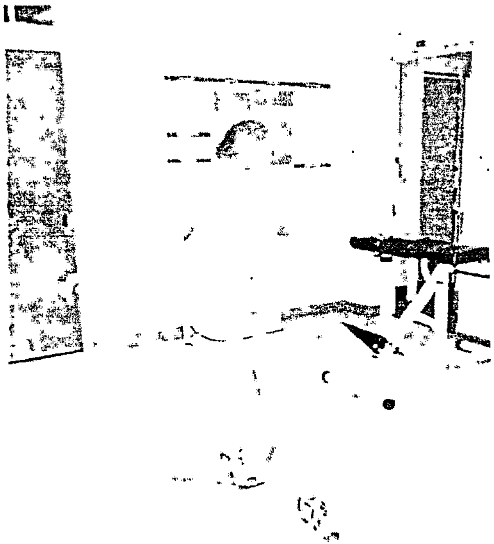




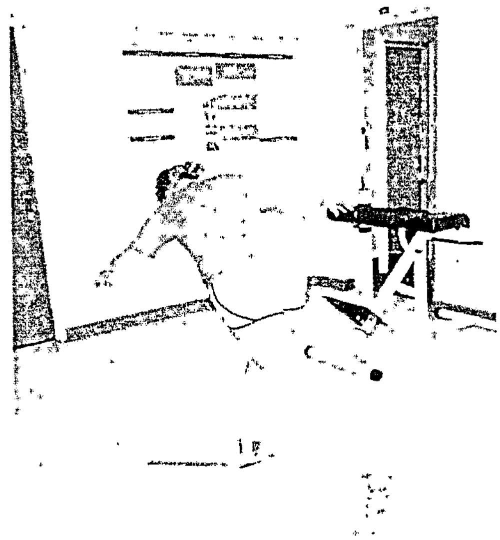
A. Straight knee

B. Bent knee

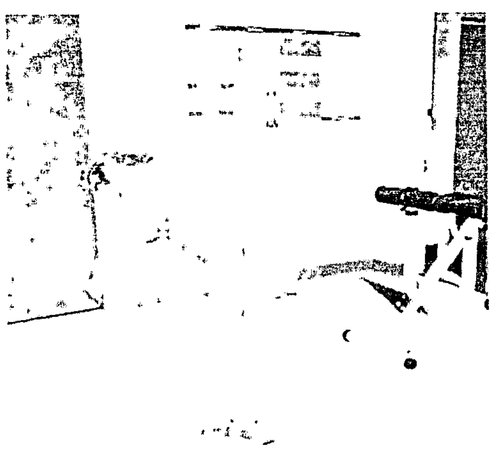
Appendix A.17: Testing positions for Star Excursion Balance Test



A. Anterior

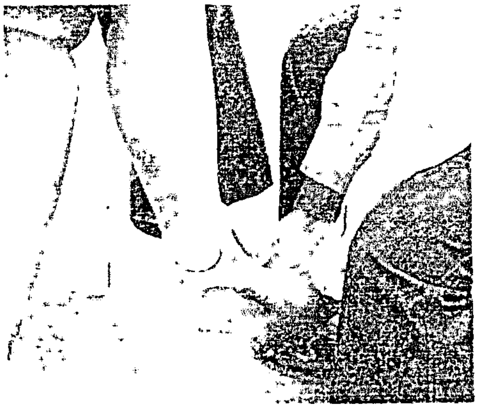


B. Posteriolateral



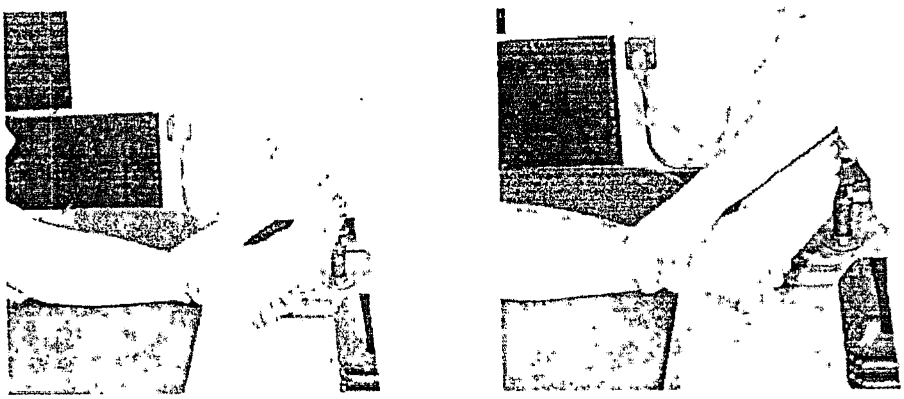
C: Posteriomedial

Appendix A.18: Testing positions for posterior talar glide, manual anterior drawer and talar tilt



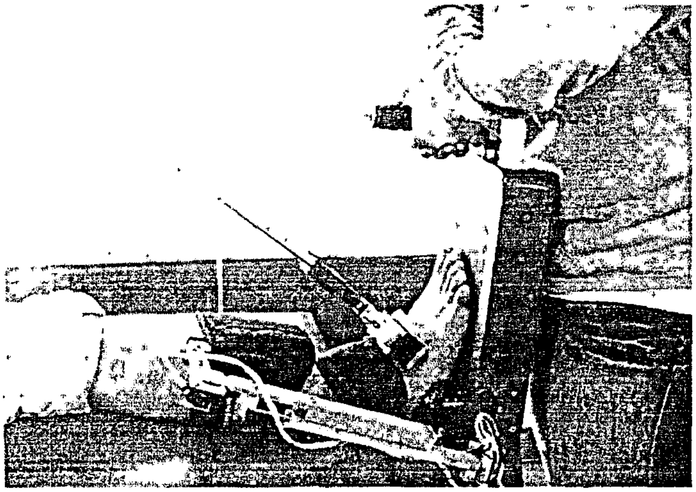
A. Posterior talar glide

B. Manual anterior drawer

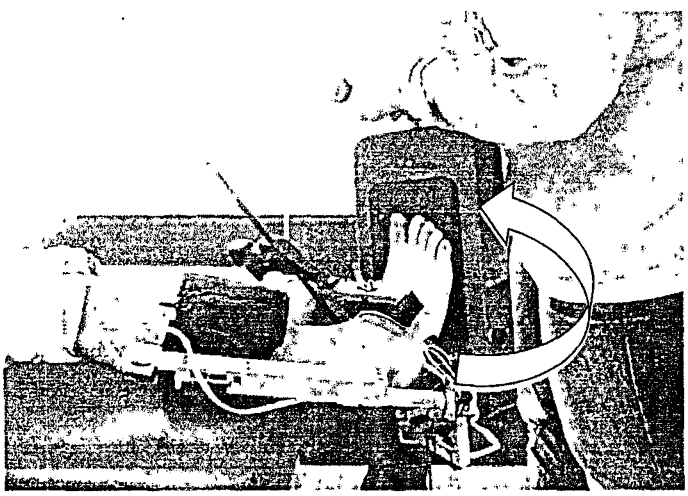


C. Manual talar tilt

Appendix A.19: Testing positions for ankle arthrometer



A. Anterior direction



B. Inversion rotation

Appendix A.20: Data collection sheet for Vicon

Subject

Date

Mass Height Shoe

Left Value		Right Value
	Leg length	
	Knee width	
	Ankle width	

Appendix A.21: Data collection sheet for clinical variables

Subject ______________ Gender ______ Age ______________ Date ______________

Height ______________ Weight ______________

	Leg length	Arch Height-sitting	Arch Height-standing	Bess-floor	Bess-foam	AROM-dorsiflextion			AROM-planterflexion			AROM-inversion			AROM-eversion			Posterior Talar Glide			Wt bearing dorsiflexion-st leg			Wt bearing dorsiflexion-bent leg			SEBT-anterior			SEBT-posteriolateral			SEBT-posteriomedial		
Right																																			
Left																																			

Right	Hypo	Normal	Mild	Moderate	Extreme
Anterior Drawer	0	1	2	3	4
Talar Tilt	0	1	2	3	4
Left					
Anterior Drawer	0	1	2	3	4
Talar Tilt	0	1	2	3	4

Researcher ______________

APPENDIX B

ADDITIONAL RESULTS

Table B.1: Between-subjects ANOVA for demographics.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
Godin	Between Groups	1192.388	2	596.194	.583	.563
	Within Groups	36792.586	36	1022.016		
	Total	37984.974	38			
PCS12	Between Groups	69.388	2	34.694	3.831	.031
	Within Groups	326.032	36	9.056		
	Total	395.420	38			
MCS12	Between Groups	97.897	2	48.948	1.053	.359
	Within Groups	1673.620	36	46.489		
	Total	1771.517	38			
FAAM	Between Groups	569.859	2	284.929	21.696	.000
	Within Groups	472.789	36	13.133		
	Total	1042.648	38			
FAAMS	Between Groups	5689.731	2	2844.865	40.474	.000
	Within Groups	2530.421	36	70.289		
	Total	8220.152	38			
Height (cm)	Between Groups	58.520	2	29.260	.337	.716
	Within Groups	3121.165	36	86.699		
	Total	3179.685	38			
Weight (kgs)	Between Groups	611.244	2	305.622	1.639	.208
	Within Groups	6712.054	36	186.446		
	Total	7323.298	38			
Age	Between Groups	91.747	2	45.874	.937	.401
	Within Groups	1762.612	36	48.961		
	Total	1854.359	38			
prev spains	Between Groups	219.374	2	109.687	29.705	.000
	Within Groups	132.933	36	3.693		
	Total	352.308	38			
howlong	Between Groups	17887.552	1	17887.552	8.106	.009
	Within Groups	52962.909	24	2206.788		
	Total	70850.462	25			

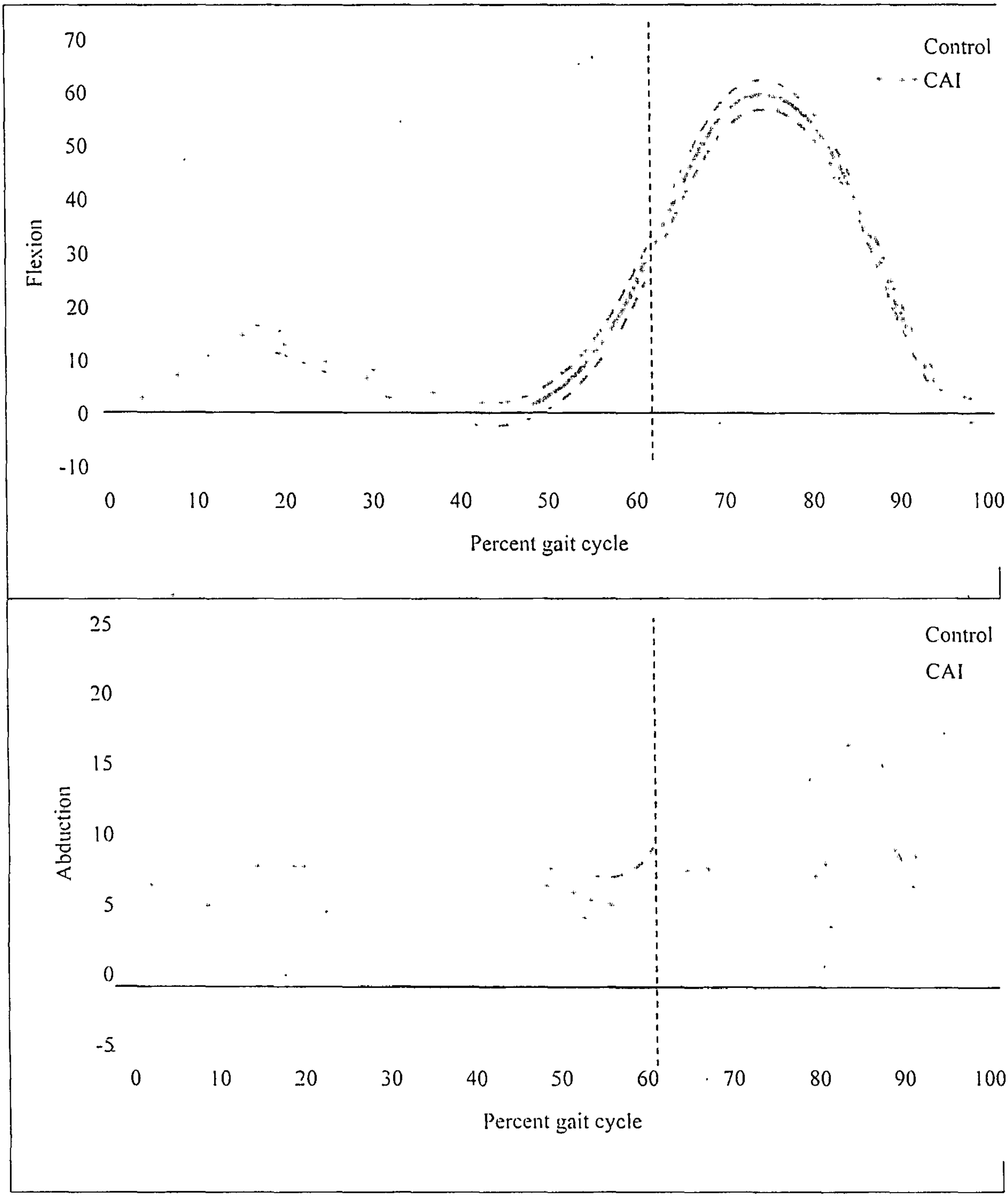


Figure B.1: Knee kinematics while walking between controls and CAI. 0% of gait cycle represents initial contact; toe off occurred at 62%; 100% is terminal swing. Solid lines represent group means; dashed lines represent the 90% confidence interval. A) Sagittal plane kinematics. B) Frontal plane kinematics.

