Investigating the Relationship Between FAI Questionnaires and Measures of Static and Dynamic Postural Stability

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Lateral ankle sprains are a common injury among all levels of athletic competition and can lead to the development of functional ankle instability (FAI). Individuals with FAI often display postural stability deficits. Numerous ankle questionnaires have been developed to classify subjects with FAI; however, the relationship between ankle questionnaires and postural stability is limited and warrants investigation. The primary purpose of this study was to compare measures of static and dynamic postural stability between FAI and healthy controls. The secondary purpose was to identify the relationship between ankle questionnaires and postural stability in FAI subjects. A total of 24 recreationally active subjects, 12 FAI and 12 healthy controls, between the ages of 18-35 were recruited to participate in this study. Static postural stability was assessed during eyes open and eyes closed single-leg stance. Dynamic postural stability was assessed during single-leg jump landings in the anterior and lateral directions. The ankle questionnaires included the Functional Ankle Disability Index, Ankle Instability Instrument, Ankle Joint Functional Assessment Tool, and Cumberland Ankle Instability Tool. Demographic, postural stability and questionnaire variables were compared using independent samples t-tests. A series of Pearson correlation coefficients were computed to determine the relationship between ankle questionnaires and measures of static and dynamic postural stability. The FAI subjects demonstrated worse (greater perceived symptoms of functional instability) scores on the Functional Ankle Disability Index-Sport, Ankle Instability Instrument, Ankle Joint Functional Assessment Tool, and Cumberland Ankle Instability Tool than the healthy controls. Additionally, FAI subjects demonstrated worse (higher) scores for the medial/lateral ground reaction force standard deviation during eyes closed single-leg stance, vertical stability index, and DPSI during anterior and lateral jumps. Significant correlations were observed between the medial lateral stability index and Ankle Joint Functional Assessment Tool and Cumberland Ankle Instability Tool during lateral jumps. The results of the study demonstrate FAI subjects have static and dynamic postural stability deficits compared to healthy controls. Additionally, the ankle questionnaires were poorly correlated with static and dynamic postural stability suggesting the ankle questionnaires may be inadequate at detecting postural stability deficits in FAI subjects.

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PREFACE

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1.0 INTRODUCTION

Ankle sprains are one of the most prevalent lower extremity injuries in high school, collegiate, and recreational sports.[45, 103, 148] Approximately 85-95% of all ankle sprains occur to the lateral ligament complex.[30] Injuries to the lateral ligament complex of the ankle result in more time lost from participation than any other single sport related injury.[31, 44] Previous studies estimated approximately 40% of individuals who suffered an initial ankle injury will continue to report ankle dysfunction.[109, 129] Recurrent ankle sprains are frequent with reports ranging up to 73% in athletic populations.[46, 148] The subjective feeling of the ankle "giving way" after an initial ankle sprain and the repetitive incidences of instability resulting in numerous ankle sprains has been termed chronic ankle instability (CAI).[62]

Traditionally CAI has been attributed to two potential causes: mechanical ankle instability and functional ankle instability (FAI).[62] According to Tropp et al.[136] mechanical deficits are a cause of CAI due to pathological laxity after ankle ligament injury. Freeman et al.[38, 40] were the first to describe functional ankle instability and attributed CAI to proprioceptive deficits after ligamentous injury. Hertel[61] has offered a more recent definition of FAI as being the occurrence of repetitive ankle instability and the sensation of joint instability due to the lack of contribution from mechanoreceptors as well as a lack of neuromuscular control. Functional ankle instability may be caused by specific insufficiencies in proprioception, neuromuscular control, postural stability, or strength.[62]

1.1 QUESTIONNAIRES

Subjective reports of function completed by patients are an important outcome measure for health care practitioners.[56, 93] Many clinical research studies utilize questionnaires as primary outcome measures to accurately reflect symptoms and disabilities that are specific and important to patients.[93] With all the variation surrounding the definition of functional ankle instability (FAI) and the conflicting results from research focusing on FAI it would seem relevant to develop an objective means of assessing this condition[33] and determine if the questionnaires truly relate to a specific functional task. Several investigators have undertaken the task of developing assessment tools to identify functional limitations in individuals with FAI. Four commonly used self-reported questionnaires in the literature are: the Foot and Ankle Disability Index (FADI),[56] the Ankle Instability Instrument (AII),[33] the Ankle Joint Functional Assessment Tool (AJFAT),[127] and the Cumberland Ankle Instability Tool (CAIT).[66] Of the four questionnaires two of them, AFJAT and CAIT, consist of twelve and nine questions respectively and are scored on a Likert-scale. The AII consists of nine questions that are answered in a yes or no format. The FADI consists of two questionnaires, one assesses activities of daily living, whereas the other, FADI-Sport, assesses functional activities. Both the FADI and FADI-Sport are scored on a Likert-scale. It has been demonstrated that individuals with FAI display postural stability deficits.[122, 124-126, 137, 139, 140] Functional ankle instability questionnaires should correlate with dynamic postural stability deficits. However, no "gold standard" questionnaire exists to determine the presence of FAI leaving researchers to develop their own criteria which can vary from study to study potentially resulting in ambiguous conclusions.

1.2 PROPRIOCEPTION

Proprioception has been defined by Lephart et al.[89] as a specialized variation of the sensory modality of touch that encompasses the perception of joint movement and joint position as well as contributing to the motor programming for neuromuscular control required for precise movements. Mechanoreceptors for proprioception are found in the skin, muscles, joints, joint capsule, articular cartilage, ligaments, and tendons and provide input to the central nervous system regarding tissue deformation.[55, 89] Mechanoreceptors are sensitive to joint pressure and tension caused by dynamic movement. Proprioceptive deficits after an ankle injury are speculated to occur because of damage to mechanoreceptors in the ligaments, muscles, and skin, contributing to subsequent feelings of instability.[88, 89] Freeman et al.[40] theory of articular deafferentation suggests that damage to the joint afferents during an initial ankle sprain causes altered afferent feedback which results in delayed reflex responses to inversion stresses at the ankle.[40] There is current evidence suggesting that dynamic control of ankle stability relies heavily on the feed-forward motor control of the central nervous system.[27, 86]

In contrast, it is suggested feedback and feed-forward mechanisms are concomitant. Johansson and Magnusson[80] describe feedback control as acting *post facto* in response to perturbations, or events, sensed by the system, whereas feed-forward control acts appropriately before the external disturbance affects the system, in anticipation of its impending effect. Myers et al.[101] and Riemann et al.[118] examined the effects of local anesthesia to the lateral ankle ligaments and failed to find substantial sensorimotor control deficits when compared to a placebo or control, demonstrating despite the loss of sensory information from these ligaments there was still adequate sensory information from other receptors to allow for unimpaired sensorimotor control.[65] This contradicted Freeman et al.[40] theory that ankle sprains lead to postural stability deficits because of damage to sensory receptors in injured ligaments. Studies conducted by Refshauge et al.[113, 114] and Hall and McCloskey[58] proposed muscle afferents surrounding the major joints in the body provide the most important proprioceptive information to the central nervous system suggesting joint mechanoreceptors may duplicate information provided by muscle afferents. Joint mechanoreceptors fire maximally when the joint capsule is tightened which typically occurs when the joint reaches its limit of motion, therefore, a decrease in joint mechanoreceptors discharge would not result in a noticeable deficit. [58]

1.3 NEUROMUSCULAR CONTROL

Aspects of neuromuscular control may be quantified through measures of postural stability. Postural stability has been defined as the ability to maintain an upright posture and to keep the center of gravity within the limits of the base of support.[82] Postural stability may be further classified as either static or dynamic. Static postural stability refers to the attempt to maintain a base of support with minimal movement, whereas dynamic postural stability is the attempt to maintain a stable base of support while completing a prescribed movement.[15, 52] Both static and dynamic postural stability are the result of complex coordinated central processing from visual, vestibular, and somatosensory pathways, as well as the resultant efferent response.[106] Static postural stability deficits in single limb stance associated with CAI using instrumented force plate measures has been reported in the literature however, there has not been consistency in the evidence as to whether these deficits can be observed with the use of these measures.[5, 78, 95, 108, 127] Freeman et al.[38, 40] used single-leg Rhomberg tests to identify balance impairments; other investigators have used instrumented force plates to identify balance deficits in subjects with FAI. [47, 48, 65, 78, 82, 122, 124, 125, 133] Ground reaction force (GRF) measures have been used to quantify balance in functionally unstable individuals.[125] Ross et al.[125] demonstrated that the standard deviation of the medial/lateral (M/L) GRF was one of the most accurate force plate measures for discriminating between stable and unstable ankles. Although less accurate than M/L GRF standard deviation, anterior/posterior (A/P) GRF standard deviation were also able to detect static balance impairments associated with FAI.[125] A criticism of static balance testing is the assessment technique may not be sensitive enough to detect motor control deficits related to chronic ankle instability.[65] Also, the task of maintaining quiet standing may not place adequate demands on the postural control system.[65] Dynamic postural stability has been examined through a variety of ways. A relatively new measure of dynamic postural stability is the Dynamic Postural Stability Index (DPSI) which determines how well balance is maintained as an individual transition’s from a dynamic state to a static state.[137, 146] According to Wikstrom et al.[137] DPSI is a functional measurement of neuromuscular control because it is calculated during a single-leg hop stabilization maneuver.

1.4 SUMMARY

Functional ankle instability questionnaires have been implemented to differentiate between individuals with FAI and individuals with stable ankles. It has been shown that individuals with FAI display postural stability deficits, but little consensus exist in the sensitivity of FAI questionnaires to detect changes in postural stability. With no “gold standard” questionnaire currently existing to determine postural stability deficits in individuals with FAI has left researchers developing their own criteria which can vary from study to study resulting in potentially invalid conclusions.

1.5 STATEMENT OF PURPOSE

Reliability, and in some cases validity, tests have been conducted on all of the FAI questionnaires to be used in this study; however, none have compared multiple questionnaire scores with static and dynamic measures of postural stability. Functional ankle instability questionnaires should be able to detect the numerous deficits individuals with FAI suffer from, one such deficit is postural stability. Functional ankle instability questionnaires have not consistently shown postural stability deficits in FAI individuals. Therefore, the primary purpose of this study is to compare static and dynamic measures of postural stability between a group of self-reported functional ankle instability and a control group as well as to determine if a relationship exists between FAI questionnaire classification and static and dynamic measures of postural stability in subjects with FAI.

1.6 SPECIFIC AIMS AND HYPOTHESES

Specific Aim 1: To compare static and dynamic measures of postural stability between a group of self-reported functional ankle instability and a healthy control group.

Hypothesis 1a: Static measures of postural stability will be homogenous between the FAI and healthy control group.

Hypothesis 1b: Dynamic measures of postural stability will be greater in the FAI than the healthy control group.

Specific Aim 2: To compare functional ankle instability questionnaire scores between a group of self-reported functional ankle instability and a healthy control group

Hypothesis 2: Functional ankle instability questionnaire scores will be different between groups with the FAI group demonstrating worse scores

Specific Aim 3: To identify the relationship between functional ankle instability questionnaires and measures of static and dynamic postural control and determine which questionnaire best represents functional outcomes in recreationally active subjects with self-reported functional ankle instability

Hypothesis 3: A *little if any* to *fair* correlation will exist between FAI questionnaires and measures of static and dynamic postural stability.

2.0 REVIEW OF LITERATURE

Ankle sprains constitute a large proportion of injuries seen in high school, recreational and collegiate athletics.[45, 103, 148] Lateral ankle sprains are one of the most common injuries sustained by military personnel in the US Armed Services.[17] Kannus et al.[81] estimated more than 23,000 ankle sprains occur per day in the United States, equating to one sprain per 10,000 people daily. Questionnaires are often used in the healthcare industry to assess functional status and activities of daily living. Although several FAI questionnaires have been developed, there exists no widely accepted outcome measurement tool to assess ankle function.[56] Currently, there is a lack of consistency in FAI questionnaires ability to detect postural stability deficits in FAI individuals. A comparison of several popular FAI questionnaires and their relationship between static and dynamic measures of postural stability in subjects with FAI is warranted.

2.1 CHRONIC ANKLE INSTABILITY

Chronic ankle instability is the occurrence of repetitive episodes of lateral ankle instability resulting in numerous ankle sprains.[62] Potential causes of chronic ankle instability have traditionally been attributed to mechanical instability and functional instability. Mechanical instability refers to anatomical insufficiencies such as pathological laxity, impaired arthrokinematics, and synovial and degenerative changes, whereas functional insufficiencies include impaired proprioception, strength deficits, diminished postural control, and altered neuromuscular control.[76] Previous investigators have viewed mechanical and functional ankle instability as dichotomous causes of CAI; however, several authors have suggested a relationship exists between mechanical and functional ankle instability. [62, 76, 136]

It has been established that a few relationships exist between FAI and mechanical ankle instability.[76] They include increased anterior laxity correlated moderately with increased dorsiflexion peak torque and an increased COP area with eyes closed. An isokinetic strength test on a Biodex 2 isokinetic dynamometer was used to measure dorsiflexion peak torque. Posterior laxity correlated moderately with the posterior-lateral reach during the Star Excursion Balance Test. It was observed as posterior laxity decreased, posterior-lateral reach decreased.[76] The authors suggest even though the relationship may seem to be limited based on the number of significant variables, those variables are important (laxity, strength, and balance) during both static and dynamic tasks. Therefore, they suggest FAI and mechanical ankle instability should be examined together.[76]

2.2 FUNCTIONAL ANKLE INSTABILITY

Functional ankle instability was first described by Freeman et al.[38] as the subjective sensation of "giving way" or feeling joint instability after repeated bouts of ankle sprains. The definition of FAI has been redefined numerous times since its first appearance. Tropp et al.[136] described FAI as joint motion that is beyond voluntary control but does not exceed the physiological range of motion. Hertel[61, 62] defined FAI as the repeated occurrence of ankle instability as well as the sensation of joint instability which is attributed to proprioceptive and neuromuscular deficits.