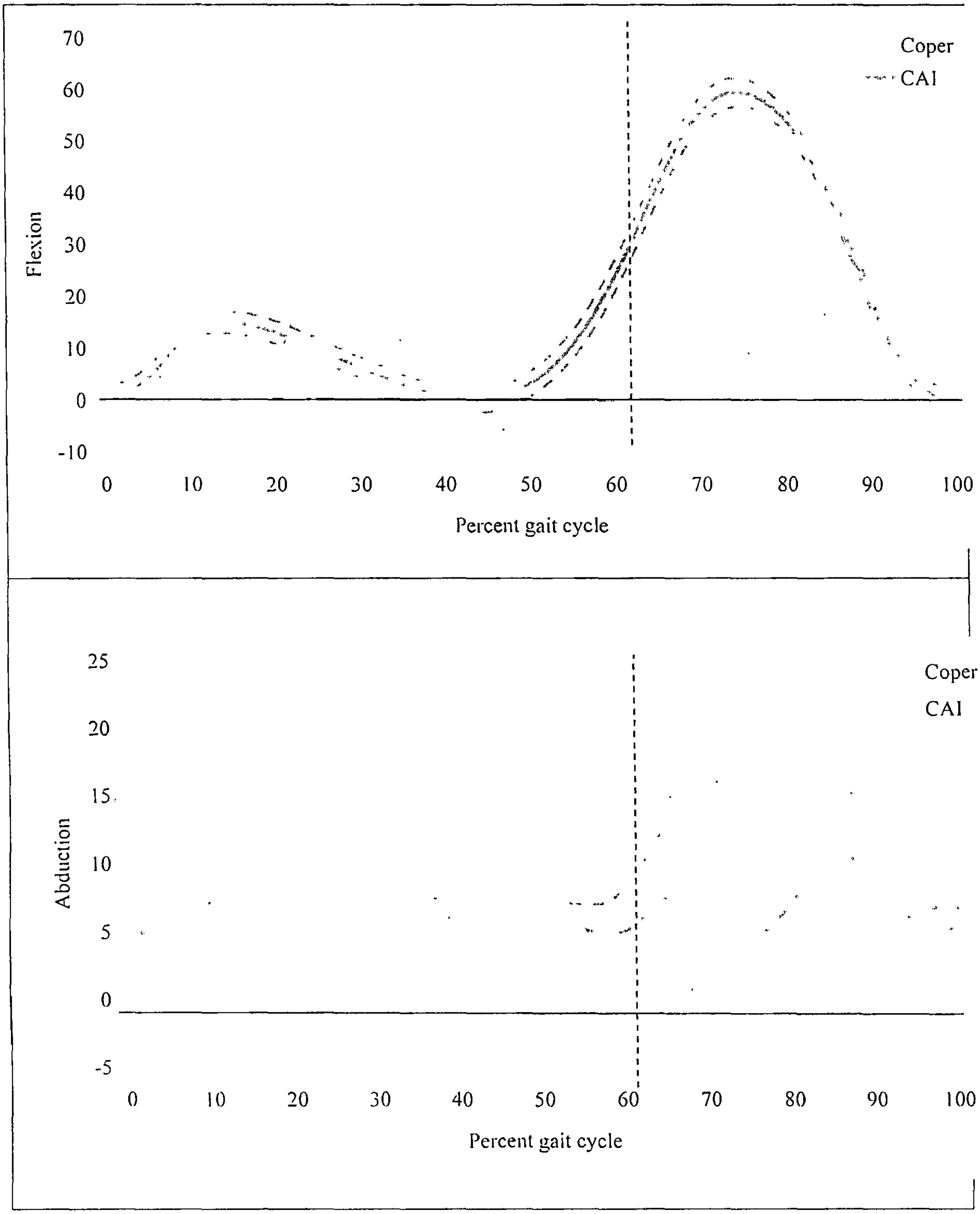


Figure B.2: Knee kinematics while walking between copers and CAI. 0% of gait cycle represents initial contact; toe off occurred at 62%; 100% is terminal swing. Solid lines represent group means; dashed lines represent the 90% confidence interval. A) Sagittal plane kinematics. B) Frontal plane kinematics.

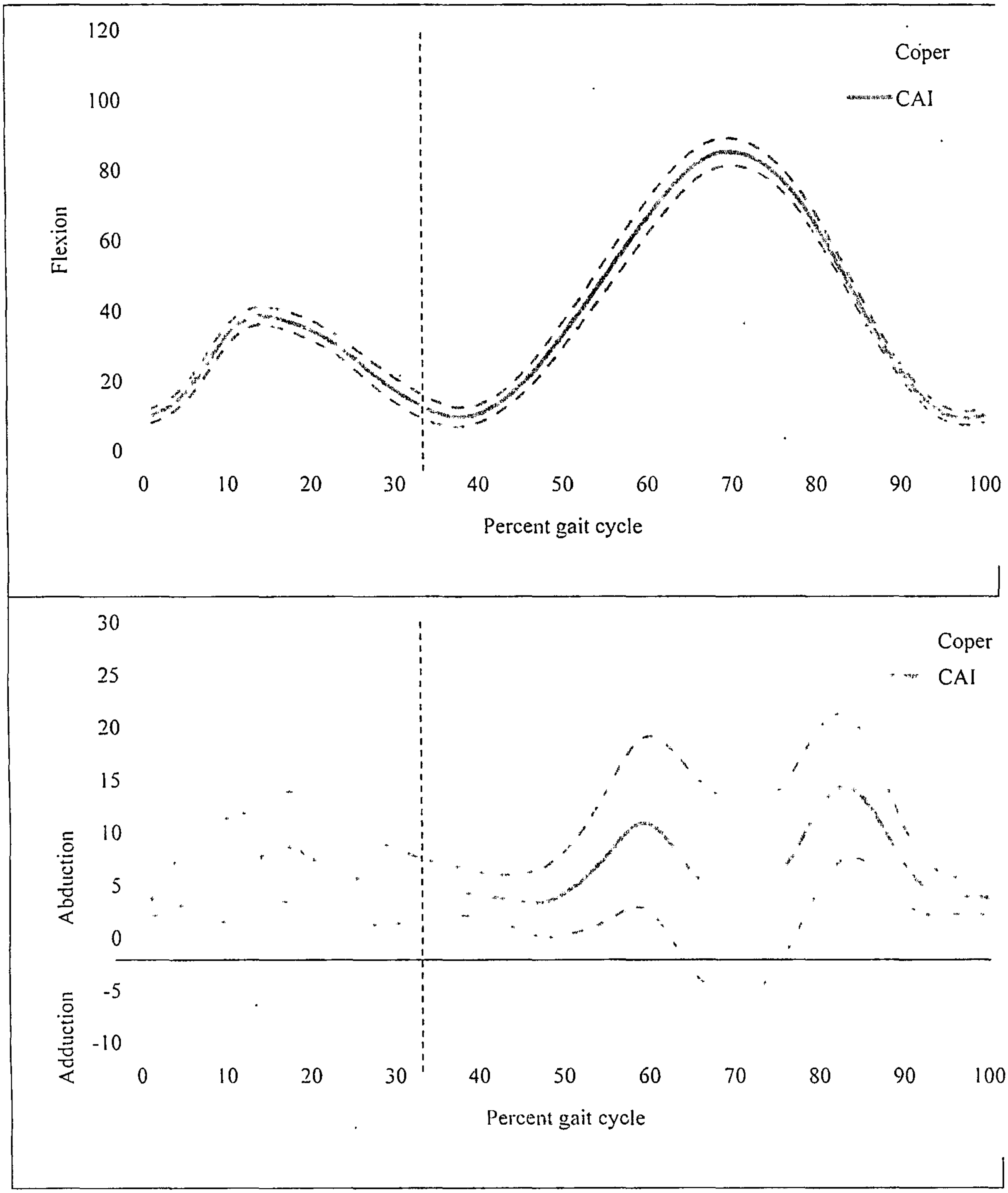


Figure B.3: Knee kinematics while jogging between copers and CAI. 0% of gait cycle represents initial contact; toe off occurred at 35%; 100% is terminal swing. Solid lines represent group means; dashed lines represent the 90% confidence interval. A) Sagittal plane kinematics. B) Frontal plane kinematics.

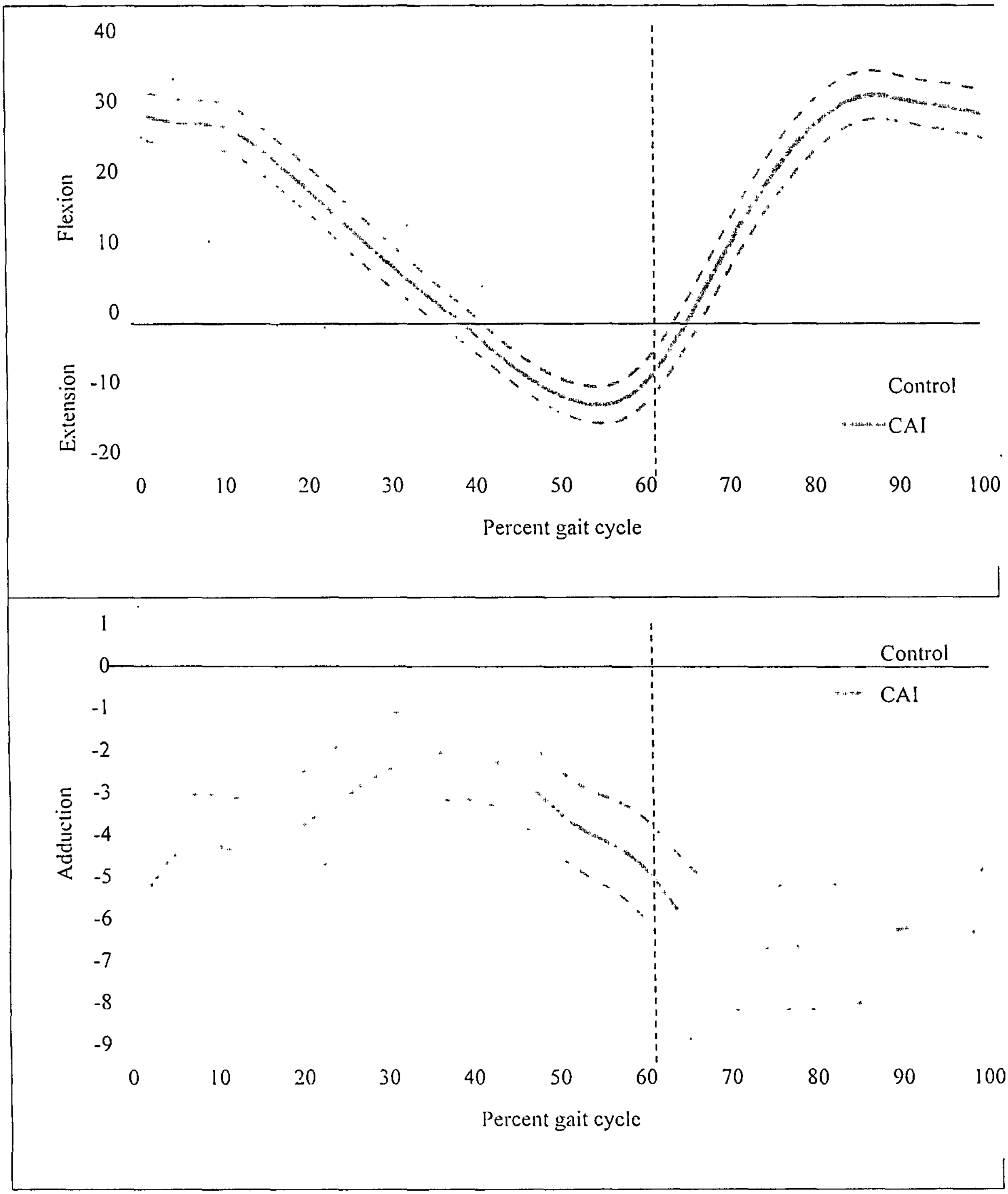


Figure B.4: Hip kinematics while walking between controls and CAI. 0% of gait cycle represents initial contact; toe off occurred at 62%; 100% is terminal swing. Solid lines represent group means; dashed lines represent the 90% confidence interval. A) Sagittal plane kinematics. B) Frontal plane kinematics.

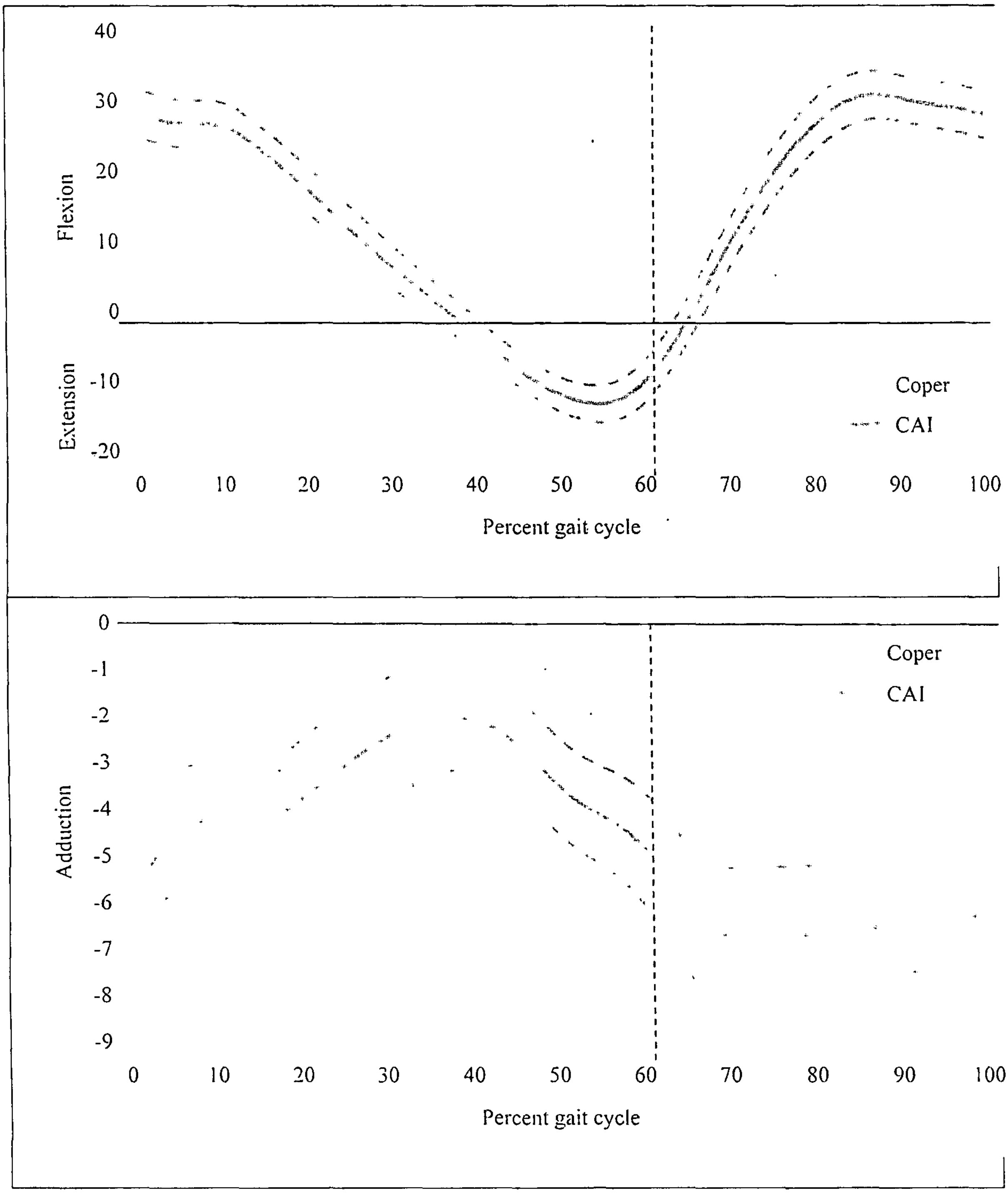
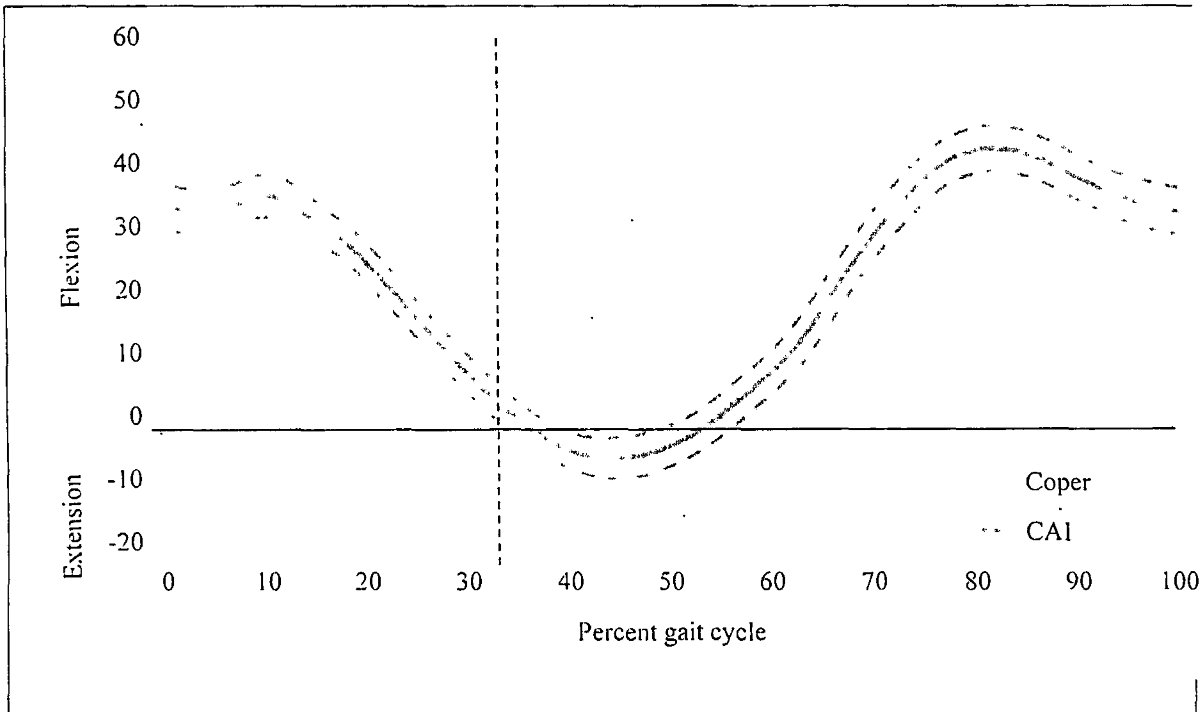


Figure B.5: Hip kinematics while walking between controls and CAI. 0% of gait cycle represents initial contact; toe off occurred at 62%; 100% is terminal swing. Solid lines represent group means; dashed lines represent the 90% confidence interval. A) Sagittal plane kinematics. B) Frontal plane kinematics.



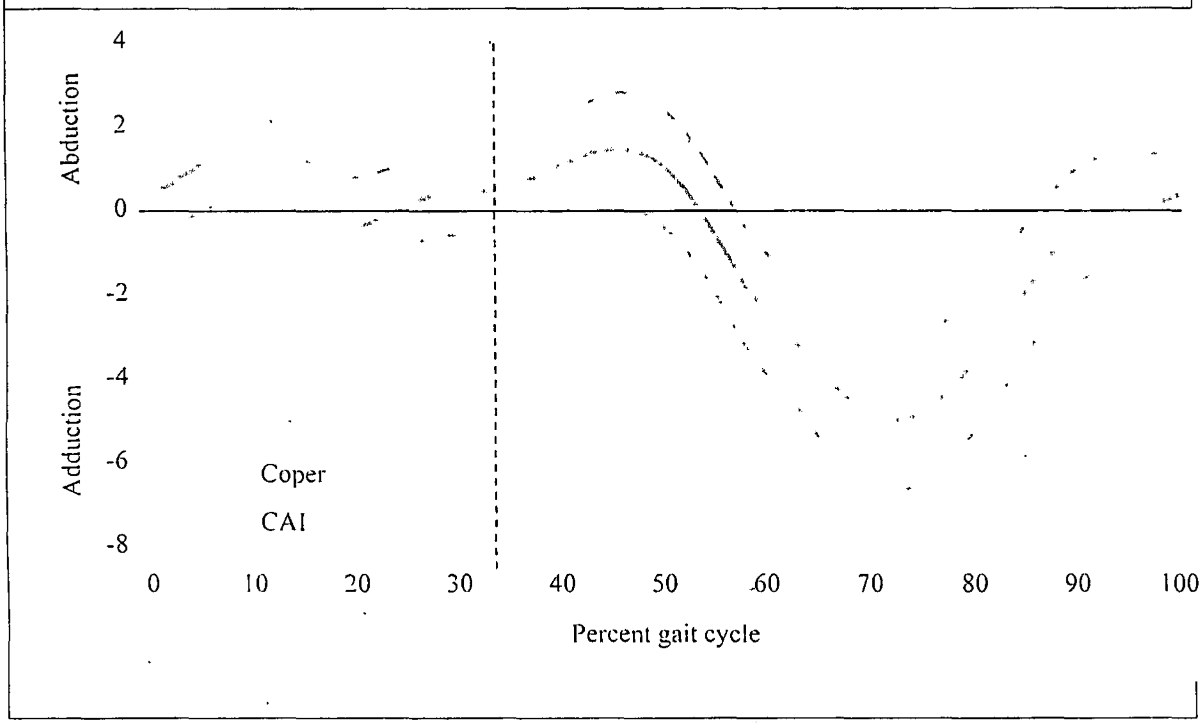


Figure B.6: Hip kinematics while jogging between copers and CAI. 0% of gait cycle represents initial contact; toe off occurred at 35%; 100% is terminal swing. Solid lines represent group means; dashed lines represent the 90% confidence interval. A) Sagittal plane kinematics. B) Frontal plane kinematics.