Functional ankle instability has been attributed to numerous insufficiencies, the most widely reported are proprioception and muscle function.[30, 32, 62] Proprioception has been defined by Riemann and Lephart[117] as afferent information arising from internal peripheral areas of the body that contribute to postural control, joint stability, and several conscious sensations. More simply put, proprioception is the ability to detect sensory stimuli, such as pain, pressure, touch and movements.[72, 89] Proprioception contributes to neuromuscular control and muscle reflex allowing for precise movements to occur as well as providing dynamic joint stability.[89] Proprioceptive mechanoreceptors are located within the skin, muscles, joints, tendons, and ligaments.[55] These sensory receptors work together to provide input to the central nervous system regarding tissue deformation.[89] Bernier and Perrin[7] reported mechanoreceptors are sensitive to joint pressure and tension caused by dynamic movement. Deficits in proprioception are thought to occur because of damage to mechanoreceptors resulting in the feeling of instability.[18, 28, 114]

Freeman et al.[40] proposed proprioceptive deficits following an ankle injury are the result of lesions to mechanoreceptors in the joint capsule and ligaments surrounding the ankle, this is often referred to as the theory of articular deafferentation. The theory contends that when ankle ligaments are injured disruption occurs not only in the collagenous connective tissue but also to sensory mechanoreceptors within the ligament and it is this damage that leads to proprioceptive deficits which in turn can lead to subsequent ankle injuries.[63] Myers et al.[101] and Riemann et al.[118] examined the effects of local anesthesia to the lateral ankle ligaments and failed to find substantial sensorimotor control deficits when compared to a placebo or control, demonstrating despite the loss of sensory information from these ligaments there was still adequate sensory information from other receptors to allow for unimpaired sensorimotor control.[65] The lack of deficits seen following anesthetization of the lateral ankle ligaments could be because of the duplication of information from articular, musculotendinous, and cutaneous receptors.[63] Refshauge et al.[113, 114] and Hall and McCloskey[58] proposed muscle afferents surrounding the major joints in the body provide the most important proprioceptive information to the central nervous system suggesting joint mechanoreceptors may be duplicating information from other sources such as muscle afferents. Joint receptors are thought to play a supportive or duplicative role to muscle receptors during most of the joint range of motion because joint receptors typically fire when the joint reaches its maximum range of motion as this is when the joint capsule becomes tightened.[62, 63] Refshauge et al.[113] indicated there are three classes of afferent responsible for proprioceptive signals. These afferents are located in the ligament and joint capsule, as well as cutaneous and muscle tissue.[113] Of the three afferent classes mentioned, it is theorized muscle afferents provide the most important information at most joints in the body; however, cutaneous input provides equally important information to muscle input at distal joints.[62, 63, 113] If this is correct, then a decrease in joint mechanoreceptors signals would not result in a noticeable proprioceptive deficit.[114]

The articular deafferentation hypothesis fails to account for feed-forward mechanisms as it only assumes a feedback mechanism of articular proprioception and sensorimotor control.[63] The body maintains joint stability by using two different control systems, feedback and feed-forward. The feedback control mechanism is initiated after sensory detection and operates on a moment-to-moment basis as it continuously processes afferent information, whereas the feed-forward control mechanism is described as anticipatory actions that occur before sensory detection, disruption, and is largely shaped by previous experience.[80, 117] The articular deafferentation hypothesis suggests damage to the joint afferents following an initial ankle sprain results in altered afferent feedback causing a delayed reflex response to inversion stresses at the ankle allowing for repeated bouts of ankle instability.[40] It has been suggested dynamic control of ankle stability relies heavily on the feed-forward motor control of the central nervous system.[27, 86] Others have suggested feedback and feed-forward mechanism occur concomitantly, for example, the maintenance of postural control uses a combination of both feedback and feed-forward mechanisms.[117]

2.3 QUESTIONNAIRES

Clinical outcome measures in orthopedics have traditionally centered on measuring deficits such as range of motion and strength, whereas patients are typically concerned with functional limitations and disability.[36, 56] Within the health care industry the importance of the patient's perspective has received more attention as it is argued to be the most important criterion for judging the effectiveness of treatment.[36, 107] Therefore, instruments such as questionnaires are appropriate tools for evaluating functional limitations and disabilities.[56] Furthermore, questionnaires promote shared decision making and facilitate practitioner-patient communication.[50] In determining which questionnaire to use it is important to consider the study population, the purpose of the questionnaire, its reliability, validity, reproducibility, and responsiveness.[10]

Questionnaires have been developed to assess function and activities of daily living for the shoulder, [60, 77] hip, [6] knee,[22, 119] and overall lower extremity function.[9] For the shoulder, the

Disability of the Arm Shoulder and Hand scale (DASH)[77] and Shoulder Pain and Disability Index (SPADI)[60] have received high ratings for their clinimetric properties and are recommended for evaluative purposes in outpatient clinics.[10] The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC)[6] is a highly regarded and widely used self-report measure of physical function in individuals with hip osteoarthritis.[111] The Oxford Knee Score (OKS)[22] has proven to be reliable, valid, and responsive to change in patients with osteoarthritis of the knee[102] and the Knee Injury and Osteoarthritis Outcome Score (KOOS)[119] has demonstrated reliability, validity, and responsiveness in evaluating the course of knee injury and treatment outcome. The Lower Extremity Functional Scale (LEFS)[9] measures lower-extremity function across a broad range of lower-limb disabilities and conditions and has demonstrated to be a valid and reliable tool in detecting changes over time.[66, 135, 149] However, with regards to the ankle, there is no widely accepted outcome measurement tool to evaluate ankle function.[56]

2.3.1 Ankle Questionnaires

The prevalence of ankle instability has been reported with estimates of approximately 40% of individuals who suffered an initial ankle injury will continue to report ankle dysfunction.[109, 129] However, there is a lack of an accepted outcome measurement tools available to measure ankle function.[56] There are two types of self-reported outcome measures, discriminative and evaluative.[83] Discriminative questionnaires can be used to assess individuals with a particular disorder, for example functional ankle instability, whereas evaluative questionnaires are used to measure a patient's change in status over time.[83] Two examples of discriminative questionnaires are the Ankle Instability Instrument (AII) and the Cumberland Ankle Instability Tool (CAIT).[18] The Ankle Joint Functional Assessment Tool (AJFAT) and the

Functional Ankle Disability Index (FADI) are examples of evaluative questionnaires.[18] These four FAI questionnaires are commonly used in research studies to differentiate between subjects with and without FAI.

2.3.2 Foot and Ankle Disability Index

2.3.2.1 Overview

The Foot and Ankle Disability Index (FADI) questionnaire is provided in Appendix A. The FADI was designed to assess functional limitations related to foot and ankle conditions and is an anatomically specific self-report of function with two components.[112] The first component (FADI) assesses activities of daily living, whereas the second component (FADI-Sport) assesses more difficult tasks that are essential to physical activity.[112] The FADI consists of 26 questions with 104 total points and the FADI-Sport has eight questions with 32 total points, each is scored as a percentage of the total points possible. For each question subjects select the most appropriate response describing their condition. Responses to choose from include: no difficulty at all (4 points), slight difficulty (3 points), moderate difficulty (2 points), extreme difficulty (1 point), and unable to do (0 points). McKeon et al.[94, 96] are the only authors to report cutoff scores for determining FAI in subjects using these questionnaires. A score of less than or equal to 90% on the FADI and a score of less than or equal to 75% on the FADI-Sport indicates a subject has FAI.

2.3.2.2 Reliability and Validity

Reliability and sensitivity of the FADI and FADI-Sport in subjects with CAI has been reported to have moderate to good reliability.[56] Reliability was determined by having fifty subjects complete the FADI and FADI-Sport questionnaires on three separate test sessions, week one, week two, and week seven. Subjects were included if they reported a history of ankle sprain with pain and/or limping for more than one day, chronic weakness, pain, or instability that they attributed to the initial injury, and giving way in the last six months. Intraclass correlation coefficients (ICCs) were calculated by comparing weeks one and two and weeks one and seven. The FADI had an ICC of 0.89 and the FADI-Sport had an ICC of 0.84 when comparing week one and week two. The ICCs improved when comparing week one and week seven. The ICC's for the FADI were 0.93 and the FADI-Sport was 0.92.

The FADI has been suggested to have content validity.[36] The initial development of the FADI had six steps: 1) defining the purpose of the instrument, 2) item generation, 3) initial item reduction, 4) index construction, 5) final item reduction, and 6) reliability and validity testing.[92] However, only steps one through four were completed, the proposed methods for steps five and six were presented. Twenty-nine members of the APTA's Foot and Ankle Special Interest Group judged the content of the FADI which at the time contained 77 questions. Each judge was asked to rate each question on a score ranging from -2 (not important) to +2 (very important), only questions with a mean score of 1 or above were kept. Lastly, to ensure the FADI was user-friendly field testing was conducted with 20 participants. Final item reduction and validity testing were not reported by the authors.

2.3.2.3 Clinical Measures

Hale and Hertel[56] examined the ability of the FADI to differentiate between healthy subjects and subjects with CAI as well as its ability to detect changes in function in those with CAI after rehabilitation. Those with CAI reported lower FADI-Sport scores compared to FADI scores, suggesting the FADI-Sport may be more sensitive in detecting impairments associated with CAI. In subjects without FAI no differences were seen in FADI scores or FADI-Sport scores between extremities suggesting the FADI-Sport is more sensitive at detecting deficits but is also more responsive to change following a rehabilitation program than the FADI, making it a more practical questionnaire for use among physically active individuals. The accuracy of these questionnaires as diagnostic tools for determining if subjects do or do not have CAI was not examined. Subjects were included in the CAI group based on the inclusion criteria of the study and not from the FADI and FADI-Sport questionnaires. Therefore, the study was investigating if the questionnaires were sensitive enough to detect a functional difference as well as to detect changes over time between a CAI and a non-CAI group.[56]

Hale et al.[57] demonstrated subjects without CAI reported greater functional ability on the FADI and FADI-Sport then those with CAI. Also, no differences were seen between subjects with and without CAI for the uninvolved limb. Both the FADI and FADI-Sport were able to detect deficits in the involved limb versus the uninvolved limb in subjects with CAI and were also able to show improvements following a four week rehabilitation program. McKeon et al.[96] demonstrated no significant differences between pre-test measures for the FADI and FADI-Sport in a CAI group. It was also demonstrated FADI and FADI-Sport scores improved following a balance training program in subjects with CAI.[96]

2.3.3 Ankle Instability Index

2.3.3.1 Overview

The Ankle Instability Instrument (AII) questionnaire is provided in Appendix B. The AII was developed by Docherty et al.[33] and consists of 12 questions that are answered in a “yes” or “no” format. The 12 questions can be divided into three categories: severity of initial ankle sprain, history of ankle instability, and instability during activities of daily living. The AII is designed to assess individuals with FAI and is considered to be a discriminative questionnaire and therefore, should be able to accurately identify individuals with FAI. Numerous studies[37, 70, 96] have utilized the AII to determine group membership of subjects into either a control group or FAI group; each of the studies arbitrarily selected the number of responses needing to be answered "yes" in order to be classified as having FAI. Without a quantifiable cutoff score more research is needed to determine how many "yes" responses are needed to accurately discriminate between individuals with and without FAI.

2.3.3.2 Reliability and Validity

Test-retest reliability was evaluated using ICC's for each question, each category, and the total score on the AII between test days one and two. A total of 101 healthy college students volunteered for the study. Subjects included 73 with a history of ankle sprains and 28 without a history of ankle sprains. Of those with a history of ankle sprains, 38 had sprained both ankles, for these subjects both ankles were included for analysis. The ICC's for each question ranged from as low as 0.70 to as high as 0.98. The severity of ankle sprain category had an ICC of 0.93, history of ankle instability had an ICC of 0.89 and the last category instability during activities of daily living had an ICC of 0.85. The overall instrument ICC was 0.95 and had a SEM of 1.85.[33] The AII reliability study had a number of limitations. The first being a limited number of subjects, although it did meet the minimum standard of subject-to-variable ratio.[33] Another limitation was the failure to mention how the scoring related to FAI, for example, how many answers needed to be answered "yes" to be classified as having FAI.

The AII has demonstrated to possess content validity.[33] Development of the AII began with reviewing foot and ankle literature which resulted in an initial instrument of 21 questions.

Questionnaire content was also established by consulting with a general medical physician, an orthopedic surgeon, and several other health care providers such as physical therapists and athletic trainers. The expertise of these individuals in the area of foot and ankle research was not disclosed. Exploratory factor analysis was conducted on all 21 questions with the expectation that the factors would represent the subcomponents of FAI and when combined would represent the entire presence of FAI.[33] The initial 21 questions were reduced to 12 questions that were then divided into three categories: severity of ankle sprain, history of ankle sprain, and instability during activities of daily life.

2.3.3.3 Clinical Measures

Fox et al.[37] examined eccentric ankle torque during inversion, eversion, plantar-flexion, and dorsiflexion movements in a FAI and control group. The study utilized the AII questionnaire to determine which group subjects were allocated too. A KinCom III isokinetic dynamometer was used to test the movements with a test speed of 90 degrees a second for all ranges of motion. A statistically significant deficit in plantar-flexion torque was detected in subjects with FAI when compared to a matched ankle in the control group.

McKeon et al.[96] investigated the effects of balance training on function and postural control in subjects with CAI. Subjects were included in the CAI group if they answered four or more “yes” responses on the AII as well as achieving a score of 90% or less on the FADI and FADI-Sport questionnaire. Once subjects were classified as having CAI they were randomly divided into two groups, a balance training group and a control group. Those in the balance training group underwent 12 balance training sessions during a four week period and the control group was allowed to continue with their normal level of activity prior to enrollment in the study for the duration of the four weeks. Subjects completed the FADI and FADI-Sport questionnaires before and after the four week balance training program. Following the completion of the balance training program subjects reported a significant improvement in the FADI and FADI-Sport scores, whereas the control group remained the same.

2.3.4 Ankle Joint Functional Assessment Tool

2.3.4.1 Overview

The Ankle Joint Functional Assessment Tool (AJFAT) questionnaire is provided in Appendix C. The AJFAT was developed in a study examining balance training for individuals with FAI.[127] The AJFAT consists of 12 questions which were based on assessment tools utilized for evaluating the functional level of the knee.[127] For each question there are five possible choices to select from and are based on comparison to the contralateral ankle. Each possible answer has a score ranging from 0 to 4, with a higher score representing less functional instability with a total of 48 points possible. The first study using AJFAT[127] the mean score for the FAI group was 17.11 ± 3.44 and 22.92 ± 5.22 for the non-injured group, Tukey post hoc analysis determined this to be statistically significant. Other studies have used scores ranging from 17 to 26 to classify subjects as having FAI.[122, 124-127] The AJFAT has demonstrated the ability to detect changes in both a FAI and control group following a balance training program; the scores improved in the FAI group from 17.11 ± 3.44 to 25.78 ± 3.80 and the control group improved from 22.92 ± 5.22 to 29.15 ± 5.27.[127]

2.3.4.2 Reliability and Validity

Reliability for this questionnaire has been established, however, validity has yet to be established. The AJFAT has demonstrated high test-retest reliability based on piloting data with an ICC of 0.94, and precision with a SEM of 1.5.[124] However, no subject demographics or ankle injury history were disclosed for those in the pilot data, therefore, caution should be used when interpreting its reliability.

2.3.4.3 Clinical Measures

Ross et al.[124] demonstrated the total score on the AJFAT was able to accurately identify functional limitations in 100% of participants with FAI. Subjects were included in the FAI group if they reported a history of one ankle sprain followed by at least three days of immobilization, reported a minimum of two ankle sprains and two episodes of "giving-way" during physical activity after the initial sprain. All subjects, FAI and control, completed the AJFAT questionnaire. The authors suggest AJFAT scores can be used to identify functional limitations associated with FAI and a score of equal to or less than 26 indicates subjects as having some degree of functional limitations. A single-leg jump-landing test was utilized which required subjects to jump a distance of 70 cm and a height of 50 % of their vertical jump max, land on one leg on a force plate, and stabilize as quickly as possible. The anterior-posterior and medial-lateral ground reaction forces were combined to form a resultant vector (RV). Time to stabilization was then calculated for the RV. The AJFAT was shown to be more accurate at discriminating between a group with FAI and controls than the RV time to stabilization did. The total score on the AJFAT accurately identified functional limitations in 100% of the subjects with FAI; RV time to stabilization was able to identify functional limitations in FAI subjects but, not as accurately as AJFAT. The total score on the AJFAT in the control group was 22.37 ± 1.15 and 32.87 ± 3.90 in the FAI group. Resultant vector time to stabilization in the control group was 1.5 ± 0.32 and 1.8 ± 0.53 in the FAI group. Receiver operating characteristics (ROC) curves and area under curve (AUC) were calculated for both the AJFAT and RV time to stabilization. The AUC score for the AJFAT was 1.0 and 0.72 for RV time to stabilization. The investigators reported (AUC) scores of 0.90 to 1.0 is considered excellent, 0.80 to 0.89 are good, and 0.70 to 0.79 is fair, therefore, AJFAT outperformed the RV time to stabilization.

Ross, Guskiewicz, and Yu[126] examined time to stabilization in subjects with FAI and controls to determine if those with FAI take longer to return to stabilization. Subjects in the FAI group were matched to a control subject based on height, mass, age, sex, and test leg. All subjects completed the AJFAT, those with FAI had a mean score of 17 ± 4 and those without FAI had a mean score of 26 ± 4. Time to stabilization was calculated following a jump landing task which required subjects to stand 70 cm away from a force plate, jump forward with both feet, touch a marker positioned 50% of their maximum vertical jump, land on a force plate with only the test limb, and to stabilize as quickly as possible for 20 seconds. Time to stabilization was worse in subjects with FAI compared to controls suggesting FAI may have impaired their ability to stabilize following a jump landing task.

Ross and Guskiewicz[123] examined the effects of coordination training with and without stochastic resonance stimulation on dynamic postural stability. A total of 60 subjects, 30 with and 30 without FAI, participated in the study. All subjects completed the AJFAT, no cutoff scores were presented to determine FAI or control, however; the mean score on the AJFAT for the FAI group was 15.5 ± 4.63. The subjects were then split into three groups: conventional coordination training (CCC), stochastic resonance stimulation coordination training (SCT), and a control group. Those in the CCC and SCT groups completed six weeks of coordination training in which they trained five days a week for ten minutes each day. Dynamic postural stability was assessed by having subjects perform a jump-landing task. Subjects were positioned 70 cm away from a force plate, performed a two footed jump forward, touched a marker positioned 50% of their maximum vertical jump, landed on a force plate, and stabilized for 20 seconds. Time to stabilization was then calculated. Subjects completed the jump-landing task at the end of each week. Time to stabilization in the anterior-posterior direction improved after only two weeks of CCT and medial-lateral time to stabilization improved after four weeks of CCT. Those in the SCT group had slightly better improvements than the CCT group, although not statistically significant.

2.3.5 Cumberland Ankle Instability Tool

2.3.5.1 Overview

The Cumberland Ankle Instability Tool (CAIT) questionnaire is provided in Appendix D. The CAIT is different from other questionnaires in several ways. First, the CAIT does not require comparison with the contralateral ankle and secondly, concurrent, construct, and discriminative validity has been reported for the CAIT. The CAIT consists of nine questions with a total of 30 points possible, lower scores indicate more severe functional ankle instability.[66] A score of less than or equal to 27 indicates a subject has FAI, whereas a score of 28 or higher indicates no FAI.[23, 66]

2.3.5.2 Reliability and Validity

Test-retest reliability was evaluated by having 18 subjects complete the questionnaire for both ankles, resulting in 36 responses, on two separate occasions two weeks apart. Of the 18 subjects, eight did not have a previous ankle sprain, five had a history of unilateral ankle sprain, and five had a history of bilateral ankle sprain. The CAIT had excellent reliability with an ICC of 0.96.[66]

The authors who developed the Cumberland Ankle Instability Tool (CAIT) questionnaire report it has concurrent, construct, and discriminative validity.[66] Concurrent validity is tested by comparing a scale against the criterion standard for the condition being tested. The scale in this case is the CAIT questionnaire and the condition being tested is FAI. Currently, there is no criterion standard for FAI. Therefore, the authors compared the CAIT questionnaire to the Lower Extremity Functional Scale as well as to the visual analog scale because they have been reported to be reliable and valid. However, the Lower Extremity Functional Scale and the visual analog scale have not been used in previous studies examining FAI and therefore, may not be appropriate to use to establish validity for a questionnaire examining FAI.

Construct validity can be defined as the extent to which a test measures a theoretical construct or trait.[11] According to Bowman et al.[11] to determine construct validity a researcher compares results using the target measure with expected results based on theory. Construct validity for the CAIT questionnaire was established by using Rasch analysis. Hiller et al.[66] report Rasch analysis converts ordinal data to interval data and creates a hierarchy, in this case least stable to most stable, that is applied to each question and person. The Rasch analysis uses a goodness-of-fit statistic for each question and person allowing researchers to examine the proportion of people whose data meet the Rasch assumption, the assumption being people with greater ankle stability will be more likely to receive higher CAIT scores then those with less ankle stability.[66] The goodness-of-fit statistic indicates how well the CAIT questions conform to the assumptions of the Rasch model.[66] Portney and Watkins[110] report one part of construct validity is content validity; one must be able to define the content universe that represents that construct to develop a test to measure it. Content validity is the degree to which elements of an assessment questionnaire are relevant and representative of the targeted concept for a particular assessment purpose.[59] Although the CAIT questionnaire underwent concurrent validity testing it was not tested for content validity.

Discriminative validity for the CAIT questionnaire was established by determining if the CAIT could discriminate between subjects with and without FAI. The first step in establishing discriminative validity was to determine the cutoff score that best differentiated between subjects with and without ankle sprains. The authors used a history of ankle sprains as the discriminative measure. They proposed those without ankle sprains would score at the top of the scale and those with ankle sprains would score at the bottom of the scale. One potential problem of using history of ankle sprains as the discriminative measure is they never accounted for the cause of the ankle sprains, the severity of the ankle sprains, or the length of perceived symptoms. The cuffoff scores were determined by finding the score that yielded the maximum Youden Index and was confirmed by using a receiver operative curve.

2.3.5.3 Clinical Measures

Hiller et al.[66] were the first to report on the association between CAIT scores and FAI. Subjects were classified as having FAI if they had a score of 27 or less, a score of 28 or higher indicated they did not have FAI. Hiller et al.[66] reported these cutoff scores were determined by finding the score that yielded the maximum Youden index which is calculated as sensitivity (%) plus specificity (%) divided by 100. Also, a receiver operating curve was used to confirm the cutoff point. Other studies have used different scores to determine FAI. For instance, Hiller et al.[67] and Sawkins et al.[131] used scores less than or equal to 24 to determine FAI, no explanation was provided for using these scores as cutoffs.

A study investigating the relationship between FAI and postural control utilized the CAIT questionnaire to determine whether subjects were assigned to the FAI or control group.[23] The average CAIT score for the FAI subjects was 19.9 ± 5.8.[23] Postural control was assessed by having subjects hop down from a 16 cm high step onto a force plate and calculating time to stabilization. The authors correlated the CAIT scores against the time-to-stabilization and found no correlation existed. The investigators hypothesized this may have occurred because FAI was defined only by the CAIT score and did not take into account the time since the last ankle sprain and only two items on the CAIT questionnaire are relevant to postural stability.[23]

2.4 POSTURAL STABILITY

Riemann, Guskiewicz and Shields[116] describe postural stability as the process of coordinating corrective movement strategies and movements at the selected joints to remain in postural equilibrium. Johannson and Magnusson[80] defined postural equilibrium as the balanced state of forces and moments acting on the center of gravity resulting in minimal motion. Aspects of neuromuscular control can be quantified through measures of postural stability, which can be measured either statically or dynamically. Static postural stability is the ability to maintain the center of mass over a base of support with minimal movement, conversely, dynamic postural stability is the ability to maintain the center of mass over a base of support that is moving.[15, 52] Traditionally postural stability was measured during quiet stance, however, these measures have received scrutiny and more recent investigations have incorporated the use of dynamic tasks to evaluate postural stability. It has been suggested static measures of postural stability may not be indicative of dynamic postural stability and dynamic measures are viewed as being more applicable to functional activity and a better indicator of functional activity.[69] Sell et al.[133] compared static postural stability to dynamic postural stability and found low correlations between the two measures exist. Postural stability deficits have consistently been reported in subjects following an acute ankle sprain. In regards to those suffering from FAI, discrepancies are found in the literature if postural stability deficits exist, especially during static tasks. The contradictory findings in the literature may be due to differences in instrumentation, protocol, or FAI subject inclusion criteria.[115]

2.4.1 Static Postural Stability

The literature is split on whether static postural stability deficits exist in subjects with FAI.[57, 125] Static postural stability was initially measured using center of pressure (COP) based measures such as COP standard deviation, COP mean excursion, COP maximum excursion, total COP excursion, COP velocity, and COP area.[125] Karlsson and Frykberg[82] believe these kinds of measures have limited usefulness due to their lack of ability to determine whether a value for a subject falls within the range for a particular diagnostic group. Also, COP based measures to assess postural stability have failed to yield consistent findings when assessing subjects with FAI which lead researchers to develop more sophisticated measurements.

Another approach to quantify static postural stability is to examine the ground reaction forces in the anterior-posterior, medial-lateral and vertical directions. Ross et al.[125] demonstrated medial/lateral ground reaction force standard deviation as being more accurate than COP based measures in discriminating between a group of FAI and a control group; anterior/posterior ground reaction force standard deviation was also shown to be highly reliable. They concluded medial/lateral ground reaction force standard deviation is the preferred measurement to use when assessing static balance.

2.4.2 Dynamic Postural Stability

Dynamic postural stability has become the preferred measurement to evaluate postural stability in physically active subjects with FAI because these tasks are believed to stress the sensorimotor system more so than static balance and is thought to mimic sporting activities.[15, 139, 146] When investigating FAI postural stability deficits, de Noronha et al.[23] suggested hop-landing tasks should be utilized because they mimic the high-velocity and high-impact movements seen during athletic activities. Wikstrom et al.[139] compared a step down task and a single-leg jump-landing task and suggested the single-leg jump-landing task should be utilized when using FAI subjects because it produced the highest ground reaction forces which most closely resemble sporting activities. There are two predominant ways to quantify dynamic postural stability, time to stabilization (TTS) and dynamic postural stability index (DPSI).

Time to stabilization is a measure of dynamic stabilization that analyzes ground reaction forces in three directions, anterior-posterior, medial-lateral, and vertical during the time a subject is returning to a static state following either a dynamic task or an external perturbation to the body, and assesses the time it takes for ground reaction forces to return to a stable range.[15, 122, 126] Time to stabilization is unique, as it provides separate measures of dynamic postural stability in the frontal and sagittal planes.[124] According to Ross and Guskiewicz[120, 126] the first step in calculating TTS is to define the range of variation of a given ground reaction force component; range of variation is defined as the smallest absolute range value of a ground reaction force component during the last 10 seconds of the single-leg stance portion of a jump-landing task. To put it in other words, TTS indicates when the ground reaction force range of variation following a single-leg jump landing resembles the ground reaction force range of variation at the beginning of the test.[126]

Numerous studies have consistently shown subjects with FAI take significantly longer than controls to stabilize following a single-leg jump-landing task.[122, 125, 139] All of the studies utilized the same single-leg jump-landing protocol that required subjects to stand 70 cm away from a force plate, jump up 50% of their maximum vertical jump height, land on a force plate, and stabilize for 20 seconds.

A relatively new measure of dynamic postural stability has been developed, the dynamic postural stability index (DPSI). The DPSI is similar to TTS in that they both indicate how well a subject can dissipate ground reaction forces from a jump landing. Wikstrom et al.[140] describes the DPSI as a measure of motor control for the lower extremity and is dependent on proprioceptive feedback as well as reflexive, preprogrammed, and voluntary muscle responses. Unlike TTS which only indicates how well a subject performed for the three different force directions, DPSI provides a score for each of the three directional indices: anterior/posterior, medial/lateral, and vertical but also provides a common measure among the three force directions.[140, 146] Wikstrom et al.[146] demonstrated a sampling interval of three seconds should be used because it most closely mimics functional activities. The DPSI has been shown to be a more reliable and precise measurement than TTS during a single-leg jump task with an ICC of 0.96 and a SEM of 0.03.[146] According to Wikstrom et al.[146] the biggest difference between TTS and DPSI is the time component with time to stabilization providing time based directional changes and DPSI providing directional and global measures, therefore, the two measures can be used for answering different clinical questions.

Dynamic postural stability index has been used in numerous studies examining a variety of factors such as subjects with FAI and potential deficits in dynamic postural stability,[140] effects of prophylactic ankle stabilizers in subjects with FAI,[137] if gender and limb dominance affect dynamic postural stability,[143] as well as if static and dynamic measures of postural stability correlate.[133]

Dynamic postural stability deficits were detected in a group of individuals suffering from FAI when compared to controls.[140] The DPSI was used to quantify postural stability. Subjects were instructed to jump in an anterior-posterior direction, reach up and touch a marker positioned 50% of their maximum vertical jump height, land on a force plate with only the test leg, and to stabilize as quickly as possible. Those with FAI had higher, worse, anterior/posterior and vertical stability indices and composite DPSI scores indicating they have worse dynamic postural stability compared to controls.[140]

The effects of prophylactic ankle braces on DPSI scores were examined in a group of subjects with FAI.[137] The inclusion criteria for FAI consisted of sensations of weakness and episodes of "giving way" during daily activity. Also, subjects were free from mechanical instability which was assessed via the anterior drawer and talar tilt orthopedic tests which were performed by a certified athletic trainer. Subjects were positioned 70 cm from the center of the force plate and were instructed to jump forward, touch a marker positioned 50% of their maximum vertical jump height, and to land on a force plate. A soft and a semi-rigid prophylactic ankle brace were compared to not wearing an ankle brace. Dynamic postural stability did not improve while wearing a prophylactic ankle brace when compared to not wearing a brace.

Dynamic postural stability index was used by Wikstrom et al.[143] to examine gender and limb dominance in healthy individuals. The study had two purposes. The first purpose was to observe if gender and limb dominance affect DPSI scores; the second purpose was to assess the reliability of DPSI. Both legs were tested for each subject. The testing procedures required subjects to stand 70 cm away from a force plate, jump up 50% of their maximum vertical jump height, and to land on a force plate with only the test leg. The reliability for DPSI was shown to be excellent, 0.96. The results also demonstrated females displayed higher dynamic postural stability in the vertical direction as well as having a higher DPSI composite score. However, limb dominance was not statistically significant.

Static postural stability was compared to dynamic postural stability to determine if a relationship exists between the two measures.[133] Static postural stability was assessed using a single-leg balance tasks during eyes open and eyes closed trials. Dynamic postural stability was assessed during an anterior-posterior jump and a medial-lateral jump. For the anterior-posterior jump subjects were positioned 40% of their body height from a force plate and were instructed to jump forward over a 12 inch hurdle and to land on only the dominant leg on the center of a force plate. During the medial-lateral jump subjects were positioned 33% of their body height from a force plate and were instructed to jump laterally over a six inch hurdle and to land on only the dominant leg on the center of a force plate. Dynamic postural stability was calculated by using the DPSI. The results revealed no correlation existed between static and dynamic measures of postural stability.

2.5 METHODOLOGICAL CONSIDERATIONS

2.5.1 Jump-Landing Task

There are two jump-landing protocols that have been used previously when calculating DPSI scores; one standardizes jump height[137, 140, 143, 146] while the other standardizes jump distance.[133] The first study using DPSI incorporated a jump landing protocol that required subjects to stand 70 cm away from the center of the force plate, jump forward with both legs and touch a marker overhead that was positioned approximately 50% of the subjects maximum vertical jump height before landing on the force plate with only the test leg, stabilize as quickly as possible, and balance for 10 seconds with hands on their hips while looking straight ahead.[146] The DPSI possesses high reliability between test sessions with an ICC of 0.96 as well as being very precise (SEM of 0.03).

Sell et al.[133] modified the original jump landing protocol to standardize the jump distance rather than the jump height as well as incorporating a medial/lateral jump. For the anterior-posterior jump protocol, subjects were positioned 40% of their body height from the edge of the force plate and a 30 cm hurdle was placed at the midpoint between the starting position and the force plate. Subjects were required to jump forward with both legs, clearing the hurdle, and to land on the force plate with only the test leg, stabilize as quickly as possible, and balance for 10 seconds with hands on their hips while looking forward. Their protocol also utilized a medial-lateral jump in which subjects were positioned 33% of their body height away from the edge of the force plate. A 15 cm hurdle was placed at the midpoint between the starting position and the force plate. The lateral jump direction was determined by the subject's dominant foot. Subjects jumped laterally with both feet, cleared the hurdle, and landed on only the test leg, stabilized as quickly as possible, placed hands on hips, and looked straight ahead for 10 seconds. The DPSI in the anterior-posterior direction had an ICC of 0.86 and a SEM of 0.01, the DPSI in the medial-lateral direction had an ICC of 0.92 and a SEM of 0.01.

2.5.2 Dynamic Postural Stability Index Calculation

The DPSI is a composite score that is composed of three stability indices in the anterior-posterior, medial-lateral, and vertical directions. According to Wikstrom et al.[146] the indices are mean square deviations assessing fluctuations around a zero point as opposed to standard deviations assessing fluctuations around a group mean. Data is typically collected for 10 seconds and can then be reduced to five and three second post landing time frames; a sampling interval of three seconds is recommended as this most closely resembles athletic performance[146] and is most commonly reported.[133, 137, 139, 143] The original DPSI formulas used the square root of the number of samples as the denominator; the modified formulas instead use the number of samples as the denominator.[137, 146] The modified formulas make it possible to calculate the average magnitude of the ground reaction force vector around zero points in the anterior-posterior, medial-lateral, and vertical directions of the force plate.[137]

2.5.3 Static Postural Stability

There are a variety of protocols established to evaluate single-leg static postural stability.[47, 48, 96, 122, 125, 133] The main difference between the protocols is the length of testing and when to discard trials. Goldie et al.[47] protocol initially used a test duration of 15 seconds, however, this proved to be to challenging during eyes closed single-leg stance and instead recommended using a five second test duration.[48] Other authors have used 10[96, 133] and 20[122, 125] second test trials. The second difference between protocols is when to discard trials. Goldie et al.[47, 48] and Sell et al.[133] discarded trials when subjects touched down with the non-stance leg off of the force plate, if the touchdown occurred on the force plate the trial was kept. According to Goldie et al.[48] the effect of a touchdown on the force-platform contributes to the force-platform measures in a manner consistent with using the variability of the signal to quantify steadiness. Other investigators[96, 122, 125] discarded trials if a touch down occurred, regardless if it occurred on the force plate or the ground.