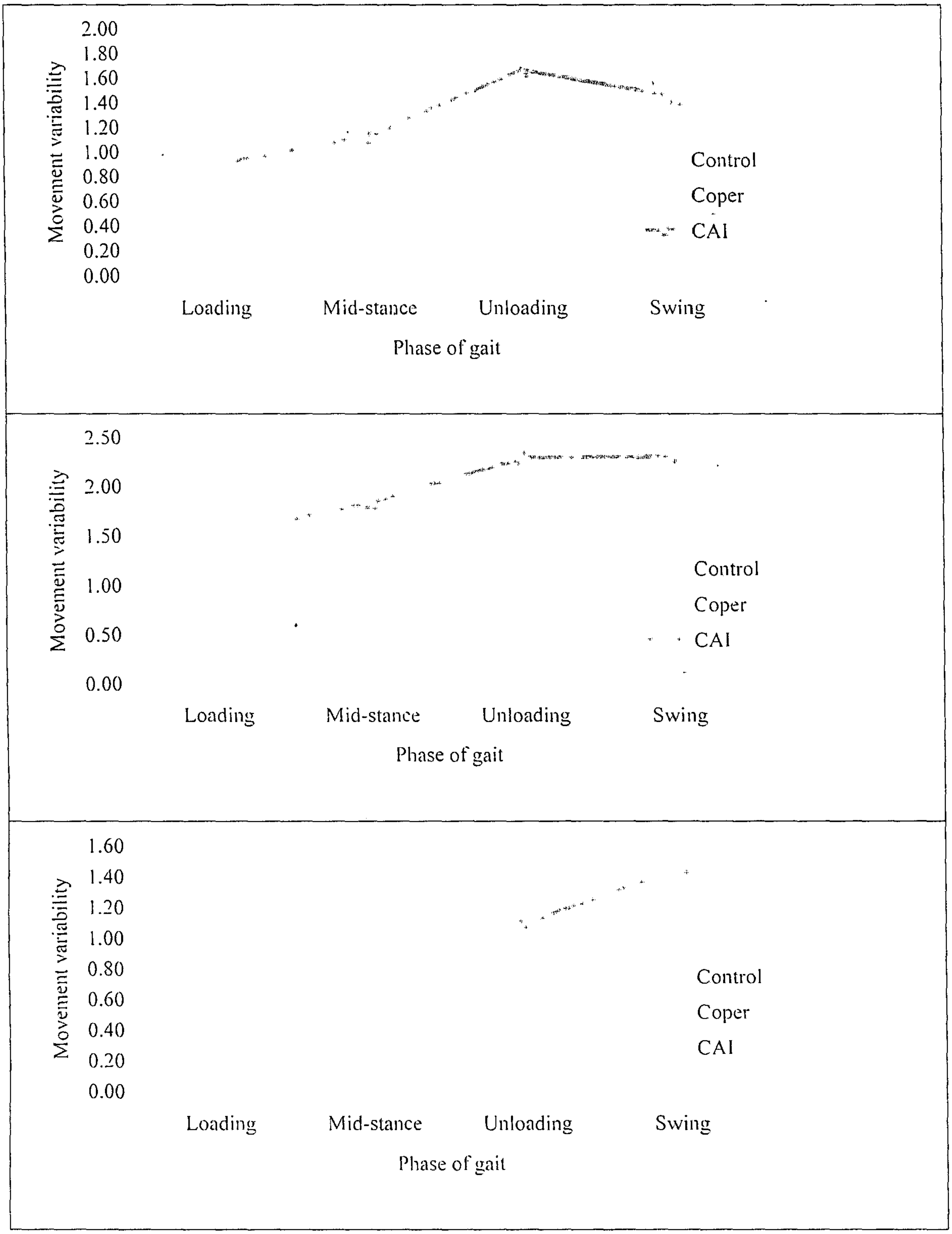


Figure B.7: Estimated marginal means of movement variability while walking. A) Ankle. B) Knee. C) Hip.

Table B. 2: Multivariate tests for movement variability while walking.

Multivariate Tests[c]

Effect			Value	F	Hypothesis df	Error df	Sig.
Between Subjects	Intercept	Pillai's Trace	.969	136.048[a]	6.000	26.000	.000
		Wilks' Lambda	.031	136.048[a]	6.000	26.000	.000
		Hotelling's Trace	31.396	136.048[a]	6.000	26.000	.000
		Roy's Largest Root	31.396	136.048[a]	6.000	26.000	.000
	group	Pillai's Trace	.335	.905	12.000	54.000	.548
		Wilks' Lambda	.693	.873[a]	12.000	52.000	.578
		Hotelling's Trace	.404	.842	12.000	50.000	.609
		Roy's Largest Root	.235	1.059[b]	6.000	27.000	.411
Within Subjects	time	Pillai's Trace	.903	7.229[a]	18.000	14.000	.000
		Wilks' Lambda	.097	7.229[a]	18.000	14.000	.000
		Hotelling's Trace	9.294	7.229[a]	18.000	14.000	.000
		Roy's Largest Root	9.294	7.229[a]	18.000	14.000	.000
	time * group	Pillai's Trace	.818	.577	36.000	30.000	.942
		Wilks' Lambda	.335	.567[a]	36.000	28.000	.946
		Hotelling's Trace	1.533	.554	36.000	26.000	.950
		Roy's Largest Root	1.129	.941[b]	18.000	15.000	.554

a. Exact statistic

b. The statistic is an upper bound on F that yields a lower bound on the significance level.

c. Design: Intercept + group
Within Subjects Design: time

Table B.3: Univariate tests of within-subjects effects for movement variability while walking.

Univariate Tests

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.
time	ankle_sag	Sphericity Assumed	8.563	3	2.854	23.832	.000
		Greenhouse-Geisser	8.563	2.461	3.479	23.832	.000
		Huynh-Feldt	8.563	2.862	2.992	23.832	.000
		Lower-bound	8.563	1.000	8.563	23.832	.000
	ankle_front	Sphericity Assumed	3.687	3	1.229	18.498	.000
		Greenhouse-Geisser	3.687	2.490	1.481	18.498	.000
		Huynh-Feldt	3.687	2.899	1.272	18.498	.000
		Lower-bound	3.687	1.000	3.687	18.498	.000
	knee_sag	Sphericity Assumed	13.660	3	4.553	17.645	.000
		Greenhouse-Geisser	13.660	2.695	5.068	17.645	.000
		Huynh-Feldt	13.660	3.000	4.553	17.645	.000
		Lower-bound	13.660	1.000	13.660	17.645	.000
	knee_front	Sphericity Assumed	11.822	3	3.941	56.197	.000
		Greenhouse-Geisser	11.822	2.429	4.868	56.197	.000
		Huynh-Feldt	11.822	2.820	4.192	56.197	.000
		Lower-bound	11.822	1.000	11.822	56.197	.000
	hip_sag	Sphericity Assumed	1.860	3	.620	6.504	.000
		Greenhouse-Geisser	1.860	2.685	.693	6.504	.001
		Huynh-Feldt	1.860	3.000	.620	6.504	.000
		Lower-bound	1.860	1.000	1.860	6.504	.016
	hip_front	Sphericity Assumed	.629	3	.210	9.004	.000
		Greenhouse-Geisser	.629	2.323	.271	9.004	.000
		Huynh-Feldt	.629	2.685	.234	9.004	.000
		Lower-bound	.629	1.000	.629	9.004	.005
time * group	ankle_sag	Sphericity Assumed	.293	6	.049	.408	.872
		Greenhouse-Geisser	.293	4.922	.060	.408	.839
		Huynh-Feldt	.293	5.724	.051	.408	.864
		Lower-bound	.293	2.000	.147	.408	.668
	ankle_front	Sphericity Assumed	.311	6	.052	.780	.587

		Greenhouse-Geisser	.311	4.979	.062	.780	.566
		Huynh-Feldt	.311	5.797	.054	.780	.584
		Lower-bound	.311	2.000	.156	.780	.467
	knee_sag	Sphericity Assumed	.613	6	.102	.396	.880
		Greenhouse-Geisser	.613	5.391	.114	.396	.863
		Huynh-Feldt	.613	6.000	.102	.396	.880
		Lower-bound	.613	2.000	.306	.396	.676
	knee_front	Sphericity Assumed	.248	6	.041	.590	.738
		Greenhouse-Geisser	.248	4.857	.051	.590	.703
		Huynh-Feldt	.248	5.640	.044	.590	.728
		Lower-bound	.248	2.000	.124	.590	.561
	hip_sag	Sphericity Assumed	.253	6	.042	.442	.849
		Greenhouse-Geisser	.253	5.369	.047	.442	.830
		Huynh-Feldt	.253	6.000	.042	.442	.849
		Lower-bound	.253	2.000	.126	.442	.647
	hip_front	Sphericity Assumed	.083	6	.014	.591	.737
		Greenhouse-Geisser	.083	4.646	.018	.591	.695
		Huynh-Feldt	.083	5.369	.015	.591	.719
		Lower-bound	.083	2.000	.041	.591	.560
Error(time)	ankle_sag	Sphericity Assumed	11.139	93	.120		
		Greenhouse-Geisser	11.139	76.298	.146		
		Huynh-Feldt	11.139	88.726	.126		
		Lower-bound	11.139	31.000	.359		
	ankle_front	Sphericity Assumed	6.178	93	.066		
		Greenhouse-Geisser	6.178	77.175	.080		
		Huynh-Feldt	6.178	89.861	.069		
		Lower-bound	6.178	31.000	.199		
	knee_sag	Sphericity Assumed	24.000	93	.258		
		Greenhouse-Geisser	24.000	83.554	.287		
		Huynh-Feldt	24.000	93.000	.258		
		Lower-bound	24.000	31.000	.774		
	knee_front	Sphericity Assumed	6.522	93	.070		
		Greenhouse-Geisser	6.522	75.286	.087		
		Huynh-Feldt	6.522	87.421	.075		
		Lower-bound	6.522	31.000	.210		

	hip_sag	Sphericity Assumed	8.864	93	.095		
		Greenhouse-Geisser	8.864	83.226	.107		
		Huynh-Feldt	8.864	93.000	.095		
		Lower-bound	8.864	31.000	.286		
	hip_front	Sphericity Assumed	2.164	93	.023		
		Greenhouse-Geisser	2.164	72.020	.030		
		Huynh-Feldt	2.164	83.227	.026		
		Lower-bound	2.164	31.000	.070		

Table B.4: Univariate tests of between-subjects effects for movement variability while walking.

Tests of Between-Subjects Effects

Transformed Variable:Average

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	ankle_sag	218.408	1	218.408	482.118	.000
	ankle_front	104.003	1	104.003	528.829	.000
	knee_sag	458.088	1	458.088	499.450	.000
	knee_front	71.040	1	71.040	350.980	.000
	hip_sag	193.711	1	193.711	273.509	.000
	hip_front	57.536	1	57.536	520.118	.000
group	ankle_sag	.208	2	.104	.229	.797
	ankle_front	.130	2	.065	.331	.721
	knee_sag	.691	2	.346	.377	.689
	knee_front	.168	2	.084	.416	.663
	hip_sag	.595	2	.298	.420	.660
	hip_front	.251	2	.126	1.135	.334
Error	ankle_sag	14.044	31	.453		
	ankle_front	6.097	31	.197		
	knee_sag	28.433	31	.917		
	knee_front	6.275	31	.202		
	hip_sag	21.956	31	.708		
	hip_front	3.429	31	.111		

Table B.5: Multivariate tests for movement variability while jogging.