2.6 SUMMARY

The feeling of the ankle "giving way" after an initial ankle sprain and repetitive bouts of ankle sprains has been termed chronic ankle instability.[62] Recurrent ankle sprains are frequent with estimates as high as 73% in an athletic population.[46, 148] Chronic ankle instability has traditionally been attributed to mechanical and functional insufficiencies.[62] Functional ankle instability is the occurrence of repetitive ankle instability and feeling of joint instability which may be caused by insufficiencies in proprioception, neuromuscular control, postural stability, or strength.[61, 62]

The patient's perspective has received more attention within the healthcare industry as it has been argued to be the most important criterion for judging the effectiveness of treatment.[36, 107] Instruments such as questionnaires are suitable tools for assessing functional limitations and disabilities. Numerous questionnaires have been developed to assess function in those with CAI, however, no widely accepted outcome measurement tool is available to measure ankle function.[56]

Individuals with FAI have consistently displayed dynamic postural stability deficits.[122, 125, 137, 139, 140] Functional ankle instability questionnaires should be able to detect postural stability deficits in individuals with FAI. Understanding which FAI questionnaire is able to detect postural stability deficits will be beneficial for both researchers and clinicians. This information will be useful for researchers who use questionnaires as part of their inclusion/exclusion criteria for FAI subjects as well as for rehabilitation specialists who treat these individuals.

3.0 MATERIALS AND METHODS

3.1 EXPERIMENTAL DESIGN

The primary purpose of this study was to compare static and dynamic measures of postural stability between a group of self-reported functional ankle instability and a healthy control group as well as to determine if a relationship exists between FAI questionnaire scores and static and dynamic measures of postural stability in subjects with FAI. A series of Pearson correlation coefficients and independent samples t-tests were utilized. Ground reaction forces and dynamic postural stability index were measured for each subject while performing a static and dynamic task. The dependent and independent variables in this study include:

3.1.1 Dependent Variables

- Anterior/posterior and medial/lateral ground reaction force standard deviations during a single-leg static balance task
- Dynamic postural stability index for the single-leg jump landings in the anterior and lateral jump directions
- FAI questionnaires scores

3.1.2 Independent Variables

- Functional ankle instability condition

3.2 SUBJECTS

A total of 24 physically active male subjects, 12 with functional ankle instability and 12 healthy controls, between the ages of 18-35 years were recruited to participate in this study. Physically active was operationally defined as engaging in physical activity for a minimum of 30 minutes three times a week. Each subject was informed of the methods, risks, and benefits of this study. Upon voluntary consent subjects were asked to sign an informed consent to participate form, as approved by the University of Pittsburgh Institutional Review Board. All testing procedures were performed at the Neuromuscular Research Laboratory. Subjects reported for a single test session lasting approximately 90 minutes. Eligibility was determined by the following inclusion/exclusion criteria:

3.2.1 Inclusion Criteria

3.2.1.1 Non-FAI Subjects

- Males between the ages of 18-35
- Physically active at least 3 times per week
- No previous ankle sprains on dominant leg
- No sensations of ankle “giving way” with weight-bearing activities on dominant leg

3.2.1.2 FAI Subjects

- Males between the ages of 18-35
- Physically active at least 3 times per week
- History of an inversion ankle sprain injury
- Report at least one additional ankle sprain on the same leg during physical activity after initial injury
- Report episodes of ankle "giving way" or feeling "unstable" on the same leg within the previous year
- With each ankle sprain subjects displayed signs and symptoms of an acute injury (pain, loss of function, mild point tenderness, swelling, and/or abnormal range of motion)

3.2.2 Exclusion Criteria

- Currently displaying acute signs and symptoms of an ankle injury
- Lower extremity surgery or fracture
- Bilateral ankle instability
- Currently enrolled in a lower extremity rehabilitation program
- Ankle sprains within the previous month
- Head injuries (such as concussions) within the previous three months
- Any disorders that could affect equilibrium or neuromuscular control

3.3 POWER ANALYSIS

A cross-sectional study design was utilized in which two groups of individuals were used, those with FAI and healthy controls. The FAI condition was known for each subject prior to testing; subjects were assigned to the FAI or healthy control group based on the inclusion criteria employed by this study. To determine the appropriate sample size an independent samples t-test was performed using data from a previous study.[141] In order to achieve a power level of 80% at the statistical level of 0.05 a total of 12 subjects with FAI were needed (Table 1). Therefore, 12 subjects with FAI and 12 healthy controls were recruited to participate in this study.

Table 1. Power Analysis

Power	Alpha	N
0.95	0.05	19
0.90	0.05	15
0.80	0.05	12

3.4 SUBJECT RECRUITMENT

Subjects were recruited by means of posting flyers throughout local universities and recreational clubs. Potential subjects contacted the Neuromuscular Research Laboratory (NMRL) to schedule a test session.

3.5 INSTRUMENTATION

3.5.1 FAI Questionnaires

Four ankle questionnaires were used in this study to measure functional ankle instability. This study utilized the Functional Ankle Disability Index, Ankle Instability Instrument, Ankle Joint Functional Assessment Tool, and the Cumberland Ankle Instability Tool. Each questionnaire was scored according to their specific guidelines.

3.5.1.1 Functional Ankle Disability Index

The Functional Ankle Disability Index (FADI) contains two components; one assesses activities of daily living (FADI) and the other assessing tasks that are deemed essential to sporting activities (FADI-Sport). The FADI consists of 26 questions, whereas the FADI-Sport contains only eight questions. Subjects select the response that most closely resembles their condition within the past week. Each question is scored from 0 to 4 points: 4 points (no difficulty at all), 3 points (slight difficulty), 2 points (moderate difficulty), 1 point (extreme difficulty), and 0 points (unable to do). The maximum score for the FADI is 104 and 32 points for the FADI-Sport. Higher scores indicate greater perceived levels of functional stability. A score of less than or equal to 90% on the FADI and a score of less than or equal to 75% on the FADI-Sport were used to indicate a subject has FAI.[94, 96] Intraclass correlation coefficients (ICC) have been reported for both the FADI and FADI-Sport ranging from 0.89-0.93 and 0.84-0.92, respectively.[56]

3.5.1.2 Ankle Instability Instrument

The Ankle Instability Instrument (AII) consists of 12 questions which are answered in a "yes" or "no" format. The 12 questions can be divided into three categories: severity of ankle sprain, history of ankle sprain, and instability during activities of daily living. Those with more "yes" responses are perceived as having greater levels of functional instability. A cut-off score has not been established for this questionnaire, however, a score of four or more "yes" responses has been used to indicate a subject has FAI.[96] Reliability for this questionnaire has been established with an ICC score of 0.95.[33]

3.5.1.3 Ankle Joint Functional Assessment Tool

The Ankle Joint Functional Assessment Tool (AJFAT) was developed based on assessment tools used to evaluate the functional level of the knee and consists of 12 questions. Each question has five possible choices to select from with point values ranging from zero to four. The questions are based on comparison to the contralateral ankle: 4 points (much less), 3 points (slightly less), 2 points (equal), 1 point (slightly more), and 0 points (much more). There is a total of 48 points possible with higher scores representing a greater perceived functional ability. A score of 21 or less was used to classify subjects as having FAI.[127] The AJFAT has reported high reliability with an ICC of 0.94.[127]

3.5.1.4 Cumberland Ankle Instability Tool

The Cumberland Ankle Instability Tool (CAIT) is a 12 item questionnaire. Each item contains three to five potential responses. The questions cover a range of topics such as postural stability, pain, giving way, and the feeling of being unstable while on various surfaces. All the items are summed together for a total score with 30 points possible. Higher scores represent a greater perceived level of functional stability. A score of 27 or less was used to indicate subjects have FAI.[66] The CAIT has reported high reliability with an ICC of 0.96.[66]

3.5.2 Force Plate

A Kistler (Kistler 9286A, Amherst, NY) force plate was used to collect ground reaction force data to assess static and dynamic measures of postural stability. A sampling frequency of 1200 Hz was utilized for both the static and dynamic tasks. Force plate data was passed through an amplifier and analog to digital board (DT3010, Digital Translation, Marlboro, MA) and stored on a personal computer. A custom MATLAB (v7.0.4, Natick, MA) script was used to process the ground reaction force data.

3.6 PROCEDURES

3.6.1 Screening Procedures

All subjects reported to the Neuromuscular Research Laboratory for a single test session lasting approximately 90 minutes and were required to sign an informed consent to participate form as approved by the University of Pittsburgh Institutional Review Board. The inclusion and exclusion criteria were reviewed to determine eligibility for the study. A certified athletic trainer (ATC) tested each subject's ankle laxity by performing the anterior drawer orthopedic test to determine mechanical instability.[124, 125, 137] The testing procedures and grading system proposed by Ryan[128] was used to quantify ankle joint laxity. The anterior drawer test was performed with subjects supine and the knee flexed to 60 degrees to reduce gastrocnemius muscle tension. The amount of movement occurring at the talocrural joint was determined by palpating the talus and the malleoli, using the thumb and index finger on the lateral and medial aspects, respectively. The grading of the movements was: 1) Very hypomobile, 2) Slightly to moderately hypomobile, 3) Normal, 4) Slightly to moderately hypermobile, 5) Very hypermobile.[128] Subjects were considered mechanically unstable if the ankle was graded very hypermobile or if the ankle receives a grade of at least two grades greater than the stable ankle.

3.6.2 FAI Questionnaires

Subjects were asked to complete four FAI questionnaires and the order in which they are presented was randomized. Each questionnaire has slightly different instructions on how to complete the questionnaire and these instructions were explained to each subject before they began. The test administrator was present to answer any questions subjects had regarding the questionnaires.

3.6.3 Testing Procedures

3.6.3.1 Static Balance Testing

Static postural stability was assessed using two static balance tasks: eyes open (EO) and eyes closed (EC). The static postural stability assessment followed similar testing procedures published in the literature.[47, 48, 133] Subjects began the test session by balancing on a single-leg and placing their hands on their hips. Subjects in the FAI group balanced on the limb with FAI while those in the control group balanced on their dominant limb. The dominant limb was determined as the preferred kicking leg. Subjects were instructed to remain as motionless as possible while standing erect on their test leg on a force plate. Testing was done first with E) and then with EC. Subjects were instructed to place their hands on their hips and their non-weight bearing leg slightly flexed at the hip and knee as to bring the foot up to the height of approximately 15 cm from the ground. The weight-bearing leg is to be slightly flexed at the knee, and the foot should be in a neutral toe in/out position with the tips of their toes pointing straight ahead. A piece of black electrical tape was placed on the force plate to indicate foot placement. Five 10 second trials were collected for both the EO and EC conditions with the first three trials for each condition averaged and used for analyses. Subjects were given 30 seconds of rest between each trial. Subjects were asked to repeat trials if a touch down occured off the force plate, removed hands from hips for longer than five seconds, the non-weight-bearing leg came in contact the weight-bearing leg, or hopped on the weight-bearing leg. Subjects were instructed to remain as still as possible during testing and to correct their position as quickly as possible if a disturbance occurs. Trials will not be discarded if a subject touched down with the non-weight-bearing leg so long as the touchdown occurred on the force plate and they immediately resumed the one-legged stance as quickly as possible

3.6.3.2 Dynamic Postural Stability Test

Subjects were tested on a single-leg jump landing test that has previously been used in an article that is in review and has demonstrated good intersession reliability.[133] The single-leg jump landing protocol is a modified protocol previously used by Ross and Wikstrom.[121, 122, 124-126, 137, 140] The protocol used in the current study normalized the jump distance according to body height, whereas Ross[121, 122, 124-126] and Wikstrom[137, 140] normalized the vertical jump height according to the subjects maximum vertical jump height. The single-leg jump landing test required subjects to complete two separate jumps, one in the anterior-posterior direction and one in the medial-lateral direction. For the anterior single-leg jump landing test subjects were positioned 40% of their body height away from the edge of a force plate. A 30 cm hurdle was placed at the midpoint between the starting position and the force plate. Subjects were instructed to jump in the anterior direction using a two-footed jump over the 30 cm hurdle and to land on the force plate on only the test leg, stabilize as quickly as possible, place their hands on their hips, and balance for 10 seconds while looking straight ahead. A total of five successful trials were collected and the first three trials were averaged for analyses.

For the lateral jump subjects were positioned 33% of their body height away from the edge of a force plate. A 15 cm hurdle was placed halfway between the starting position and the force plate. The lateral jump direction was determined by either the presence of FAI or the dominant limb. For example, a subject with FAI in their right ankle was instructed to the jump laterally to the right side. Subjects were asked to jump in a lateral direction, to the side with the FAI condition or the dominant limb, using a two-footed jump over a 15 cm hurdle, and onto a force plate. Subjects were to land on the test leg only, stabilize as quickly as possible, place their hands on their hips, and balance for 10 seconds while looking straight ahead. Five successful trials were collected and the first three trails were averaged for analyses.

Trials were discarded and repeated if subjects failed to jump over or came in contact with the hurdle, hopped on the test leg after landing, the non-weight-bearing leg touched down off of the force place, or removed hands from their hips for longer than five seconds. Trials were not discarded if a subject touched down with the non-weight-bearing leg so long as the touch down occurred on the force plate and they resumed the one-legged stance as quickly as possible. Subjects were given a two minute rest period between each jump to prevent fatigue.

3.6.4 Kinetic Data Reduction

A custom MATLAB script (v7.0.4 Natick, MA) was used to process the ground reaction force data for the static single-leg balance test as well as for calculating the dynamic postural stability index for the single-leg jump landing test. Ground reaction force data was passed through a zero-lag 4th order low pass Butterworth filter with a frequency cutoff of 20 Hz.[23, 133] For the single-leg balance trials, ground reaction force standard deviations in the anterior-posterior, medial-lateral, and vertical direction were calculated for each 10 second trial. For each subject, three trials were averaged and used for final analyses. Dynamic postural stability index (DPSI) is a composite of the anterior-poster, medial-lateral and vertical ground reaction forces.[146]

DPSI Composite $=\left(\frac{\sqrt{\Sigma(0-x)^2+\Sigma(0-y)^2+\Sigma(body\ weight-z)^2}}{number\ of\ data\ points}\right) \div$ body weight

Vertical stability index $= \frac{\sqrt{\Sigma(body\ weight-z)^2}}{number\ of\ data\ points}$

Anterior-posterior stability index $= \frac{\sqrt{\Sigma(0-y)^2}}{number\ of\ data\ points}$

Medial-lateral stability index $= \frac{\sqrt{\Sigma(0-x)^2}}{number\ of\ data\ points}$

The DPSI was calculated by using the first three seconds of the ground reaction forces immediately after initial contact. Wikstrom et al.[146] have utilized this method of calculating DPSI in the past and demonstrated good reliability, 0.96. Initial contact was operationally defined as when the vertical ground reaction force exceeded 5% of the subject’s body weight. Each subject had a total of three trials which were averaged and used for final analyses.

3.7 DATA ANALYSIS

Demographic variables (age, height, weight and laxity) were compared using independent samples t-tests. Normality was assessed for all variables, if normality was violated the corresponding non-parametric test was utilized. An α-level of 0.05 was set *a priori* for all statistical analyses. All variables were compared utilizing SPSS (v13.0, SPSS Inc, Chicago IL) in the following manner:

Specific Aim 1: To compare static and dynamic measures of postural stability between a group of self-reported functional ankle instability and a healthy control group.

Independent samples t-tests were performed to compare static and dynamic measures of postural stability between FAI and healthy controls. It was hypothesized that no difference in static measures of postural stability will be present between the FAI and healthy control group; dynamic measures of postural stability will be greater (worse) in the FAI than the healthy control group.

Specific Aim 2: To compare functional ankle instability questionnaire scores between a group of self-reported functional ankle instability and a healthy control group

Independent samples t-tests were performed to compare functional ankle instability questionnaires between FAI and healthy controls. It was hypothesized that there will be a difference in functional ankle instability questionnaires between groups with the FAI group demonstrating worse questionnaire scores.

Specific Aim 3: To identify the relationship between functional ankle instability questionnaires and measures of static and dynamic postural control in recreationally active subjects with self-reported functional ankle instability.

A series of Pearson correlation coefficients were computed to determine if a relationship exists between functional ankle instability questionnaires and measures of static and dynamic postural stability. Interpretation of correlation results followed Domholdt's suggestion[34]: 0-0.25 *little if any correlation*, 0.26-0.49 *fair correlation,* 0.50-0.69 *moderate correlation,* 0.70-0.89 *high correlation*, ≥90 *very high correlation*. It was hypothesized that a *little if any* to *fair* correlation will exist between functional ankle instability questionnaires and measures of static and dynamic postural stability.

4.0 RESULTS

The primary purpose of this study was to compare static and dynamic measures of postural stability between a group of self-reported functional ankle instability (FAI) and a healthy control group. The secondary purpose was to determine if a relationship exists between FAI questionnaire scores and static and dynamic measures of postural stability in subjects with FAI. Static postural stability was assessed during eyes open and eyes closed single-leg stance. Single-leg jump landing tasks in the anterior and lateral directions were utilized to assess dynamic postural stability. Additionally, the Functional Ankle Disability Index, Ankle Instability Instrument, Ankle Joint Functional Assessment Tool, and the Cumberland Ankle Instability Tool were utilized to quantify functional ankle instability. The dependent variables were medial/lateral and anterior/posterior ground reaction force standard deviations during single-leg stance, the dynamic postural stability index during anterior and lateral jumps and FAI ankle questionnaire scores. The independent variable was FAI condition. Independent samples t-tests were utilized to make comparisons between FAI and healthy controls for demographic, postural stability and questionnaire variables. A series of Pearson correlation coefficients were used to identify the relationship between ankle questionnaires and measures of static and dynamic postural stability.

4.1 NORMALITY

The following variables were not normally distributed: medial lateral stability index during lateral jump, medial lateral stability index during anterior jump, anterior posterior stability index during anterior jump, and eyes open medial/lateral ground reaction force standard deviation. Therefore, the corresponding non-parametric tests were utilized for these variables.

4.2 DEMOGRAPHICS

A total of twenty-four, (FAI: N=12; Control: N=12), recreationally active subjects participated in this study. The demographics for the participants are presented in Table 2. Individual subject demographics are provided in Appendix E. Ankle joint laxity, as assessed by the anterior drawer orthopedic test, demonstrated those with FAI had a greater level of ankle laxity compared to healthy controls ($p < 0.001$). There were no significant group differences for age, height, and weight.

Table 2. Subject Demographics (Mean ± SD)

	Control	FAI	p-value
Age (years)	22.15 ± 1.10	21.45 ± 1.40	0.548
Height (cm)	178.64 ± 6.59	182.17 ± 5.74	0.176
Weight (kg)	77.94 ± 8.74	84.95 ± 7.83	0.060
Ankle Laxity*	3.00 ± 0.00	3.83 ± 0.58	<0.001

*Statistically significant between groups ($p < 0.05$)

4.3 POSTURAL STABILITY

Postural stability data are presented in Table 3. Individual subject scores and box plots for static and dynamic postural stability are provided in Appendix F-G. The FAI group demonstrated significantly worse (higher) scores in the eyes closed medial/lateral ground reaction force standard deviation ($p = 0.021$), anterior jump vertical stability index ($p = 0.003$) and DPSI ($p = 0.004$), and lateral jump vertical stability index ($p = 0.029$) and DPSI ($p = 0.025$). No significant group differences were found for static postural stability during eyes open and eyes closed anterior/posterior ground reaction force standard deviation. Additionally, no significant group differences were found for the medial lateral stability index and anterior posterior stability index for both the anterior and lateral jump landings.

Table 3. Postural Stability Scores (Mean ± SD)

	Control	FAI	p-value
Eyes Open			
ML GRF SD	3.22 ± 0.70	3.13 ± 1.33	0.843
AP GRF SD	2.98 ± 0.85	2.69 ± 0.50	0.326
Eyes Closed			
ML GRF SD*	8.73 ± 2.01	11.45 ± 3.19	0.021
AP GRF SD	6.21 ± 1.28	6.93 ± 1.32	0.189
Anterior Jump			
MLSI	0.03 ± 0.01	0.03 ± 0.01	0.185
APSI	0.14 ± 0.01	0.14 ± 0.01	0.828
VSI*	0.33 ± 0.04	0.37 ± 0.03	0.003
DPSI*	0.35 ± 0.04	0.40 ± 0.03	0.004
Lateral Jump			
MLSI	0.12 ± 0.01	0.13 ± 0.01	0.164
APSI	0.03 ± 0.01	0.04 ± 0.01	0.327
VSI*	0.31 ± 0.60	0.35 ± 0.03	0.029
DPSI*	0.33 ± 0.05	0.37 ± 0.03	0.025

* Significantly different between groups ($p < 0.05$)

Higher Scores represent worse postural stability

ML GRF SD = Medial/lateral Ground Reaction Force Standard Deviation

AP GRF SD = Anterior/Posterior Ground Reaction Force Standard Deviation

MLSI = Medial Lateral Stability Index

APSI = Anterior Posterior Stability Index

VSI = Vertical Stability Index

DPSI = Compositre Score

4.4 ANKLE QUESTIONNAIRE SCORES

All questionnaire scores for FAI and healthy control are presented in Table 4. Individual subject scores and box plots for FAI ankle questionnaires are provided in Appendix H. The FAI group demonstrated significantly worse (greater level of functional instability) scores for the Functional Ankle Disability Index-Sport ($p = 0.015$), Ankle Instability Instrument ($p < 0.001$), Ankle Joint Functional Assessment Tool (p < 0.001), and Cumberland Ankle Instability Tool (p < 0.001). No significant group difference was found for the Functional Ankle Instability Index (p = 0.687) questionnaire.

Table 4. Ankle Questionnaire Scores (Mean ± SD)

	Control	FAI	p-value
FADIǂ	99.91 ± 3.89	94.58 ± 5.94	0.687
FADI-Sǂ*	94.23 ± 3.21	87.00 ± 14.10	0.015
AII§*	0.00 ± 0.00	4.33 ± 1.61	<0.001
AJFATǂ*	26.18 ± 0.41	17.67 ± 4.21	<0.001
CAITǂ*	29.63 ± 0.81	23.00 ± 3.84	<0.001

*Statistically significant between groups (p < 0.05)
ǂ Higher scores indicate less perceived symptoms
§ Higher scores indicate greater perceived symptoms
FADI = Functional Ankle Disability Index
FADI-S = Functinal Ankle Disability Index - Sport
AII = Ankle Instability Instrument
AJFAT = Ankle Joint Functional Assessment Tool
CAIT = Cumberland Ankle Instability Tool

4.5 POSTURAL STABILITY AND ANKLE QUESTIONNAIRE CORRELATIONS

All correlations between postural stability variables and ankle questionnaires for the FAI subjects are presented in Tables 5-9. Interpretation of correlation results followed Domholdt's suggestion[34]: 0-0.25 *little if any correlation*, 0.26-0.49 *fair correlation*, 0.50-0.69 *moderate correlation*, 0.70-0.89 *high correlation*, ≥90 *very high correlation*. The correlations between ankle questionnaires and static postural stability measures during eyes open and eyes closed conditions were non-significant with positive and negative correlations ranging from *little if any* to *fair.* A statistically significant positive *moderate* correlation was observed between the Ankle

Joint Functional Assessment Tool and the lateral jump medial lateral stability index (p = 0.035, *r* = 0.6116,) as well as between the Cumberland Ankle Instability Tool and lateral jump medial lateral stability index (p = 0.006, *r* = 0.7349). Non-significant correlations ranging from *little if any* to *fair* were observed between the ankle questionnaires and the DPSI scores for both the anterior and lateral jump landing, with p-values ranging from 0.127 to 0.261 and 0.646 to 0.996, respectively. Additionally, non-significant correlations ranging from *little if any* to *fair* were observed between ankle questionnaires and the medial lateral stability index, anterior posterior stability index, and vertical stability index during the anterior and lateral jump landings.

Table 5. FADI Correlation with Postural Stability (*r*)

	FADI	p-value	95% CI	
Eyes Open				
ML GRF SD	-0.1499	0.642	-0.666	0.463
AP GRF SD	0.1679	0.602	-0.449	0.676
Eyes Closed				
ML GRF SD	-0.4605	0.132	-0.818	0.154
AP GRF SD	0.0767	0.813	-0.520	0.623
Anterior Jump				
MLSI	-0.2004	0.532	-0.694	0.422
APSI	0.0598	0.854	-0.532	0.612
VSI	0.4355	0.157	-0.184	0.807
DPSI	0.4282	0.165	-0.193	0.804
Lateral Jump				
MLSI	0.3093	0.328	-0.321	0.750
APSI	-0.3198	0.311	-0.755	0.311
VSI	0.1257	0.697	-0.483	0.652
DPSI	0.1481	0.646	-0.465	0.665

*Statistically significant correlation ($p < 0.05$)

FADI = Functional Ankle Disability Index

ML GRF SD = Medial/Lateral Ground Reaction Force Standard Deviation

AP GRF SD = Anterior/Posterior Ground Reaction Force Standard Deviation

MLSI = Medial Lateral Stability Index

APSI = Anterior Posterior Stability Index

VSI = Vertical Stability Index

DPSI = Composite score

Table 6. FADI-S Correlation with Postural Stability (*r*)

	FADI-S	p-value	95% CI	
Eyes Open				
ML GRF SD	-0.2243	0.4833	-0.707	0.401
AP GRF SD	0.0037	0.9910	-0.571	0.576
Eyes Closed				
ML GRF SD	-0.4170	0.1775	-0.799	0.206
AP GRF SD	-0.1028	0.7505	-0.639	0.500
Anterior Jump				
MLSI	-0.3180	0.3137	-0.754	0.313
APSI	-0.1343	0.6774	-0.657	0.476
VSI	0.3784	0.2251	-0.249	0.782
DPSI	0.3747	0.2031	-0.253	0.780
Lateral Jump				
MLSI	0.4170	0.1775	-0.206	0.799
APSI	-0.1573	0.6254	-0.670	0.457
VSI	0.1160	0.7197	-0.490	0.646
DPSI	0.1459	0.6508	-0.459	0.669

*Statistically significant correlation ($p < 0.05$)

FADI-S = Functional Ankle Disability Index - Sport

ML GRF SD = Medial/Lateral Ground Reaction Force Standard Deviation

AP GRF SD = Anterior/Posterior Ground Reaction Force Standard Deviation

MLSI = Medial Lateral Stability Index

APSI = Anterior Posterior Stability Index

VSI = Vertical Stability Index

DPSI = Composite score

Table 7. AII Correlation with Postural Stability (*r*)

	AII	p-value	95% CI	
Eyes Open				
ML GRF SD	0.1790	0.578	-0.440	0.682
AP GRF SD	-0.0341	0.916	-0.596	0.550
Eyes Closed				
ML GRF SD	-0.0357	0.912	-0.597	0.549
AP GRF SD	-0.0882	0.785	-0.630	0.511
Anterior Jump				
MLSI	0.0214	0.947	-0.559	0.588
APSI	-0.1500	0.642	-0.666	0.463
VSI	-0.3936	0.206	-0.789	0.232
DPSI	-0.4130	0.182	-0.797	0.210
Lateral Jump				
MLSI	-0.2358	0.461	-0.713	0.391
APSI	0.3513	0.263	-0.769	0.278
VSI	-0.0717	0.825	-0.620	0.523
DPSI	-0.0753	0.816	-0.622	0.521

*Statistically significant correlation ($p < 0.05$)

AII = Ankle Instability Instrument

ML GRF SD = Medial/Lateral Ground Reaction Force Standard Deviation

AP GRF SD = Anterior/Posterior Ground Reaction Force Standard Deviation

MLSI = Medial Lateral Stability Index

APSI = Anterior Posterior Stability Index

VSI = Vertical Stability Index

DPSI = Composite score

Table 8. AJFAT Correlation with Postural Stability (*r*)

	AJFAT	p-value	95% CI	
Eyes Open				
ML GRF SD	-0.1873	0.560	-0.687	0.433
AP GRF SD	-0.0526	0.871	-0.608	0.537
Eyes Closed				
ML GRF SD	-0.3269	0.300	-0.758	0.304
AP GRF SD	-0.3492	0.266	-0.768	0.281
Anterior Jump				
MLSI	0.0010	0.001	-0.574	0.573
APSI	0.2355	0.461	-0.713	0.391
VSI	0.4407	0.152	-0.809	0.178
DPSI	0.4662	0.127	-0.820	0.147
Lateral Jump				
MLSI	0.6116*	0.035	0.059	0.877
APSI	-0.3003	0.343	-0.745	0.330
VSI	0.0707	0.827	-0.524	0.619
DPSI	0.1036	0.749	-0.500	0.639

*Statistically significant correlation ($p < 0.05$)

AJFAT = Ankle Joint Funcitonal Assessment Tool

ML GRF SD = Medial/Lateral Ground Reaction Force Standard Deviation

AP GRF SD = Anterior/Posterior Ground Reaction Force Standard Deviation

MLSI = Medial Lateral Stability Index

APSI = Anterior Posterior Stability Index

VSI = Vertical Stability Index

DPSI = Composite score

Table 9. CAIT Correlation with Postural Stability (*r*)

	CAIT	p-value	95% CI	
Eyes Open				
ML GRF SD	-0.3980	0.200	-0.791	0.227
AP GRF SD	-0.0529	0.870	-0.608	0.537
Eyes Closed				
ML GRF SD	-0.4772	0.117	-0.825	0.133
AP GRF SD	-0.3303	0.294	0.760	0.300
Anterior Jump				
MLSI	-0.3018	0.341	-0.746	0.329
APSI	0.3474	0.269	-0.282	0.768
VSI	0.3176	0.314	-0.313	0.754
DPSI	0.3528	0.261	-0.277	0.770
Lateral Jump				
MLSI	0.7349*	0.006	0.279	0.920
APSI	-0.3783	0.225	-0.782	0.249
VSI	-0.0610	0.851	-0.613	0.531
DPSI	0.0018	0.996	-0.585	0.561

*Statistically significant correlation ($p < 0.05$)

CAIT = Cumberland Ankle Instability Tool

ML GRF SD = Medial/Lateral Ground Reaction Force Standard Deviation

AP GRF SD = Anterior/Posterior Ground Reaction Force Standard Deviation

MLSI = Medial Lateral Stability Index

APSI = Anterior Posterior Stability Index

VSI = Vertical Stability Index

DPSI = Composite score

5.0 DISCUSSION

The primary purpose of this study was to compare static and dynamic measures of postural stability between subjects with self-reported FAI and healthy controls. The secondary purpose of this study was to investigate the relationship between ankle questionnaires and static and dynamic measures of postural stability in subjects with FAI. The dependent variables were anterior/posterior and medial/lateral ground reaction force standard deviations during static single-leg stance, the dynamic postural stability index during anterior and lateral jump landings and the FAI ankle questionnaire scores. The independent variable was FAI condition. It was hypothesized that static measures of postural stability will be homogenous between groups and dynamic measures of postural stability will be greater (worse) in the FAI than the healthy control group. Additionally, it was hypothesized that *little if any* to *fair* correlations would exist between ankle questionnaires and measures of static and dynamic postural stability in FAI subjects.

5.1 POSTURAL STABILITY

5.1.1 Static Postural Stability

In the current study, the FAI group demonstrated higher (worse) balance scores during eyes closed single-leg stance than the FAI group. Specifically, the medial/lateral ground reaction force standard deviation was significantly different between groups. Conversely, the FAI group demonstrated lower (better) balance scores during eyes open single-leg stance than the healthy control group, although not significantly different. The results in the current study suggest that eyes closed single-stance is able to detect differences between FAI and healthy controls; whereas eyes open single-leg stance was unable to detect differences between groups which is consistent with previous investigations.[57, 75] In the current study, no significant difference was noted between groups for the anterior/posterior and medial/lateral ground reaction force standard deviation during eyes closed single-leg stance. The results of the current study support our hypothesis except for the significant difference in medial/lateral ground reaction force standard deviation during eyes closed single-leg stance.