Multivariate Tests[c]

Effect			Value	F	Hypothesis df	Error df	Sig.
Between Subjects	Intercept	Pillai's Trace	.960	120.988[a]	6.000	30.000	.000
		Wilks' Lambda	.040	120.988[a]	6.000	30.000	.000
		Hotelling's Trace	24.198	120.988[a]	6.000	30.000	.000
		Roy's Largest Root	24.198	120.988[a]	6.000	30.000	.000
	group	Pillai's Trace	.452	1.507	12.000	62.000	.146
		Wilks' Lambda	.588	1.521[a]	12.000	60.000	.142
		Hotelling's Trace	.634	1.532	12.000	58.000	.139
		Roy's Largest Root	.499	2.579[b]	6.000	31.000	.038
Within Subjects	time	Pillai's Trace	.959	23.603[a]	18.000	18.000	.000
		Wilks' Lambda	.041	23.603[a]	18.000	18.000	.000
		Hotelling's Trace	23.603	23.603[a]	18.000	18.000	.000
		Roy's Largest Root	23.603	23.603[a]	18.000	18.000	.000
	time * group	Pillai's Trace	1.218	1.645	36.000	38.000	.067
		Wilks' Lambda	.122	1.863[a]	36.000	36.000	.033
		Hotelling's Trace	4.407	2.081	36.000	34.000	.017
		Roy's Largest Root	3.641	3.844[b]	18.000	19.000	.003

a. Exact statistic
b. The statistic is an upper bound on F that yields a lower bound on the significance level.
c. Design: Intercept + group
Within Subjects Design: time

Table B.6: Univariate tests of within-subjects effects for movement variability while jogging.

Univariate Tests

Source	Measure		Type III Sum of Squares	df	Mean Square	F	Sig.
time	ankle_sag	Sphericity Assumed	369.496	3	123.165	91.785	.000
		Greenhouse-Geisser	369.496	2.173	170.025	91.785	.000
		Huynh-Feldt	369.496	2.455	150.524	91.785	.000
		Lower-bound	369.496	1.000	369.496	91.785	.000
	ankle_front	Sphericity Assumed	43.957	3	14.652	30.962	.000
		Greenhouse-Geisser	43.957	1.559	28.202	30.962	.000
		Huynh-Feldt	43.957	1.711	25.686	30.962	.000
		Lower-bound	43.957	1.000	43.957	30.962	.000
	knee_sag	Sphericity Assumed	1240.863	3	413.621	182.876	.000
		Greenhouse-Geisser	1240.863	2.141	579.651	182.876	.000
		Huynh-Feldt	1240.863	2.415	513.869	182.876	.000
		Lower-bound	1240.863	1.000	1240.863	182.876	.000
	knee_front	Sphericity Assumed	51.338	3	17.113	70.826	.000
		Greenhouse-Geisser	51.338	2.480	20.705	70.826	.000
		Huynh-Feldt	51.338	2.836	18.103	70.826	.000
		Lower-bound	51.338	1.000	51.338	70.826	.000
	hip_sag	Sphericity Assumed	306.521	3	102.174	104.141	.000
		Greenhouse-Geisser	306.521	1.882	162.834	104.141	.000
		Huynh-Feldt	306.521	2.100	145.995	104.141	.000
		Lower-bound	306.521	1.000	306.521	104.141	.000
	hip_front	Sphericity Assumed	3.007	3	1.002	27.141	.000
		Greenhouse-Geisser	3.007	2.262	1.329	27.141	.000
		Huynh-Feldt	3.007	2.565	1.172	27.141	.000
		Lower-bound	3.007	1.000	3.007	27.141	.000
time * group	ankle_sag	Sphericity Assumed	22.835	6	3.806	2.836	.013
		Greenhouse-Geisser	22.835	4.346	5.254	2.836	.027
		Huynh-Feldt	22.835	4.909	4.651	2.836	.021
		Lower-bound	22.835	2.000	11.418	2.836	.072
	ankle_front	Sphericity Assumed	2.516	6	.419	.886	.508

		Greenhouse-Geisser	2.516	3.117	.807	.886	.457
		Huynh-Feldt	2.516	3.423	.735	.886	.465
		Lower-bound	2.516	2.000	1.258	.886	.421
	knee_sag	Sphericity Assumed	33.612	6	5.602	2.477	.028
		Greenhouse-Geisser	33.612	4.281	7.851	2.477	.048
		Huynh-Feldt	33.612	4.829	6.960	2.477	.040
		Lower-bound	33.612	2.000	16.806	2.477	.099
	knee_front	Sphericity Assumed	2.790	6	.465	1.924	.084
		Greenhouse-Geisser	2.790	4.959	.563	1.924	.099
		Huynh-Feldt	2.790	5.672	.492	1.924	.088
		Lower-bound	2.790	2.000	1.395	1.924	.161
	hip_sag	Sphericity Assumed	8.965	6	1.494	1.523	.178
		Greenhouse-Geisser	8.965	3.765	2.381	1.523	.208
		Huynh-Feldt	8.965	4.199	2.135	1.523	.202
		Lower-bound	8.965	2.000	4.482	1.523	.232
	hip_front	Sphericity Assumed	.225	6	.037	1.015	.420
		Greenhouse-Geisser	.225	4.525	.050	1.015	.410
		Huynh-Feldt	.225	5.130	.044	1.015	.415
		Lower-bound	.225	2.000	.112	1.015	.373
Error(time)	ankle_sag	Sphericity Assumed	140.899	105	1.342		
		Greenhouse-Geisser	140.899	76.061	1.852		
		Huynh-Feldt	140.899	85.916	1.640		
		Lower-bound	140.899	35.000	4.026		
	ankle_front	Sphericity Assumed	49.690	105	.473		
		Greenhouse-Geisser	49.690	54.553	.911		
		Huynh-Feldt	49.690	59.897	.830		
		Lower-bound	49.690	35.000	1.420		
	knee_sag	Sphericity Assumed	237.484	105	2.262		
		Greenhouse-Geisser	237.484	74.925	3.170		
		Huynh-Feldt	237.484	84.516	2.810		
		Lower-bound	237.484	35.000	6.785		
	knee_front	Sphericity Assumed	25.370	105	.242		
		Greenhouse-Geisser	25.370	86.784	.292		
		Huynh-Feldt	25.370	99.254	.256		
		Lower-bound	25.370	35.000	.725		

	hip_sag	Sphericity Assumed	103.016	105	.981		
		Greenhouse-Geisser	103.016	65.884	1.564		
		Huynh-Feldt	103.016	73.484	1.402		
		Lower-bound	103.016	35.000	2.943		
	hip_front	Sphericity Assumed	3.878	105	.037		
		Greenhouse-Geisser	3.878	79.184	.049		
		Huynh-Feldt	3.878	89.774	.043		
		Lower-bound	3.878	35.000	.111		

Table B.7: Univariate tests of between-subjects effects for movement variability while jogging.

Tests of Between-Subjects Effects

Transformed Variable:Average

Source	Measure	Type III Sum of Squares	df	Mean Square	F	Sig.
Intercept	ankle_sag	2197.195	1	2197.195	389.449	.000
	ankle_front	450.542	1	450.542	182.037	.000
	knee_sag	3867.546	1	3867.546	381.657	.000
	knee_front	517.758	1	517.758	416.161	.000
	hip_sag	2053.713	1	2053.713	536.962	.000
	hip_front	169.742	1	169.742	708.515	.000
group	ankle_sag	85.721	2	42.861	7.597	.002
	ankle_front	3.507	2	1.753	.708	.499
	knee_sag	75.063	2	37.532	3.704	.035
	knee_front	6.203	2	3.102	2.493	.097
	hip_sag	44.489	2	22.244	5.816	.007
	hip_front	.857	2	.429	1.790	.182
Error	ankle_sag	197.463	35	5.642		
	ankle_front	86.625	35	2.475		
	knee_sag	354.675	35	10.134		
	knee_front	43.544	35	1.244		
	hip_sag	133.864	35	3.825		
	hip_front	8.385	35	.240		

Table B.8: One-way ANOVA of movement variability.

ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
load_ankle_sag	Between Groups	2.190	2	1.095	3.934	.028
	Within Groups	10.021	36	.278		
	Total	12.211	38			
midstance_ankle_sag	Between Groups	14.563	2	7.282	1.872	.168
	Within Groups	140.011	36	3.889		
	Total	154.574	38			
unload_ankle_sag	Between Groups	57.065	2	28.533	7.110	.002
	Within Groups	144.462	36	4.013		
	Total	201.527	38			
swing_ankle_sag	Between Groups	23.731	2	11.866	4.978	.012
	Within Groups	85.808	36	2.384		
	Total	109.539	38			
load_knee_sag	Between Groups	1.062	2	.531	2.004	.150
	Within Groups	9.543	36	.265		
	Total	10.605	38			
midstance_knee_sag	Between Groups	5.653	2	2.827	1.773	.184
	Within Groups	57.393	36	1.594		
	Total	63.046	38			
unload_knee_sag	Between Groups	37.845	2	18.923	2.311	.114
	Within Groups	294.797	36	8.189		
	Total	332.643	38			
swing_knee_sag	Between Groups	58.134	2	29.067	3.382	.045
	Within Groups	309.383	36	8.594		
	Total	367.518	38			

Table B.9: Paired comparison post hoc testing between groups for each phase of gait.

Multiple Comparisons

LSD

Dependent Variable	(I) group	(J) group	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
load_ankle_sag	control	coper	-.5364670*	.2161424	.018	-.974824	-.098110
		cai	-.4728202*	.1999236	.024	-.878284	-.067356
	coper	control	.5364670*	.2161424	.018	.098110	.974824
		cai	.0636467	.2094339	.763	-.361105	.488398
	cai	control	.4728202*	.1999236	.024	.067356	.878284
		coper	-.0636467	.2094339	.763	-.488398	.361105
midstance_ankle_sag	control	coper	-1.5466545	.8079169	.064	-3.185186	.091877
		cai	-.8921119	.7472928	.240	-2.407692	.623468
	coper	control	1.5466545	.8079169	.064	-.091877	3.185186
		cai	.6545426	.7828414	.409	-.933133	2.242219
	cai	control	.8921119	.7472928	.240	-.623468	2.407692
		coper	-.6545426	.7828414	.409	-2.242219	.933133
unload_ankle_sag	control	coper	-2.8241609*	.8206599	.001	-4.488536	-1.159785
		cai	-2.3111484*	.7590796	.004	-3.850633	-.771664
	coper	control	2.8241609*	.8206599	.001	1.159785	4.488536
		cai	.5130125	.7951890	.523	-1.099705	2.125730
	cai	control	2.3111484*	.7590796	.004	.771664	3.850633
		coper	-.5130125	.7951890	.523	-2.125730	1.099705
swing_ankle_sag	control	coper	-1.7707203*	.6324859	.008	-3.053461	-.487979
		cai	-1.5511710*	.5850257	.012	-2.737658	-.364684
	coper	control	1.7707203*	.6324859	.008	.487979	3.053461
		cai	.2195493	.6128553	.722	-1.023379	1.462477
	cai	control	1.5511710*	.5850257	.012	.364684	2.737658
		coper	-.2195493	.6128553	.722	-1.462477	1.023379
load_knee_sag	control	coper	-.3245244	.2109219	.133	-.752294	.103245
		cai	-.3657879	.1950949	.069	-.761459	.029883
	coper	control	.3245244	.2109219	.133	-.103245	.752294
		cai	-.0412635	.2043755	.841	-.455756	.373229
	cai	control	.3657879	.1950949	.069	-.029883	.761459
		coper	.0412635	.2043755	.841	-.373229	.455756
midstance_knee_sag	control	coper	-.7777315	.5172672	.141	-1.826798	.271335
		cai	-.8276131	.4784528	.092	-1.797960	.142734
	coper	control	.7777315	.5172672	.141	-.271335	1.826798
		cai	-.0498816	.5012127	.921	-1.066388	.966625
	cai	control	.8276131	.4784528	.092	-.142734	1.797960
		coper	.0498816	.5012127	.921	-.966625	1.066388

unload_knee_sag	control	coper	-2.5201929*	1.1723253	.038	-4.897779	-.142607
		cai	-1.1412155	1.0843569	.300	-3.340393	1.057962
	coper	control	2.5201929*	1.1723253	.038	.142607	4.897779
		cai	1.3789775	1.1359396	.233	-.924815	3.682770
	cai	control	1.1412155	1.0843569	.300	-1.057962	3.340393
		coper	-1.3789775	1.1359396	.233	-3.682770	.924815
swing_knee_sag	control	coper	-3.1178677*	1.2009775	.014	-5.553563	-.682172
		cai	-1.5808444	1.1108591	.163	-3.833771	.672082
	coper	control	3.1178677*	1.2009775	.014	.682172	5.553563
		cai	1.5370233	1.1637025	.195	-.823075	3.897121
	cai	control	1.5808444	1.1108591	.163	-.672082	3.833771
		coper	-1.5370233	1.1637025	.195	-3.897121	.823075

*. The mean difference is significant at the 0.05 level.