Little consensus exists in the literature regarding static postural stability deficits in FAI subjects.[1] The finding of medial/lateral ground reaction force standard deviation deficit in FAI subjects was not surprising as Ross et al.[125] demonstrated the medial/lateral ground reaction force standard deviation as being more accurate than center of pressure based measures as well as time to stabilization measures in discriminating between subjects with FAI and a healthy control group. Furthermore, several studies[47, 49] have identified the medial/lateral ground reaction force standard deviation as being a good predictor of single-leg balance deficits in those who have suffered inversion ankle sprains. The anterior/posterior ground reaction force standard deviation during eyes closed single-leg stance has only been reported in healthy subjects, [47, 48] thus, comparisons are limited. The healthy controls in the current study had anterior/posterior ground reaction force standard deviations during eyes closed single-leg stance similar to those previous reported in the literature.[47, 48] In the current study, no significant differences were demonstrated between groups for the medial/lateral and anterior/posterior ground reaction force standard deviation during eyes open single-stance. It has been proposed that eyes open single-leg stance may not be challenging to the postural control system making this test inadequate in detecting differences between individuals with FAI and healthy controls.[115] Goldie et al.[49] also failed to detect a difference in anterior/posterior ground reaction force standard deviation during eyes open single-leg stance in individuals with a history of inversion ankle sprains compared to those with stable ankles. Additionally, Ross et al.[122] did not detect a difference in anterior/posterior and medial/lateral mean sway during eyes open single-leg stance between FAI and a control group. Conversely, Ross et al.[125] demonstrated differences in the anterior/posterior and medial/lateral ground reaction force standard deviation during eyes open single-leg stance between FAI and healthy controls. Additionally, Goldie et al.[49] demonstrated significant differences in medial/lateral ground reaction force standard deviation during eyes open single-leg stance between individuals with a history of inversion ankle sprains and stable ankles.

The investigations that reported differences[49, 125] in the anterior/posterior and medial/lateral ground reaction force standard deviation during eyes open single-leg stance required subjects to maintain single-leg stance for 20 seconds, whereas the current study required subjects to maintain single-leg stance for 10 seconds. Functional ankle instability subjects are more prone to touching down during single-leg stance than healthy controls,[25, 79] therefore, a longer test duration would allow for more touchdowns to occur on the force plate which would increase the ground reaction force standard deviation in FAI subjects. The finding of medial/lateral ground reaction force standard deviation deficits during eyes closed single-leg stance was not surprising as ankle sprains occur in the frontal plane. The deficit in medial/lateral ground reaction force standard deviation in FAI subjects may be attributable to laxity or damage to the anterior talofibular ligament (ATFL). Bahr et al.[3] demonstrated that when the foot is in plantar-flexion, the ATFL becomes parallel with the long axis of the fibula functioning as the main collateral ligament. Additionally, the majority of ankle sprains occur during plantar-flexion[20, 104, 147] and the ATFL would be the first ligament to be injured[3] and has the lowest load to failure rate.[20, 104] The FAI subjects in the current study support this claim as the average FAI laxity score indicated increased laxity, hypermobility.

5.1.2 Dynamic Postural Stability

The FAI group demonstrated significantly worse dynamic postural stability as compared to the control group during the anterior and lateral jumps. Specifically, the FAI group demonstrated significantly greater (worse) vertical stability index and DPSI scores than the healthy control group in both jump directions indicating FAI subjects are not as efficient at dissipating ground reaction forces as healthy controls. However, the FAI subjects in the current study demonstrated equal ability as the healthy controls to control ground reaction forces in the anterior/posterior and medial/lateral directions. Conversely, no differences in anterior posterior stability index or medial lateral stability index during either jump direction were observed. The findings in the current study partially support our hypothesis as there were significant differences between groups for the vertical stability index and DPSI during both jump directions with the FAI group demonstrating worse dynamic postural stability. Our hypothesis was not supported in that no difference was demonstrated between groups for the anterior posterior stability index and medial lateral stability index during both jump directions.

The finding of significant differences between groups for the vertical stability index and DPSI scores are consistent with previous FAI studies that reported increased DPSI[14, 140, 141] and vertical stability index[14, 140] in FAI subjects as compared to healthy controls in anterior jumps.

Additionally, these findings are in alignment with previous studies reporting longer time to stabilization[13, 53, 91, 122, 125, 139] in FAI subjects during anterior single-leg jump landings.

The results from the current study may differ from previous research due to methodological differences in the jump landing protocol and a higher sampling rate. Previous research[140, 141] standardized the jump distance at 70cm and subjects were required to jump 50% of their maximum vertical leap, whereas the current study required subjects to jump forward 40% of their body height over a standardized 30cm hurdle. The single-leg jump landing protocol utilized in the current study was selected to minimize the equipment needed to be used in a clinical setting as well as for potential field testing. With regards to the sampling rate, previous research that used the same sampling rate as our study[14] did not demonstrate a difference in anterior posterior stability index, whereas research[140, 141] using a lower sampling rate demonstrated differences in anterior posterior stability index. Additionally, the values in the current study for the vertical stability index and DPSI for both the anterior and lateral jumps are consistent with the results reported by Brown et al.[14]

The findings in the lateral jump direction are similar to those observed in the anterior direction. Subjects with FAI demonstrated greater (worse) vertical stability index and DPSI scores indicating the FAI subjects are not as efficient at dissipating and controlling ground reaction forces as healthy controls. The results in the current study are supported by previous publications. Brown et al.[14] reported greater vertical stability and DPSI scores in CAI subjects during lateral jumps. A previous study[145] assessing the influence of jump direction on DPSI scores in uninjured individuals indicated that lateral jumps resulted in increased medial lateral stability index scores compared to an anterior jump. Similar findings were also reported in a CAI group.[14] The lateral jump direction was included in the current study as it has been hypothesized to be more challenging in the frontal plane, which may have implications for ankle sprains and thus FAI subjects.[145] Although an increase in the medial lateral stability index score was observed in the lateral jump compared to the anterior jump, there was no significant difference between groups.

Although the current investigation did not test for differences between jump directions, both the FAI and healthy controls demonstrated greater medial lateral stability index scores in the lateral jump compared to the anterior jump and greater anterior posterior stability index scores in the anterior jump compared to the lateral jump. These findings are supported by previous results in controls[145] and CAI.[14] Incorporating different jump directions into dynamic postural stability testing may be able to reveal differences in neuromuscular control that cannot be identified in an anterior jump.[14, 145] Thus, when evaluating dynamic postural stability in subjects with FAI it may be important to incorporate different jump directions in order to influence the different components (anterior posterior stability index, medial lateral stability index, and vertical stability index) of the DPSI.

5.2 QUESTIONNAIRE SCORES

5.2.1 Functional Ankle Disability Index

The FADI is designed to assess functional limitations of the foot and ankle. The first component (FADI) assesses activities of daily living, whereas the second component (FADI-Sport) assesses more difficult tasks that are essential to physical activity. The FADI consists of 26 questions with 104 total points and the FADI-Sport has eight questions with 32 total points.

Each questionnaire is scored as a percentage of the total points possible. Cutoff scores have been identified to determine the presence of FAI, with a score of less than or equal to 90% on the FADI and a score of less than or equal to 75% on the FADI-Sport indicating FAI.[94, 96]

In the current study, there was a significant difference between groups for the FADI-Sport, however, no significant difference was observed for the FADI. The healthy controls had an average score of 99% and the FAI group had an average score of 94.58% on the FADI. Using the cutoff of 90% to indicate the presence of FAI, the FADI questionnaire failed to classify the FAI subjects as a group as having FAI. The FADI was able to accurately classify 16.6% (2 out of 12 subjects) of the FAI subjects as having FAI. With regards to the FADI-Sport questionnaire, the healthy controls had an average of score of 94.23%, whereas FAI subjects had an average score of 87%. The FADI-Sport was able to accurately classify 16.6% (2 out of 12 subjects) of the FAI subjects as having FAI. In the current study the proposed cutoff score of 75% failed to classify the FAI subjects as a group as having FAI. Although our average FAI score for the FADI-Sport was above the suggested cutoff, a statistically significantly difference in the FADI-Sport scores was observed between the FAI group and the controls, with the FAI demonstrating a lower score (greater perceived symptoms of functional instability). The lack of a significant difference between groups for the FADI may be attributable to the questionnaire focusing primarily on activities of daily living which may not be sensitive enough to detect functional limitations in FAI subjects. The findings for the FADI and FADI-Sport questionnaires partially support our hypothesis in that the FAI group demonstrated significantly worse scores for the FADI-Sport than the healthy controls. Our hypothesis was not supported in that there were no significant differences in FADI scores between groups.

The FADI and FADI-Sport questionnaire has been utilized in numerous investigations. Similar to the findings in the current study, Brown et al.[12] observed scores of 93.75% and 77.52% for the FADI and FADI-Sport, respectively. Although, these FADI-Sport scores obtained were lower than in the current study, the scores were still above the proposed cutoffs of 90% and 75%. Additionally, Marshall et al.[91] observed averages scores above the proposed cutoffs, with average scores of 92.9% and 84.2% for the FADI and FADI-Sport, respectively. Furthermore, Wikstrom et al.[142] reported the highest scores for the FADI and FADI-Sport, with average scores of 95.2% and 92.9%, respectively.

Conversely, other investigators have reported scores equal to or below the proposed cutoff scores for the FADI and FADI-Sport. Drewes et al.[35] reported average scores of 81.7% on the FADI and 67.6% on the FADI-Sport. Other authors[51, 53, 54, 56, 57, 75, 97, 132] have reported average scores for the FADI ranging from 81.7% to 89.6% and for the FADI-Sport ranging from 67.6% to 80.31%.

5.2.2 Ankle Instability Instrument

The Ankle Instability Instrument (AII) is a discriminative questionnaire designed to identify individuals with FAI. The AII consists of 12 questions that are answered in a “yes/no” format. The questionnaire is designed around three categories: severity of initial ankle sprain, history of ankle instability, and instability during activities of daily living. The AII is scored by summing the number of “yes” responses, with a maximum score of nine: the more “yes” responses the greater the level of functionally instability. Currently, a quantifiable cutoff score has yet to be determined, making it difficult to classify someone as having FAI with this questionnaire.

A significant difference was demonstrated between groups for the AII with the FAI group demonstrating worse scores than the healthy controls. The average number of "yes" responses observed in this study was 4.33 for FAI subjects and 0 for healthy control subjects. The finding of FAI subjects having significantly worse scores for the AII questionnaire compared to the healthy controls supports our hypothesis. The results in the current study were similar to several other investigations[70, 97, 132] which required subjects to answer "yes" to a total of four questions to be classified as having FAI. Conversely, Drewes et al.[35] used the AII as part of the inclusion/exclusion criteria and reported FAI subjects had an average of 7.1 "yes" responses. One investigation[16] required subjects to answer "yes" to questions 1 and 4, as well as answering "yes" to at least one of questions 5 through 9 in order to be classified as FAI. Furthermore, several studies incorporated the AII as part of the inclusion/exclusion criteria but did not report the number of "yes" responses or the cutoff score utilized for the FAI subjects.[2, 37, 105]

5.2.3 Ankle Joint Functional Assessment Tool

The Ankle Joint Functional Assessment Tool (AJFAT) consists of 12 questions which ask subjects to compare their FAI ankle to the contralateral uninjured ankle. For each question there are a total of five possible options from which to choose. Higher scores represent better functional ability with a total of 48 points possible. No specific cutoff score has been reported in the literature; however, scores ranging from 17.11 to 26 have been used to classify subjects as having FAI.[124, 127]

A significant difference was demonstrated between groups for the AJFAT questionnaire with the FAI group having significantly worse scores compared to the healthy controls. In the current study, an average score of 17.67 was observed for FAI subjects, whereas healthy controls had an average score of 26.18. The finding of FAI subjects having worse AJFAT questionnaire scores than the healthy controls supports our hypothesis. The average score for FAI subjects in the current study supports results previously reported in FAI studies, with average scores ranging from 15.33 to 17.90.[122, 123, 126, 127, 141, 142] Several investigators[13, 98] selected a cutoff score of less than or equal to 20 but did not report the average AJFAT scores. Interestingly, Ross et al.[124] reversed the AJFAT grading system so that higher scores would represent greater functional instability and determined that the best cutoff score for discriminating between FAI and healthy controls was 26 and observed an average score of 32.87.

5.2.4 Cumberland Ankle Instability Tool

The Cumberland Ankle Instability Tool (CAIT) was designed to be able to accurately identify those with FAI and is different from the other aforementioned ankle questionnaires in that it does not require comparison with the contralateral (non-injured) ankle. The CAIT consists of nine questions, with a maximum total of 30 points: lower scores indicate more severe functional instability. A cutoff score of less than or equal to 27 indicates a subject has FAI.[66]

A significant difference was demonstrated between groups for the CAIT questionnaire with the FAI group having worse scores compared to the healthy controls. An average score of 23 was observed for FAI subjects in the current study, whereas the control group had an average score of 29.63. As a group the FAI subjects were correctly identified as having FAI based on the proposed cutoff. The CAIT was able to accurately classify 100% (12 out of 12 subjects) of the FAI subjects as having FAI. The finding of FAI subjects having worse CAIT questionnaire scores compared to the healthy controls supports our hypothesis. The average score for the FAI subjects is comparable to other studies using the CAIT, in which average scores ranged from

19.9 to 26.3.[21, 23, 29, 68] However, considerably lower average CAIT scores than what was observed in the current study have been reported previously, with average scores ranging from of 14.4 to 18.[24, 91, 131, 134] Also, one investigation[67] used a cutoff score of less than or equal to 24 to classify FAI but failed to report the average CAIT score.

5.3 ANKLE QUESTIONNAIRES AND POSTURAL STABILITY CORRELATIONS

Interpretation of correlation results followed Domholdt's suggestion[34]: 0-0.25 *little if any correlation*, 0.26-0.49 *fair correlation*, 0.50-0.69 *moderate correlation*, 0.70-0.89 *high correlation*, and ≥90 *very high correlation*.

5.3.1 Ankle Questionnaire Correlations with Static Postural Stability

None of the static postural stability measures were statistically significantly correlated with the ankle questionnaires with *little if any* to *fair* correlations ranging from -0.4605 to 0.1790. This finding supports our hypothesis of *little if any* to *fair* correlations between ankle questionnaires and measures of static postural stability. The eyes closed medial/lateral ground reaction force standard deviation demonstrated the highest correlation with the Functional Ankle Disability Index and the Cumberland Ankle Instability Tool, -0.4605 and -0.4772, respectively. However, these correlations are considered to be *fair*. The finding of the Functional Ankle Disability Index as having one of the highest correlations with static postural stability measures is interesting because the Functional Ankle Disability Index was one of the worst questionnaires at classifying FAI subjects as having FAI as it correctly identified only 16.6% (2 out of 12 subjects). Additionally, the finding of positive correlations between the anterior/posterior ground reaction force standard deviation, Functional Ankle Disability Index and Functional Ankle Disability Index-Sport was surprising. Higher scores for both the Functional Ankle Disability Index and Functional Ankle Disability Index-Sport represent less perceived symptoms of functional instability and higher anterior/posterior ground reaction force standard deviation scores indicate worse static postural stability. The positive correlation indicates that as Functional Ankle Disability Index and Functional Ankle Disability Index-Sport scores become higher (less perceived functional symptoms) the anterior/posterior ground reaction force standard deviation increases (worse static postural stability). A negative correlation was expected to be observed between these ankle questionnaires and static postural stability measures. The Ankle Instability Instrument demonstrated negative correlations with three of the four static postural stability measures. A positive correlation was expected to be observed with this questionnaire as higher scores for the Ankle Instability Instrument indicate greater perceived functional instability symptoms and higher static postural stability scores indicate better static postural stability.