Table B.10: Bivariate correlations between clinical variables and maximum inversion in swing phase while walking.

Correlations[a]

		Max_INV_walk	PCS12	MCS12	FAAM	FAAMS	HT	WT
Max_INV_walk	Pearson Correlation	1	-.274	.148	-.595*	-.610*	-.126	-.073
	Sig. (2-tailed)		.322	.599	.019	.016	.654	.797
PCS12	Pearson Correlation	-.274	1	-.562*	.361	.326	-.083	-.112
	Sig. (2-tailed)	.322		.029	.186	.236	.768	.690
MCS12	Pearson Correlation	.148	-.562*	1	-.134	-.049	-.151	-.151
	Sig. (2-tailed)	.599	.029		.633	.862	.590	.590
FAAM	Pearson Correlation	-.595*	.361	-.134	1	.916**	-.391	-.466
	Sig. (2-tailed)	.019	.186	.633		.000	.150	.080
FAAMS	Pearson Correlation	-.610*	.326	-.049	.916**	1	-.334	-.465
	Sig. (2-tailed)	.016	.236	.862	.000		.224	.081
HT	Pearson Correlation	-.126	-.083	-.151	-.391	-.334	1	.923**
	Sig. (2-tailed)	.654	.768	.590	.150	.224		.000
WT	Pearson Correlation	-.073	-.112	-.151	-.466	-.465	.923**	1
	Sig. (2-tailed)	.797	.690	.590	.080	.081	.000	
BESS_FLOOR	Pearson Correlation	-.587*	.065	-.187	.084	.177	.234	.243
	Sig. (2-tailed)	.022	.818	.505	.766	.527	.401	.382
BESS_FOAM	Pearson Correlation	-.350	-.319	.128	-.209	-.130	.361	.432
	Sig. (2-tailed)	.202	.246	.649	.455	.643	.186	.108
DF	Pearson Correlation	-.060	-.115	-.161	-.054	-.217	-.313	-.110
	Sig. (2-tailed)	.831	.683	.566	.849	.437	.256	.697
PF	Pearson Correlation	-.187	.037	.386	.311	.504	-.176	-.384
	Sig. (2-tailed)	.505	.895	.155	.260	.055	.530	.157
IN	Pearson Correlation	-.491	.067	.118	.449	.608*	.147	.129
	Sig. (2-tailed)	.063	.812	.676	.093	.016	.602	.646
EV	Pearson Correlation	.201	.047	.332	-.052	.093	-.435	-.315
	Sig. (2-tailed)	.473	.868	.227	.853	.741	.105	.252
PTGT	Pearson Correlation	-.079	.019	.126	-.095	.135	-.089	-.190
	Sig. (2-tailed)	.778	.947	.655	.736	.631	.752	.497
WBSK	Pearson Correlation	-.187	.055	-.162	.237	.098	.179	-.016
	Sig. (2-tailed)	.505	.845	.565	.395	.728	.523	.954
WBBK	Pearson Correlation	.005	-.219	.162	.240	.227	-.361	-.501
	Sig. (2-tailed)	.985	.432	.564	.388	.416	.187	.057

SEBT_ANT	Pearson Correlation	-.307	-.024	.171	.632*	.632*	-.502	-.710**
	Sig. (2-tailed)	.265	.934	.542	.011	.012	.057	.003
SEBT_PL	Pearson Correlation	.201	.098	.162	.237	.140	-.199	-.113
	Sig. (2-tailed)	.473	.729	.564	.395	.619	.477	.687
SEBT_PM	Pearson Correlation	.146	-.013	.496	.086	.028	-.161	-.027
	Sig. (2-tailed)	.604	.964	.060	.761	.920	.567	.923
AA_AP	Pearson Correlation	.020	-.449	.014	.245	.213	-.015	.024
	Sig. (2-tailed)	.943	.093	.961	.379	.447	.958	.932
AA_INV	Pearson Correlation	.212	-.040	-.336	-.141	-.111	.033	-.144
	Sig. (2-tailed)	.449	.889	.221	.616	.692	.908	.608
AD	Pearson Correlation	.108	.036	.024	-.430	-.385	.123	.213
	Sig. (2-tailed)	.701	.898	.934	.109	.157	.661	.446
TT	Pearson Correlation	-.009	.006	.024	-.162	-.081	.155	.060
	Sig. (2-tailed)	.975	.983	.931	.564	.774	.582	.833

Correlations[a]

		BESS_FLOOR	BESS_FOAM	DF	PF	IN	EV	PTGT
Max_INV_walk	Pearson Correlation	-.587*	-.350	-.060	-.187	-.491	.201	-.079
	Sig. (2-tailed)	.022	.202	.831	.505	.063	.473	.778
PCS12	Pearson Correlation	.065	-.319	-.115	.037	.067	.047	.019
	Sig. (2-tailed)	.818	.246	.683	.895	.812	.868	.947
MCS12	Pearson Correlation	-.187	.128	-.161	.386	.118	.332	.126
	Sig. (2-tailed)	.505	.649	.566	.155	.676	.227	.655
FAAM	Pearson Correlation	.084	-.209	-.054	.311	.449	-.052	-.095
	Sig. (2-tailed)	.766	.455	.849	.260	.093	.853	.736
FAAMS	Pearson Correlation	.177	-.130	-.217	.504	.608*	.093	.135
	Sig. (2-tailed)	.527	.643	.437	.055	.016	.741	.631
HT	Pearson Correlation	.234	.361	-.313	-.176	.147	-.435	-.089
	Sig. (2-tailed)	.401	.186	.256	.530	.602	.105	.752
WT	Pearson Correlation	.243	.432	-.110	-.384	.129	-.315	-.190
	Sig. (2-tailed)	.382	.108	.697	.157	.646	.252	.497
BESS_FLOOR	Pearson Correlation	1	.565*	-.087	.065	.426	-.053	-.216
	Sig. (2-tailed)		.028	.759	.818	.113	.850	.439
BESS_FOAM	Pearson Correlation	.565*	1	-.233	-.068	.376	-.080	.016
	Sig. (2-tailed)	.028		.404	.810	.167	.777	.954
DF	Pearson Correlation	-.087	-.233	1	-.516*	-.478	-.181	-.102
	Sig. (2-tailed)	.759	.404		.049	.072	.518	.719

PF	Pearson Correlation	.065	-.068	-.516*	1	.537*	.438	.466
	Sig. (2-tailed)	.818	.810	.049		.039	.102	.080
IN	Pearson Correlation	.426	.376	-.478	.537*	1	.243	.223
	Sig. (2-tailed)	.113	.167	.072	.039		.382	.424
EV	Pearson Correlation	-.053	-.080	-.181	.438	.243	1	.284
	Sig. (2-tailed)	.850	.777	.518	.102	.382		.305
PTGT	Pearson Correlation	-.216	.016	-.102	.466	.223	.284	1
	Sig. (2-tailed)	.439	.954	.719	.080	.424	.305	
WBSK	Pearson Correlation	.103	-.240	.064	.127	-.095	-.659**	-.224
	Sig. (2-tailed)	.715	.389	.821	.653	.737	.007	.422
WBBK	Pearson Correlation	-.095	-.404	.139	.420	-.127	.067	.227
	Sig. (2-tailed)	.736	.136	.621	.119	.653	.811	.416
SEBT_ANT	Pearson Correlation	.098	-.263	-.096	.621*	.236	.010	.170
	Sig. (2-tailed)	.728	.343	.733	.014	.398	.972	.546
SEBT_PL	Pearson Correlation	-.264	-.237	-.075	-.098	.071	.122	-.506
	Sig. (2-tailed)	.342	.394	.790	.727	.802	.665	.054
SEBT_PM	Pearson Correlation	-.538*	-.314	.122	.011	.011	.343	-.071
	Sig. (2-tailed)	.039	.255	.665	.970	.968	.211	.802
AA_AP	Pearson Correlation	-.223	.137	.013	-.059	.185	-.070	.065
	Sig. (2-tailed)	.425	.625	.964	.834	.509	.805	.817
AA_INV	Pearson Correlation	-.160	-.099	-.239	.267	-.180	.055	.307
	Sig. (2-tailed)	.569	.726	.391	.336	.520	.846	.265
AD	Pearson Correlation	-.036	-.314	.419	-.356	-.395	.164	.062
	Sig. (2-tailed)	.898	.255	.120	.192	.145	.559	.827
TT	Pearson Correlation	.019	-.457	.157	.122	-.079	.057	.201
	Sig. (2-tailed)	.946	.087	.577	.665	.780	.840	.472

Correlations[a]

		WBSK	WBBK	SEBT_ANT	SEBT_PL	SEBT_PM	AA_AP	AA_INV
Max_INV_walk	Pearson Correlation	-.187	.005	-.307	.201	.146	.020	.212
	Sig. (2-tailed)	.505	.985	.265	.473	.604	.943	.449
PCS12	Pearson Correlation	.055	-.219	-.024	.098	-.013	-.449	-.040
	Sig. (2-tailed)	.845	.432	.934	.729	.964	.093	.889
MCS12	Pearson Correlation	-.162	.162	.171	.162	.496	.014	-.336
	Sig. (2-tailed)	.565	.564	.542	.564	.060	.961	.221
FAAM	Pearson Correlation	.237	.240	.632*	.237	.086	.245	-.141
	Sig. (2-tailed)	.395	.388	.011	.395	.761	.379	.616

FAAMS	Pearson Correlation	.098	.227	.632*	.140	.028	.213	-.111
	Sig. (2-tailed)	.728	.416	.012	.619	.920	.447	.692
HT	Pearson Correlation	.179	-.361	-.502	-.199	-.161	-.015	.033
	Sig. (2-tailed)	.523	.187	.057	.477	.567	.958	.908
WT	Pearson Correlation	-.016	-.501	-.710**	-.113	-.027	.024	-.144
	Sig. (2-tailed)	.954	.057	.003	.687	.923	.932	.608
BESS_FLOOR	Pearson Correlation	.103	-.095	.098	-.264	-.538*	-.223	-.160
	Sig. (2-tailed)	.715	.736	.728	.342	.039	.425	.569
BESS_FOAM	Pearson Correlation	-.240	-.404	-.263	-.237	-.314	.137	-.099
	Sig. (2-tailed)	.389	.136	.343	.394	.255	.625	.726
DF	Pearson Correlation	.064	.139	-.096	-.075	.122	.013	-.239
	Sig. (2-tailed)	.821	.621	.733	.790	.665	.964	.391
PF	Pearson Correlation	.127	.420	.621*	-.098	.011	-.059	.267
	Sig. (2-tailed)	.653	.119	.014	.727	.970	.834	.336
IN	Pearson Correlation	-.095	-.127	.236	.071	.011	.185	-.180
	Sig. (2-tailed)	.737	.653	.398	.802	.968	.509	.520
EV	Pearson Correlation	-.659**	.067	.010	.122	.343	-.070	.055
	Sig. (2-tailed)	.007	.811	.972	.665	.211	.805	.846
PTGT	Pearson Correlation	-.224	.227	.170	-.506	-.071	.065	.307
	Sig. (2-tailed)	.422	.416	.546	.054	.802	.817	.265
WBSK	Pearson Correlation	1	.431	.483	-.170	-.360	-.102	.009
	Sig. (2-tailed)		.109	.068	.545	.187	.717	.975
WBBK	Pearson Correlation	.431	1	.679**	-.516*	-.301	.326	.262
	Sig. (2-tailed)	.109		.005	.049	.276	.236	.345
SEBT_ANT	Pearson Correlation	.483	.679**	1	-.078	-.203	.025	.177
	Sig. (2-tailed)	.068	.005		.782	.468	.930	.528
SEBT_PL	Pearson Correlation	-.170	-.516*	-.078	1	.693**	-.230	-.311
	Sig. (2-tailed)	.545	.049	.782		.004	.410	.260
SEBT_PM	Pearson Correlation	-.360	-.301	-.203	.693**	1	-.102	-.399
	Sig. (2-tailed)	.187	.276	.468	.004		.718	.140
AA_AP	Pearson Correlation	-.102	.326	.025	-.230	-.102	1	.112
	Sig. (2-tailed)	.717	.236	.930	.410	.718		.690
AA_INV	Pearson Correlation	.009	.262	.177	-.311	-.399	.112	1
	Sig. (2-tailed)	.975	.345	.528	.260	.140	.690	
AD	Pearson Correlation	-.203	-.069	-.322	-.050	.264	-.428	-.228
	Sig. (2-tailed)	.468	.808	.242	.858	.341	.111	.414
TT	Pearson Correlation	.150	.151	.183	.003	.150	-.477	.115

	Sig. (2-tailed)	.593	.592	.514	.991	.593	.072	.682

Correlations[a]

		AD	TT
Max_INV_walk	Pearson Correlation	.108	-.009
	Sig. (2-tailed)	.701	.975
PCS12	Pearson Correlation	.036	.006
	Sig. (2-tailed)	.898	.983
MCS12	Pearson Correlation	.024	.024
	Sig. (2-tailed)	.934	.931
FAAM	Pearson Correlation	-.430	-.162
	Sig. (2-tailed)	.109	.564
FAAMS	Pearson Correlation	-.385	-.081
	Sig. (2-tailed)	.157	.774
HT	Pearson Correlation	.123	.155
	Sig. (2-tailed)	.661	.582
WT	Pearson Correlation	.213	.060
	Sig. (2-tailed)	.446	.833
BESS_FLOOR	Pearson Correlation	-.036	.019
	Sig. (2-tailed)	.898	.946
BESS_FOAM	Pearson Correlation	-.314	-.457
	Sig. (2-tailed)	.255	.087
DF	Pearson Correlation	.419	.157
	Sig. (2-tailed)	.120	.577
PF	Pearson Correlation	-.356	.122
	Sig. (2-tailed)	.192	.665
IN	Pearson Correlation	-.395	-.079
	Sig. (2-tailed)	.145	.780
EV	Pearson Correlation	.164	.057
	Sig. (2-tailed)	.559	.840
PTGT	Pearson Correlation	.062	.201
	Sig. (2-tailed)	.827	.472
WBSK	Pearson Correlation	-.203	.150
	Sig. (2-tailed)	.468	.593
WBBK	Pearson Correlation	-.069	.151
	Sig. (2-tailed)	.808	.592
SEBT_ANT	Pearson Correlation	-.322	.183
	Sig. (2-tailed)	.242	.514
SEBT_PL	Pearson Correlation	-.050	.003
	Sig. (2-tailed)	.858	.991
SEBT_PM	Pearson Correlation	.264	.150
	Sig. (2-tailed)	.341	.593
AA_AP	Pearson Correlation	-.428	-.477
	Sig. (2-tailed)	.111	.072
AA_INV	Pearson Correlation	-.228	.115
	Sig. (2-tailed)	.414	.682
AD	Pearson Correlation	1	.710**
	Sig. (2-tailed)		.003
TT	Pearson Correlation	.710**	1
	Sig. (2-tailed)	.003	

Table B. 11: Bivariate correlations between clinical variables and maximum inversion in swing phase while jogging.

Correlations[a]

		Max_INV_jog	PCS12	MCS12	FAAM	FAAMS	HT	WT
Max_INV_jog	Pearson Correlation	1	-.422	.209	-.698**	-.549*	-.012	-.035
	Sig. (2-tailed)		.103	.438	.003	.028	.964	.898
PCS12	Pearson Correlation	-.422	1	-.571*	.318	.280	-.114	-.154
	Sig. (2-tailed)	.103		.021	.230	.293	.673	.570
MCS12	Pearson Correlation	.209	-.571*	1	-.101	-.017	-.114	-.097
	Sig. (2-tailed)	.438	.021		.710	.951	.673	.722
FAAM	Pearson Correlation	-.698**	.318	-.101	1	.920**	-.322	-.360
	Sig. (2-tailed)	.003	.230	.710		.000	.223	.170
FAAMS	Pearson Correlation	-.549*	.280	-.017	.920**	1	-.264	-.354
	Sig. (2-tailed)	.028	.293	.951	.000		.323	.179
HT	Pearson Correlation	-.012	-.114	-.114	-.322	-.264	1	.924**
	Sig. (2-tailed)	.964	.673	.673	.223	.323		.000
WT	Pearson Correlation	-.035	-.154	-.097	-.360	-.354	.924**	1
	Sig. (2-tailed)	.898	.570	.722	.170	.179	.000	
BESS_FLOOR	Pearson Correlation	-.224	.068	-.188	.077	.167	.222	.221
	Sig. (2-tailed)	.404	.802	.485	.778	.537	.409	.410
BESS_FOAM	Pearson Correlation	.118	-.263	.084	-.255	-.184	.274	.302
	Sig. (2-tailed)	.662	.326	.756	.341	.495	.305	.255
DF	Pearson Correlation	.068	-.076	-.188	-.101	-.259	-.351	-.178
	Sig. (2-tailed)	.801	.781	.487	.710	.334	.183	.510
PF	Pearson Correlation	-.145	.008	.402	.339	.525*	-.124	-.293
	Sig. (2-tailed)	.593	.978	.123	.199	.037	.648	.271
IN	Pearson Correlation	-.346	.044	.135	.465	.619*	.175	.169
	Sig. (2-tailed)	.189	.872	.617	.069	.011	.518	.532
EV	Pearson Correlation	.156	.067	.306	-.081	.057	-.452	-.342
	Sig. (2-tailed)	.565	.804	.249	.766	.833	.079	.195
PTGT	Pearson Correlation	.262	.050	.092	-.136	.080	-.134	-.246
	Sig. (2-tailed)	.327	.854	.733	.615	.767	.621	.359
WBSK	Pearson Correlation	-.202	.067	-.171	.212	.076	.153	-.044
	Sig. (2-tailed)	.454	.804	.526	.430	.781	.571	.872
WBBK	Pearson Correlation	.148	-.224	.167	.245	.233	-.339	-.456
	Sig. (2-tailed)	.584	.404	.536	.360	.386	.199	.076
SEBT_ANT	Pearson Correlation	-.303	-.014	.160	.603*	.600*	-.502*	-.691**
	Sig. (2-tailed)	.253	.960	.553	.013	.014	.047	.003

SEBT_PL	Pearson Correlation	-.352	.078	.176	.256	.163	-.164	-.066
	Sig. (2-tailed)	.182	.775	.514	.339	.546	.544	.808
SEBT_PM	Pearson Correlation	-.305	-.088	.490	.183	.142	-.012	.150
	Sig. (2-tailed)	.250	.745	.054	.499	.601	.964	.580
AA_AP	Pearson Correlation	.348	-.374	-.030	.160	.125	-.087	-.082
	Sig. (2-tailed)	.186	.153	.911	.553	.644	.750	.763
AA_INV	Pearson Correlation	.208	.004	-.358	-.192	-.167	-.034	-.222
	Sig. (2-tailed)	.439	.989	.174	.477	.536	.901	.408
AD	Pearson Correlation	.048	.021	.036	-.398	-.351	.142	.232
	Sig. (2-tailed)	.861	.938	.893	.127	.182	.601	.387
TT	Pearson Correlation	-.151	-.010	.038	-.135	-.055	.174	.090
	Sig. (2-tailed)	.577	.972	.888	.617	.840	.520	.740

Correlations[a]

		BESS_FLOOR	BESS_FOAM	DF	PF	IN	EV	PTGT
Max_INV_jog	Pearson Correlation	-.224	.118	.068	-.145	-.346	.156	.262
	Sig. (2-tailed)	.404	.662	.801	.593	.189	.565	.327
PCS12	Pearson Correlation	.068	-.263	-.076	.008	.044	.067	.050
	Sig. (2-tailed)	.802	.326	.781	.978	.872	.804	.854
MCS12	Pearson Correlation	-.188	.084	-.188	.402	.135	.306	.092
	Sig. (2-tailed)	.485	.756	.487	.123	.617	.249	.733
FAAM	Pearson Correlation	.077	-.255	-.101	.339	.465	-.081	-.136
	Sig. (2-tailed)	.778	.341	.710	.199	.069	.766	.615
FAAMS	Pearson Correlation	.167	-.184	-.259	.525*	.619*	.057	.080
	Sig. (2-tailed)	.537	.495	.334	.037	.011	.833	.767
HT	Pearson Correlation	.222	.274	-.351	-.124	.175	-.452	-.134
	Sig. (2-tailed)	.409	.305	.183	.648	.518	.079	.621
WT	Pearson Correlation	.221	.302	-.178	-.293	.169	-.342	-.246
	Sig. (2-tailed)	.410	.255	.510	.271	.532	.195	.359
BESS_FLOOR	Pearson Correlation	1	.550*	-.078	.059	.417	-.049	-.206
	Sig. (2-tailed)		.027	.774	.829	.108	.857	.445
BESS_FOAM	Pearson Correlation	.550*	1	-.152	-.117	.318	-.037	.074
	Sig. (2-tailed)	.027		.573	.666	.230	.893	.785
DF	Pearson Correlation	-.078	-.152	1	-.537*	-.494	-.141	-.046
	Sig. (2-tailed)	.774	.573		.032	.052	.604	.866
PF	Pearson Correlation	.059	-.117	-.537*	1	.549*	.398	.405

	Sig. (2-tailed)	.829	.666	.032		.028	.127	.119
IN	Pearson Correlation	.417	.318	-.494	.549*	1	.217	.185
	Sig. (2-tailed)	.108	.230	.052	.028		.419	.494
EV	Pearson Correlation	-.049	-.037	-.141	.398	.217	1	.305
	Sig. (2-tailed)	.857	.893	.604	.127	.419		.250
PTGT	Pearson Correlation	-.206	.074	-.046	.405	.185	.305	1
	Sig. (2-tailed)	.445	.785	.866	.119	.494	.250	
WBSK	Pearson Correlation	.105	-.206	.082	.107	-.106	-.638**	-.199
	Sig. (2-tailed)	.699	.444	.762	.693	.696	.008	.459
WBBK	Pearson Correlation	-.096	-.402	.123	.421	-.118	.059	.210
	Sig. (2-tailed)	.723	.123	.651	.104	.664	.827	.434
SEBT_ANT	Pearson Correlation	.100	-.235	-.078	.595*	.223	.019	.179
	Sig. (2-tailed)	.714	.382	.774	.015	.406	.944	.507
SEBT_PL	Pearson Correlation	-.265	-.260	-.101	-.072	.088	.102	-.517*
	Sig. (2-tailed)	.322	.331	.708	.790	.747	.707	.040
SEBT_PM	Pearson Correlation	-.472	-.401	-.022	.110	.086	.214	-.171
	Sig. (2-tailed)	.065	.124	.935	.686	.752	.426	.527
AA_AP	Pearson Correlation	-.203	.212	.086	-.116	.128	-.020	.128
	Sig. (2-tailed)	.450	.430	.751	.669	.637	.941	.636
AA_INV	Pearson Correlation	-.146	-.015	-.157	.198	-.212	.092	.348
	Sig. (2-tailed)	.588	.957	.561	.462	.431	.734	.187
AD	Pearson Correlation	-.038	-.327	.382	-.330	-.375	.148	.039
	Sig. (2-tailed)	.888	.216	.144	.213	.152	.585	.885
TT	Pearson Correlation	.016	-.465	.127	.139	-.062	.041	.173
	Sig. (2-tailed)	.952	.069	.640	.607	.819	.880	.521

Correlations[a]