Contrary to the results of the current study, Hubbard et al.[76] observed fair and moderate to good relationships between the Functional Ankle Disability Index and COP velocity and area during eyes open and closed single-leg stance tests. Furthermore, moderate to good relationships were observed between the Functional Ankle Disability Index-Sport and center-of-pressure velocity and area during eyes open and closed single-leg stance tests. The subject inclusion criteria and the static single-leg stance tasks were the same as the current study. The difference in correlations observed between studies is likely due to the measurement (center-of-pressure vs. ground reaction force standard deviation) used to quantify static postural stability. The correlations between ground reaction forces and center-of-pressure based measures have been reported to be relatively weak.[47] Additionally, it has been suggested that different force plate measures quantify different aspects of stance.[82]

5.3.2 Ankle Questionnaire Correlations with Dynamic Postural Stability

Several statistically significant positive correlations were observed between the ankle questionnaires and postural stability measures. Our hypothesis was partially supported as the majority of the correlations between ankle questionnaires and measures of dynamic postural stability were *little if any* to *fair*, however, several correlations were *moderate* and *high*. Specifically, a *moderate* correlation was observed between the medial/lateral stability index and Ankle Joint Functional Assessment Tool and a *high* correlation was observed between the medial/lateral stability index and the Cumberland Ankle Instability Tool during lateral jumps. For the anterior/posterior stability index, vertical stability index, and DPSI during the lateral jump demonstrated *little if any* to *fair* correlations with the ankle questionnaires and were not statistically significant. The result of the medial/lateral stability index having statistically significant correlations with the Ankle Joint Functional Assessment Tool and Cumberland Ankle Instability Tool are surprising because the medial/lateral stability index was not statistically significantly different between groups indicating this variable was poor at discriminating between FAI and healthy controls. Additionally, the correlations between the medial/lateral stability index, Ankle Joint Functional Assessment Tool and Cumberland Ankle Instability Tool were positive. This finding is interesting as higher scores for both the Ankle Joint Functional Assessment Tool and Cumberland Ankle Instability Tool represent less perceived symptoms of functional instability and higher medial/lateral stability index scores represent worse dynamic postural stability. Thus, a positive correlation indicates as Ankle Joint Functional Assessment

Tool and Cumberland Ankle Instability Tool scores become higher (less perceived symptoms of functional instability) the medial/lateral stability index scores become higher (worse dynamic postural stability). A negative correlation was expected to be observed between the Ankle Joint Functional Assessment Tool, Cumberland Ankle Instability Tool and medial/lateral stability index. Additionally, the lateral jump DPSI demonstrated positive correlations with the Functional Ankle Disability Index, Functional Ankle Disability Index-Sport, Ankle Joint Functional Assessment Tool and Cumberland Ankle Instability Tool. It was expected these correlations would be negative as higher ankle questionnaire scores represent less perceived functional instability symptoms and higher DPSI scores indicate worse dynamic postural stability.

With regards to the anterior jump none of the dynamic postural stability measures were statistically significantly correlated with the ankle questionnaires. The anterior jump DPSI demonstrated *fair* correlations with all ankle questionnaires, with correlation values ranging from -0.4130 to 0.4662. The anterior jump DPSI and the Ankle Joint Functional Assessment Tool questionnaire had the highest correlation value, 0.4662, but still demonstrate a *fair* correlation. A majority of the correlations between anterior jump dynamic postural stability and ankle questionnaires were positive which is surprising as negative correlations were expected because higher ankle questionnaire scores represent greater perceived functional instability symptoms and higher dynamic postural stability measures indicate worse dynamic postural stability.

The unexpected findings of positive correlations between many of the dynamic postural stability measures during both the anterior and lateral jumps and the ankle questionnaires may indicate these ankle questionnaires are poorly related to dynamic postural stability deficits in FAI subjects. Additionally, the sample size estimation used for the current study was based on previous DPSI data to detect DPSI differences between FAI and healthy controls. Thus, the sample size may lack sufficient power for correlations between postural stability measures and ankle questionnaires. This is the first study to investigate the correlations between ankle questionnaires and dynamic postural stability; therefore, comparisons cannot be made.

5.4 LAXITY

A significant difference in ankle laxity between groups was demonstrated in the current study, with the FAI group exhibiting greater ankle laxity. The anterior drawer orthopedic stress test was utilized to determine the extent of mechanical laxity by using the procedures outlined by Ryan.[128] The anterior drawer orthopedic stress test is a common clinical examination test to evaluate the integrity of the anterior talofibular ligament of the ankle by determining the amount of anterior talar displacement in the sagittal plane. However, the validity and sensitivity of the anterior drawer orthopedic stress test has been questioned.[38, 42, 64, 73, 75, 128, 136] Additionally, an *in vitro* study demonstrated poor correlations between the anterior drawer orthopedic stress test and the degree of ligamentous disruption.[42]

The average laxity score observed in FAI subjects was 3.8, indicating these subjects were slightly hypermobile. Previous investigations using the same procedures did not report the average laxity score for FAI subjects; thus, comparison of the average laxity score to other studies is not possible. Ryan[128] reported 24% of their FAI subjects also had concomitant ankle laxity. Similarly, Tropp et al.[136] observed 39% of their FAI population also demonstrated ankle laxity. Additionally, Ross et al.[124] utilized the same methodology but did not report the average laxity score or percentage of those with FAI also exhibiting ankle laxity.

Numerous causes of CAI have been reported in the literature,[62] with ligament laxity being identified as one potential cause.[64, 71, 73] Ankle laxity and functional instability can occur in isolation and were once considered to be distinct conditions; however, recently it has been proposed that FAI and ankle laxity are likely to occur concurrently.[62, 136] Scores of studies have examined talocrural joint laxity in subjects with CAI, resulting in little consensus as some investigators reported increased laxity[64, 73, 75, 90] while others failed to observe increased laxity.[38, 128, 136] The lack of consensus regarding ankle laxity may be explained by differences in methodology as some authors used manual stress tests while others utilized ankle arthrometers. Several investigations have assessed ankle laxity after an acute ankle sprain and reported that despite rehabilitation and training approximately 30% still displayed laxity up to a year after an initial ankle sprain.[19, 39, 85, 100] Hubbard et al.[73] demonstrated those with FAI also had associated ankle laxity.

5.5 LIMITATIONS

5.5.1 FAI inclusion/exclusion criteria

The criterion used to define FAI varies greatly across studies, potentially resulting in cohorts with different characteristics. Konradsen[84] highlighted this problem by suggesting there is no universally agreed upon definition of FAI. Additionally, there are no agreed upon requirements as to how many recurring ankle sprains, frequency of “giving way”, or severity of initial and subsequent ankle sprains.[84] Delahunt et al.[26] conducted a meta-analysis and discovered the most common inclusion criteria used in postural stability studies involving FAI subjects was a history/feeling/sensation of "giving way" of the foot/ankle. The sensation of the ankle "giving way" was part of the FAI inclusion criteria in the current study. The total number of ankle sprains was also highlighted as common inclusion criteria in studies.[26] The current study required subjects to have a minimum of two ankle sprains, which is consistent with other studies.[12, 13, 41, 43, 98, 99, 127, 136] Only a few studies required subjects to have three or more ankle sprains.[78, 128] Given the potential for varying degrees of FAI subjects, a larger sample size may have resulted in the ability to stratify the FAI subjects on a discriminant analysis.

5.5.2 Ankle laxity

Ankle joint laxity was assessed using the anterior drawer orthopedic manual stress test using the same methodology as previous studies.[124, 128, 136] Although a common clinical test, the reliability and validity of this test is greatly affected by the examiner's experience. Several authors have suggested that manual stress tests are inadequate to differentiate between specific ligament injuries.[4, 42, 130] Others have utilized portable ankle arthrometers to assess ankle joint laxity, which have been reported to be highly reliable with an ICC of 0.98 and a SEM of 89mm for anterior/posterior displacement and to be a valid tool for ankle ligamentous stability assessment.[74, 87] However, a consensus on the most effective methods of assessing ankle joint laxity has yet to be established in the literature.[8] Thus, due to the lack of consensus regarding assessing ankle joint laxity the anterior drawer orthopedic manual stress test employed in this study is an appropriate selection.

5.5.3 Jump height

The single-leg jump landing methodology applied in this study was new compared to other research studies with FAI subjects.[122, 124-126, 137-141, 143-146] Previous studies normalized the jump height, whereas this study normalized the jump distance. In order to control for jump height subjects were instructed to jump just high enough to clear the hurdle without coming in contact with it. There is a possibility that subjects did not jump the same height to clear the hurdle, with some jumping higher than others. An attempt was made to discard trials in which subjects jumped considerably higher than the hurdle.

5.6 CLINICAL SIGNIFICANCE

The results of the current study confirm that static and dynamic postural stability deficits exist in subjects with FAI. Deficits were noted in the medial/lateral ground reaction force standard deviation during eyes closed single-leg stance. The medial/lateral direction is the plane of motion in which lateral ankle sprains typically occur; thus, the current findings are not surprising. Additionally, deficits were observed in the vertical stability index and DPSI during the anterior and lateral jump tasks. Those with FAI landed with greater vertical force compared to their control counterparts and have overall worse dynamic postural stability. Treatment of FAI should address the specific postural stability deficits discovered in this study. Balance training should focus on improving the medial/lateral direction during static stance and dissipating ground reaction forces during jump landings.

The Functional Ankle Disability Index, Functional Ankle Disability Index-Sport, and Ankle Instability Index ankle questionnaires demonstrated little to fair relationships with postural stability measures. The Ankle Joint Functional Assessment Tool and Cumberland Ankle Instability Tool ankle questionnaires had a moderate to good relationship with one dynamic postural stability measure, medial lateral stability index during lateral jumps. These ankle questionnaires are inadequate for detecting deficits in static and dynamic postural stability in FAI subjects. Researchers and clinicians should use caution when using these ankle questionnaires to identify balance deficits in those with FAI.

5.7 FUTURE DIRECTIONS

Studies examining the relationship between ankle questionnaires and deficits commonly observed in FAI subjects are scarce; thus, future work is warranted. This is the second study to explore the relationship between ankle questionnaires and postural stability and the first to investigate the relationship with dynamic postural stability. Future studies should attempt to replicate the current methodology to confirm these results. This was the first study to utilize the Functional Ankle Disability Index and the Ankle Joint Functional Assessment Tool in a correlation study with FAI deficits: future work is needed to fully understand the relationship between these ankle questionnaires and FAI. Additionally, future studies should identify which questions in the questionnaires are best at identifying balance deficits in FAI subjects.

Future work should continue to explore postural stability deficits in FAI subjects. There is a lack of consensus regarding whether deficits exist in the anterior/posterior stability index as some investigators have reported deficits while others have not. Additionally, dynamic postural stability tests should continue to be developed. While multiple jump directions have been incorporated (anterior, medial, lateral, and diagonal), the jumps have all been unidirectional which does not replicate the movement patterns seen in many athletic activities. A rotational jump landing should be used in exploring postural stability deficits in FAI subjects as it is multidirectional and may reveal balance deficits that cannot be detected in unidirectional tasks. Furthermore, the development of postural stability tasks that can be conducted in a clinical setting that have the capability to reveal postural stability deficits in FAI subjects is warranted.

5.8 CONCLUSIONS

The findings of this research study demonstrate postural stability deficits exist in FAI subjects as compared to healthy controls. More specifically, deficits in medial/lateral ground reaction force standard deviation during eyes closed single-leg stance, vertical stability index and DPSI scores during the anterior and lateral jumps were observed in those with FAI. Additionally, a moderate to good relationship was observed between the Ankle Joint Functional Assessment Tool and the Cumberland Ankle Instability Tool questionnaires and the medial/lateral stability index during a lateral jump task. Conversely, little to fair relationships existed between the ankle questionnaires and the DPSI scores for both the anterior and lateral jump tasks.

APPENDIX A

[FUNCTIONAL ANKLE DISABILITY INDEX]

Foot and Ankle Disability Index and Food and Ankle Disability Index Sports Items

Foot and Ankle Disability Index Items	**Foot and Ankle Disability Index Sport Items**
Standing	Running
Walking on even ground	Jumping
Walking on even ground with shoes	Landing
Walking up hills	Squatting and stopping quickly
Walking down hills	Cutting, lateral movements
Going up stairs	Low-impact activities
Going down stairs	Ability to perform activity with your normal technique
Walking on uneven ground	Ability to participate in your desired sport as long as you would like
Stepping up and down curves	
Squatting	
Sleeping	
Coming up on your toes	
Walking initially	
Walking 5 minutes or less	
Walking approximately 10 minutes	
Walking 15 minutes or greater	
Home responsibilities	
Activities of daily living	
Personal care	
Light to moderate work (standing, walking)	
Heavy work (push/pulling, climbing, carrying)	
Recreational activities	
General level of pain	
Pain at rest	
Pain during your normal activity	
Pain first thing in the morning	

APPENDIX B

[ANKLE INSTABILITY INSTRUMENT]

Ankle Instability Instrument

Instructions

This form will be used to categorize your ankle instability. A separate form should be used for the right and left ankles. Please fill out the form completely. If you have any questions, please ask the administrator of the survey. Thank you for your participate.

1. Have you ever sprained your ankle?	☐ Yes	☐ No
2. Have you ever seen a doctor for an ankle sprain?	☐ Yes	☐ No
If yes, 2a. How did the doctor categorize your most serious ankle sprain? ☐ Mild (grade 1) ☐ Moderate (grade 2) ☐ Severe (grade 3)		
3. Did you ever use a device (such as crutches) because you could not bear weight due to an ankle sprain?	☐ Yes	☐ No
If yes, 3a. In the most serious case, how long did you need to use the device? ☐ 1-3 days ☐ 4-7 days ☐ 1-2 weeks ☐ 2-3 weeks ☐ >3 weeks		
4. Have you ever experienced a sensation of your ankle "giving way"?	Yes	No
If yes, 4a. When was the last time the ankle "gave way"? ☐ <1 months ☐ 1-6 months ago ☐ 6-12 months ago ☐ 1-2 years ago ☐ >2 years		
5. Does your ankle *ever feel* unstable while walking on a flat surface?	☐ Yes	☐ No
6. Does your ankle *ever feel* unstable while walking on uneven ground?	☐ Yes	☐ No
7. Does your ankle *ever feel* unstable during recreational or sport activity?	☐ Yes	☐ No
8. Does your ankle *ever feel* unstable while going *up* stairs?	☐ Yes	☐ No
9. Does your ankle *ever feel* unstable while going *down* stairs?	☐ Yes	☐ No

APPENDIX C

[FUNCTIONAL ANKLE DISABILITY INDEX]

Ankle Joint Functional Assessment Tool (AJFAT)

1. How would you describe your level of pain you experience in your ankle?

____ (4) Much less than the other ankle
____ (3) Slightly less than the other ankle
____ (2) Equal in amount to the other ankle
____ (1) Slightly more than the other ankle
____ (0) Much more than the other ankle

2. How would you describe any swelling of your ankle?

____ (4) Much less than the other ankle
____ (3) Slightly less than the other ankle
____ (2) Equal in amount to the other ankle
____ (1) Slightly more than the other ankle
____ (0) Much more than the other ankle

3. How would you describe the ability of your ankle when walking on uneven surfaces?

____ (4) Much less than the other ankle
____ (3) Slightly less than the other ankle
____ (2) Equal in amount to the other ankle
____ (1) Slightly more than the other ankle
____ (0) Much more than the other ankle

4. How would you describe the overall feeling of stability of your ankle?

____ (4) Much less than the other ankle
____ (3) Slightly less than the other ankle
____ (2) Equal in amount to the other ankle
____ (1) Slightly more than the other ankle
____ (0) Much more than the other ankle

5. How would you describe the overall feeling of your ankle?

____ (4) Much less than the other ankle
____ (3) Slightly less than the other ankle
____ (2) Equal in amount to the other ankle
____ (1) Slightly more than the other ankle
____ (0) Much more than the other ankle

6. How would you describe your ankle's ability when you descend stairs?

____ (4) Much less than the other ankle
____ (3) Slightly less than the other ankle
____ (2) Equal in amount to the other ankle

_______ (1) Slightly more than the other ankle
_______ (0) Much more than the other ankle

7. How would you describe your ankle's ability when you jog?

_______ (4) Much less than the other ankle
_______ (3) Slightly less than the other ankle
_______ (2) Equal in amount to the other ankle
_______ (1) Slightly more than the other ankle
_______ (0) Much more than the other ankle

8. How would you describe your ankle's ability to "cut" or change direction, when running?

_______ (4) Much less than the other ankle
_______ (3) Slightly less than the other ankle
_______ (2) Equal in amount to the other ankle
_______ (1) Slightly more than the other ankle
_______ (0) Much more than the other ankle

9. How would you describe the overall activity level of your ankle?

_______ (4) Much less than the other ankle
_______ (3) Slightly less than the other ankle
_______ (2) Equal in amount to the other ankle
_______ (1) Slightly more than the other ankle
_______ (0) Much more than the other ankle

10. Which statement best describes your ability to sense your ankle beginning to "roll over"?

_______ (4) Much less than the other ankle
_______ (3) Slightly less than the other ankle
_______ (2) Equal in amount to the other ankle
_______ (1) Slightly more than the other ankle
_______ (0) Much more than the other ankle

11. Compared with the other ankle, which statement best describes your ability to respond to your ankle beginning to "roll over"?