		WBSK	WBBK	SEBT_ANT	SEBT_PL	SEBT_PM	AA_AP	AA_INV
Max_INV_jog	Pearson Correlation	-.202	.148	-.303	-.352	-.305	.348	.208
	Sig. (2-tailed)	.454	.584	.253	.182	.250	.186	.439
PCS12	Pearson Correlation	.067	-.224	-.014	.078	-.088	-.374	.004
	Sig. (2-tailed)	.804	.404	.960	.775	.745	.153	.989
MCS12	Pearson Correlation	-.171	.167	.160	.176	.490	-.030	-.358
	Sig. (2-tailed)	.526	.536	.553	.514	.054	.911	.174
FAAM	Pearson Correlation	.212	.245	.603*	.256	.183	.160	-.192
	Sig. (2-tailed)	.430	.360	.013	.339	.499	.553	.477
FAAMS	Pearson Correlation	.076	.233	.600*	.163	.142	.125	-.167
	Sig. (2-tailed)	.781	.386	.014	.546	.601	.644	.536

HT	Pearson Correlation	.153	-.339	-.502*	-.164	-.012	-.087	-.034
	Sig. (2-tailed)	.571	.199	.047	.544	.964	.750	.901
WT	Pearson Correlation	-.044	-.456	-.691**	-.066	.150	-.082	-.222
	Sig. (2-tailed)	.872	.076	.003	.808	.580	.763	.408
BESS_FLOOR	Pearson Correlation	.105	-.096	.100	-.265	-.472	-.203	-.146
	Sig. (2-tailed)	.699	.723	.714	.322	.065	.450	.588
BESS_FOAM	Pearson Correlation	-.206	-.402	-.235	-.260	-.401	.212	-.015
	Sig. (2-tailed)	.444	.123	.382	.331	.124	.430	.957
DF	Pearson Correlation	.082	.123	-.078	-.101	-.022	.086	-.157
	Sig. (2-tailed)	.762	.651	.774	.708	.935	.751	.561
PF	Pearson Correlation	.107	.421	.595*	-.072	.110	-.116	.198
	Sig. (2-tailed)	.693	.104	.015	.790	.686	.669	.462
IN	Pearson Correlation	-.106	-.118	.223	.088	.086	.128	-.212
	Sig. (2-tailed)	.696	.664	.406	.747	.752	.637	.431
EV	Pearson Correlation	-.638**	.059	.019	.102	.214	-.020	.092
	Sig. (2-tailed)	.008	.827	.944	.707	.426	.941	.734
PTGT	Pearson Correlation	-.199	.210	.179	-.517*	-.171	.128	.348
	Sig. (2-tailed)	.459	.434	.507	.040	.527	.636	.187
WBSK	Pearson Correlation	1	.424	.486	-.179	-.351	-.069	.033
	Sig. (2-tailed)		.101	.057	.508	.182	.799	.905
WBBK	Pearson Correlation	.424	1	.673**	-.505*	-.229	.293	.237
	Sig. (2-tailed)	.101		.004	.046	.393	.271	.376
SEBT_ANT	Pearson Correlation	.486	.673**	1	-.085	-.207	.044	.188
	Sig. (2-tailed)	.057	.004		.753	.443	.872	.487
SEBT_PL	Pearson Correlation	-.179	-.505*	-.085	1	.650**	-.255	-.330
	Sig. (2-tailed)	.508	.046	.753		.006	.341	.211
SEBT_PM	Pearson Correlation	-.351	-.229	-.207	.650**	1	-.247	-.472
	Sig. (2-tailed)	.182	.393	.443	.006		.356	.065
AA_AP	Pearson Correlation	-.069	.293	.044	-.255	-.247	1	.190
	Sig. (2-tailed)	.799	.271	.872	.341	.356		.480
AA_INV	Pearson Correlation	.033	.237	.188	-.330	-.472	.190	1
	Sig. (2-tailed)	.905	.376	.487	.211	.065	.480	
AD	Pearson Correlation	-.210	-.063	-.326	-.038	.275	-.435	-.245
	Sig. (2-tailed)	.436	.816	.218	.889	.303	.092	.361
TT	Pearson Correlation	.140	.155	.175	.016	.182	-.483	.081
	Sig. (2-tailed)	.606	.566	.517	.953	.500	.058	.765

Correlations[a]

		AD	TT
Max_INV_jog	Pearson Correlation	.048	-.151
	Sig. (2-tailed)	.861	.577
PCS12	Pearson Correlation	.021	-.010
	Sig. (2-tailed)	.938	.972
MCS12	Pearson Correlation	.036	.038
	Sig. (2-tailed)	.893	.888
FAAM	Pearson Correlation	-.398	-.135
	Sig. (2-tailed)	.127	.617
FAAMS	Pearson Correlation	-.351	-.055
	Sig. (2-tailed)	.182	.840
HT	Pearson Correlation	.142	.174
	Sig. (2-tailed)	.601	.520
WT	Pearson Correlation	.232	.090
	Sig. (2-tailed)	.387	.740
BESS_FLOOR	Pearson Correlation	-.038	.016
	Sig. (2-tailed)	.888	.952
BESS_FOAM	Pearson Correlation	-.327	-.465
	Sig. (2-tailed)	.216	.069
DF	Pearson Correlation	.382	.127
	Sig. (2-tailed)	.144	.640
PF	Pearson Correlation	-.330	.139
	Sig. (2-tailed)	.213	.607
IN	Pearson Correlation	-.375	-.062
	Sig. (2-tailed)	.152	.819
EV	Pearson Correlation	.148	.041
	Sig. (2-tailed)	.585	.880
PTGT	Pearson Correlation	.039	.173
	Sig. (2-tailed)	.885	.521
WBSK	Pearson Correlation	-.210	.140
	Sig. (2-tailed)	.436	.606
WBBK	Pearson Correlation	-.063	.155
	Sig. (2-tailed)	.816	.566
SEBT_ANT	Pearson Correlation	-.326	.175
	Sig. (2-tailed)	.218	.517
SEBT_PL	Pearson Correlation	-.038	.016
	Sig. (2-tailed)	.889	.953
SEBT_PM	Pearson Correlation	.275	.182
	Sig. (2-tailed)	.303	.500
AA_AP	Pearson Correlation	-.435	-.483
	Sig. (2-tailed)	.092	.058
AA_INV	Pearson Correlation	-.245	.081
	Sig. (2-tailed)	.361	.765
AD	Pearson Correlation	1	.713**
	Sig. (2-tailed)		.002
TT	Pearson Correlation	.713**	1
	Sig. (2-tailed)	.002	

Table B.12: Follow-up correlations with moderately correlated clinical measures and maximum inversion during swing phase while jogging.

Correlations

		Max_INV_jog	FAAM	FAAMS	IN	SEBT_ANT	SEBT_PL	SEBT_PM	AA_AP	PCS12
Pearson Correlation	Max_INV_jog	1.000	-.698	-.549	-.346	-.303	-.352	-.305	.348	-.422
	FAAM	-.698	1.000	.920	.465	.603	.256	.183	.160	.318
	FAAMS	-.549	.920	1.000	.619	.600	.163	.142	.125	.280
	IN	-.346	.465	.619	1.000	.223	.088	.086	.128	.044
	SEBT_ANT	-.303	.603	.600	.223	1.000	-.085	-.207	.044	-.014
	SEBT_PL	-.352	.256	.163	.088	-.085	1.000	.650	-.255	.078
	SEBT_PM	-.305	.183	.142	.086	-.207	.650	1.000	-.247	-.088
	AA_AP	.348	.160	.125	.128	.044	-.255	-.247	1.000	-.374
	PCS12	-.422	.318	.280	.044	-.014	.078	-.088	-.374	1.000
Sig. (1-tailed)	Max_INV_jog	.	.001	.014	.095	.127	.091	.125	.093	.052
	FAAM	.001	.	.000	.035	.007	.169	.249	.277	.115
	FAAMS	.014	.000	.	.005	.007	.273	.300	.322	.147
	IN	.095	.035	.005	.	.203	.374	.376	.319	.436
	SEBT_ANT	.127	.007	.007	.203	.	.377	.221	.436	.480
	SEBT_PL	.091	.169	.273	.374	.377	.	.003	.170	.387
	SEBT_PM	.125	.249	.300	.376	.221	.003	.	.178	.373
	AA_AP	.093	.277	.322	.319	.436	.170	.178	.	.077
	PCS12	.052	.115	.147	.436	.480	.387	.373	.077	.
N	Max_INV_jog	16	16	16	16	16	16	16	16	16
	FAAM	16	16	16	16	16	16	16	16	16
	FAAMS	16	16	16	16	16	16	16	16	16
	IN	16	16	16	16	16	16	16	16	16
	SEBT_ANT	16	16	16	16	16	16	16	16	16
	SEBT_PL	16	16	16	16	16	16	16	16	16
	SEBT_PM	16	16	16	16	16	16	16	16	16
	AA_AP	16	16	16	16	16	16	16	16	16
	PCS12	16	16	16	16	16	16	16	16	16

Table B.13: Stepwise regression output while jogging.

Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	FAAM	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	AA_AP	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).

a. Dependent Variable: Max_INV_jog

Table B.14: Model summery of stepwise regression analysis while jogging.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Change Statistics				
					R Square Change	F Change	df1	df2	Sig. F Change
1	.698[a]	.488	.451	4.599	.488	13.323	1	14	.003
2	.840[b]	.705	.660	3.622	.217	9.576	1	13	.009

a. Predictors: (Constant), FAAM

b. Predictors: (Constant), FAAM, AA_AP

Table B.15: One way ANOVA evaluating regression models while jogging.

ANOVA[c]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	281.818	1	281.818	13.323	.003[a]
	Residual	296.143	14	21.153		
	Total	577.961	15			
2	Regression	407.436	2	203.718	15.530	.000[b]
	Residual	170.526	13	13.117		
	Total	577.961	15			

a. Predictors: (Constant), FAAM

b. Predictors: (Constant), FAAM, AA_AP

c. Dependent Variable: Max_INV_jog

Table B.16: Regression coefficients for significant predictors of maximum inversion during swing phase while jogging.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	91.958	22.607		4.068	.001
	FAAM	-.859	.235	-.698	-3.650	.003
2	(Constant)	93.871	17.813		5.270	.000
	FAAM	-.952	.188	-.774	-5.071	.000
	AA_AP	1.019	.329	.472	3.095	.009

a. Dependent Variable: Max_INV_jog

Table B.17: Excluded variables from the regression models while jogging.

Excluded Variables[c]

Model		Beta In	t	Sig.	Partial Correlation	Collinearity Statistics
						Tolerance
1	FAAMS	.606[a]	1.269	.227	.332	.154
	IN	-.027[a]	-.120	.907	-.033	.783
	SEBT_ANT	.185[a]	.760	.461	.206	.636
	SEBT_PL	-.185[a]	-.930	.369	-.250	.934
	SEBT_PM	-.184[a]	-.941	.364	-.252	.967
	AA_AP	.472[a]	3.095	.009	.651	.974
	PCS12	-.223[a]	-1.115	.285	-.295	.899
2	FAAMS	.676[b]	1.934	.077	.488	.153
	IN	-.059[b]	-.334	.744	-.096	.780
	SEBT_ANT	.225[b]	1.210	.249	.330	.634
	SEBT_PL	-.039[b]	-.230	.822	-.066	.845
	SEBT_PM	-.053[b]	-.319	.755	-.092	.888
	PCS12	.001[b]	.003	.998	.001	.713

a. Predictors in the Model: (Constant), FAAM

b. Predictors in the Model: (Constant), FAAM, AA_AP

c. Dependent Variable: Max_INV_jog

APPENDIX C

RECOMMENDATIONS FOR FUTURE RESEARCH

Questions requiring further study:

- Do shoes affect gait differently in those with CAI differently than healthy individuals?
- Does an increase in movement variability during unloading and swing increase the risk of suffering from subsequent ankle sprains?
- What is the affect of ankle tape on subjects with CAI during dynamic activities such as cutting and jumping?
- Are self-reported function and anterior ankle laxity accurate predictors for lateral ankle sprains?