_______ (4) Much less than the other ankle
_______ (3) Slightly less than the other ankle
_______ (2) Equal in amount to the other ankle
_______ (1) Slightly more than the other ankle
_______ (0) Much more than the other ankle

12. Following a typical incident of your ankle "rolling" which statement best describes the time required to return to activity?

_______ (4) More than 2 days
_______ (3) 1 to 2 days
_______ (2) More than 1 hour and less than 1 day
_______ (1) 15 minutes to 1 hour
_______ (0) Almost immediately

APPENDIX D

[CUMBERLAND ANKLE INSTABILITY TOOL]

The Cumberland Ankle Instability Tool
Please tick the ONE statement in EACH question that BEST describes your ankles.

	LEFT	RIGHT	SCORE
1. I have pain in my ankle			
Never	☐	☐	5
During sport	☐	☐	4
Running on uneven surfaces	☐	☐	3
Running on level surfaces	☐	☐	2
Walking on uneven surfaces	☐	☐	1
Walking on level surfaces	☐	☐	0
2. My ankle feels UNSTABLE			
Never	☐	☐	4
Sometimes during sport (not every time)	☐	☐	3
Frequently during sport (every time)	☐	☐	2
Sometimes during daily activity	☐	☐	1
Frequently during daily activity	☐	☐	0
3. When I make SHARP turns, my ankle feels UNSTABLE			
Never	☐	☐	3
Sometimes when running	☐	☐	2
Often when running	☐	☐	1
When walking	☐	☐	0
4. When going down the stairs, my ankle feels UNSTABLE			
Never	☐	☐	3
If I go fast	☐	☐	2
Occasionally	☐	☐	1
Always	☐	☐	0
5. My ankle feels UNSTBLE when standing on ONE leg			
Never	☐	☐	2
On the ball of my foot	☐	☐	1
With my foot flat	☐	☐	0
6. My ankle feels UNSTABLE when			
Never	☐	☐	3
I hop from side to side	☐	☐	2
I hop on the spot	☐	☐	1
When I jump	☐	☐	0
7. My ankle feels UNSTABLE when			

Never	☐	☐	4
I run on uneven surfaces	☐	☐	3
I jog on uneven surfaces	☐	☐	2
I walk on uneven surfaces	☐	☐	1
I walk on a flat surface	☐	☐	0
8. TYPICALLY, when I start to roll over (or twist) on my ankle, I can stop			
Immediately	☐	☐	4
Often	☐	☐	3
Sometimes	☐	☐	2
Never	☐	☐	1
I have never rolled over on my ankle	☐	☐	0
9. After a TYPICAL incident of my ankle rolling over, my ankle returns to “normal “			
Almost immediately	☐	☐	4
Less than one day	☐	☐	3
1-2 days	☐	☐	2
More than 2 days	☐	☐	1
I have never rolled over on my ankle	☐	☐	0

APPENDIX E

[INDIVIDUAL SUBJECT DEMOGRAPHIC DATA]

	Subject	Age	Heigth (cm)	Weight (kg)	Laxity
Control	1	20	175	83.78	3
	2	19	183	85.53	3
	3	22	182	75.08	3
	4	21	171	66.8	3
	5	23	183.5	86.8	3
	6	22	172.5	68.62	3
	7	18	174.5	68.75	3
	8	19	177.5	77.28	3
	9	20	179	77.56	3
	10	22	172	67.77	3
	11	23	179.2	84.46	3
	12	22	194.5	92.8	3
FAI	1	18	175.4	70.91	3
	2	22	188.5	79.27	4
	3	21	173.1	91.97	4
	4	19	179	80.2	3
	5	20	187	99.78	4
	6	19	189	88.38	4
	7	25	187.5	81.52	5
	8	20	185	81.76	3
	9	21	177.5	91.97	4
	10	18	187.2	89.58	4
	11	21	177.3	86.07	4
	12	21	179.5	78.04	4

APPENDIX F

[INDIVIDUAL SUBJECT STATIC POSTURAL STABILITY SCORES]

		Eyes Open		Eyes Closed	
	Subject	**ML GRF SD**	**AP GRF SD**	**ML GRF SD**	**AP GRF SD**
Control	1	2.53	2.83	12.32	8.30
	2	3.34	3.21	8.89	7.09
	3	2.69	2.20	6.89	5.51
	4	1.72	1.70	5.86	4.91
	5	3.39	2.74	10.55	6.90
	6	3.56	3.29	7.24	5.93
	7	2.93	2.41	7.17	6.18
	8	3.45	3.37	9.65	5.93
	9	3.43	2.89	11.44	8.35
	10	3.70	2.67	6.79	3.99
	11	4.56	5.19	9.20	5.65
	12	3.39	3.21	8.76	5.83
FAI	1	2.23	2.84	8.96	7.03
	2	5.21	2.91	12.86	6.45
	3	2.49	1.78	12.52	5.30
	4	2.63	3.33	11.55	7.23
	5	2.47	2.92	10.70	7.45
	6	3.09	2.45	11.18	6.47
	7	2.10	2.32	9.89	7.37
	8	2.28	2.31	4.65	4.33
	9	2.51	2.57	13.82	8.09
	10	1.96	2.27	13.57	8.54
	11	5.08	3.60	17.84	8.95
	12	5.57	2.97	9.86	6.00

ML GRF SD = medial/lateral ground reaction force standard deviation

AP GRF SD = anterior/posterior ground reaction force standard deviation

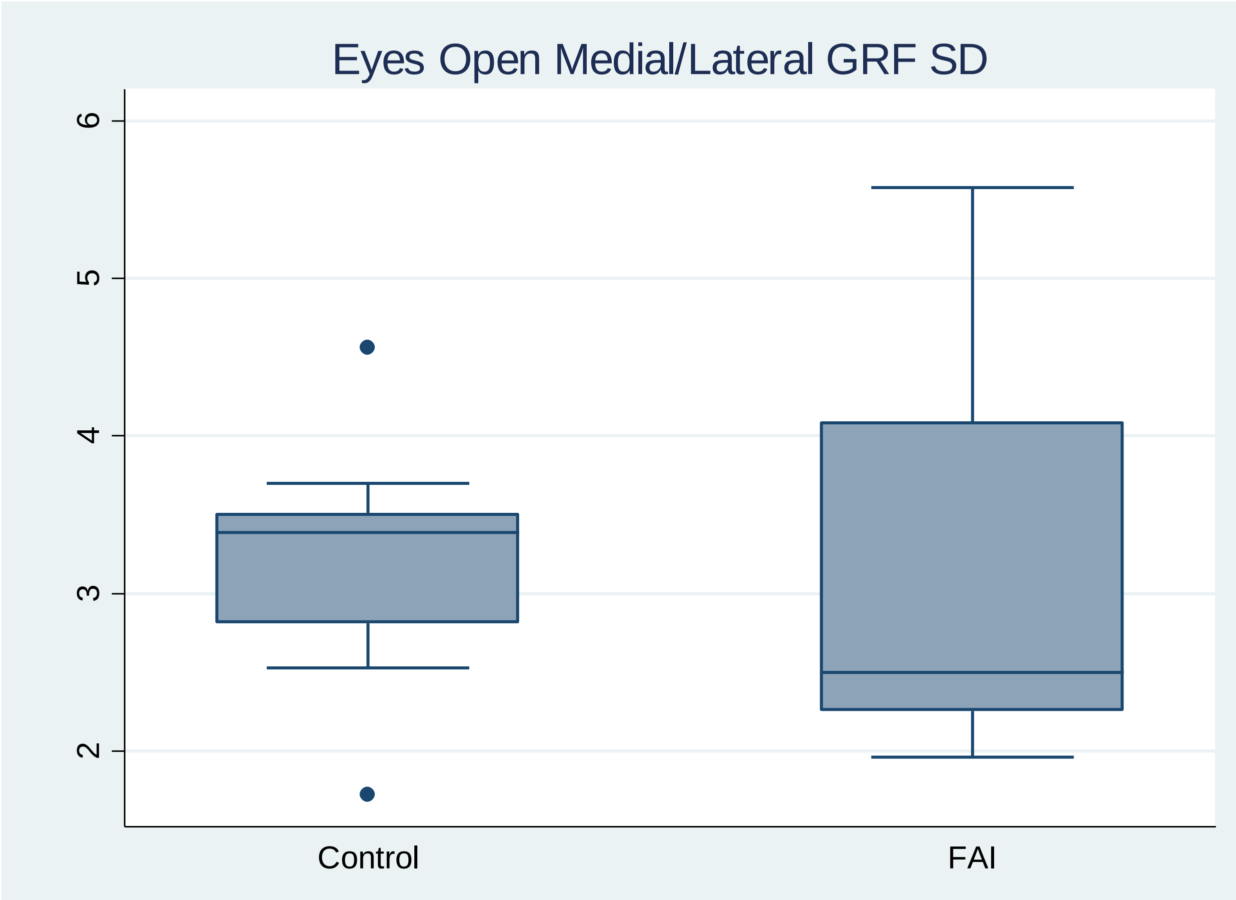

Figure 1. Eyes Open M/L GRF SD Raw Data

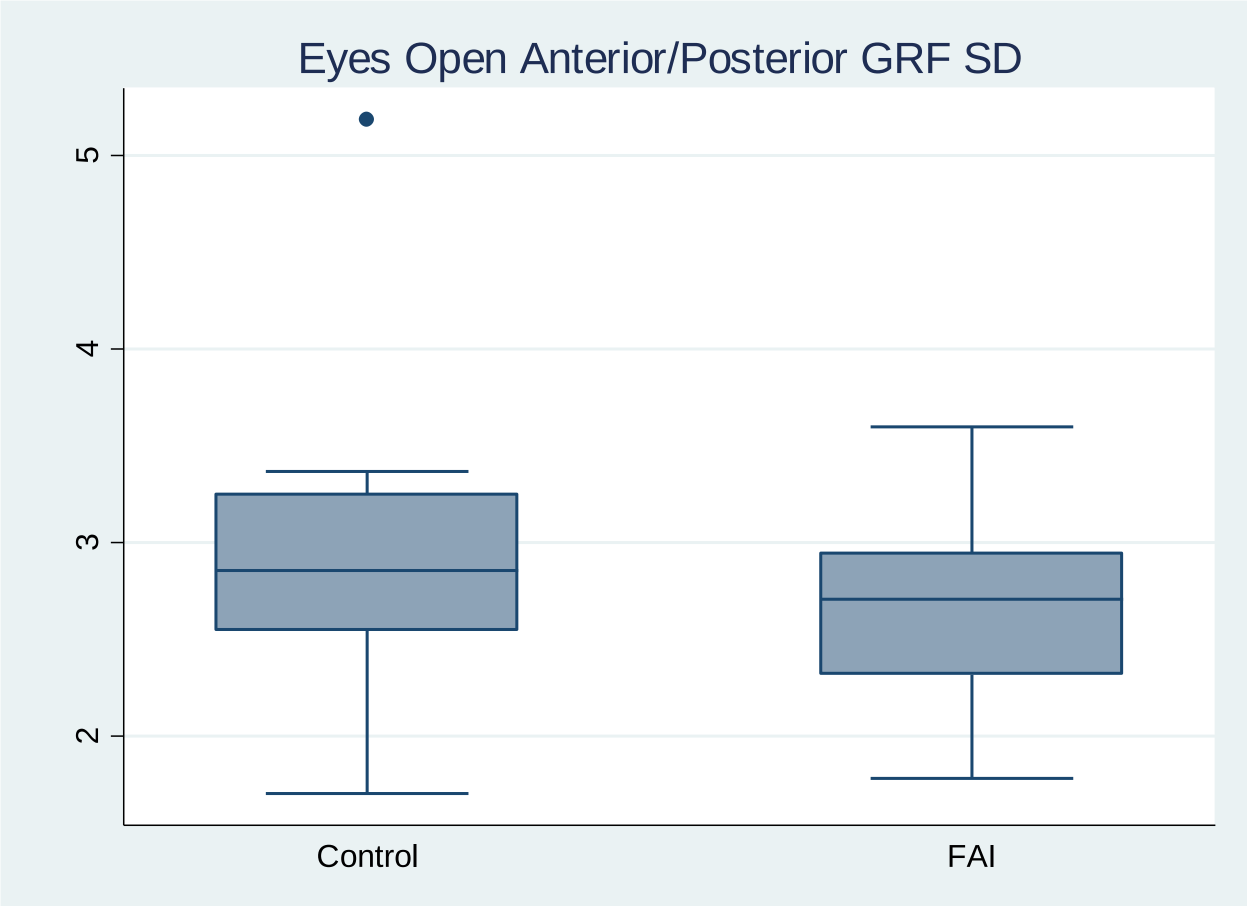

Figure 2. Eyes Open A/P GRF SD Raw Data

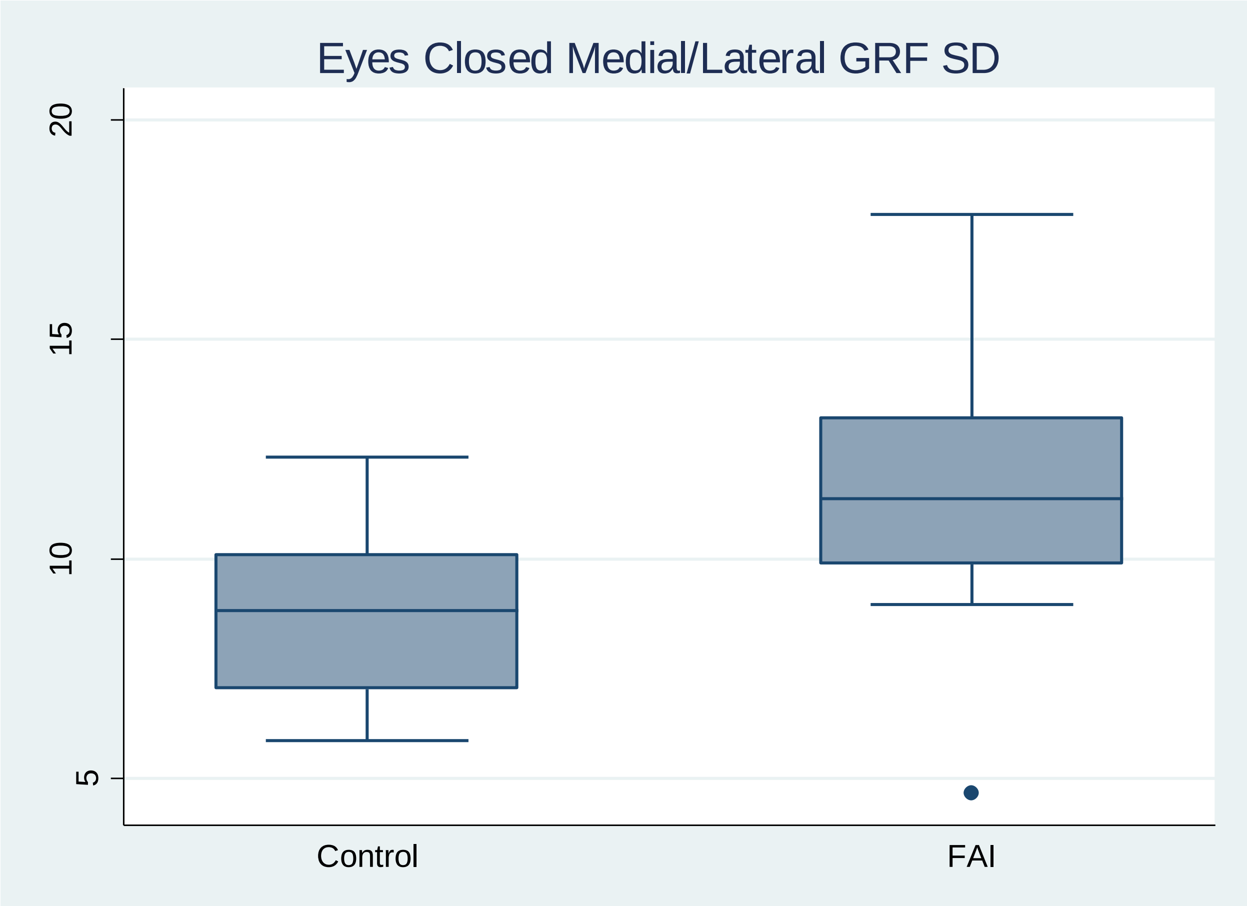

Figure 3. Eyes Closed M/L GRF SD Raw Data

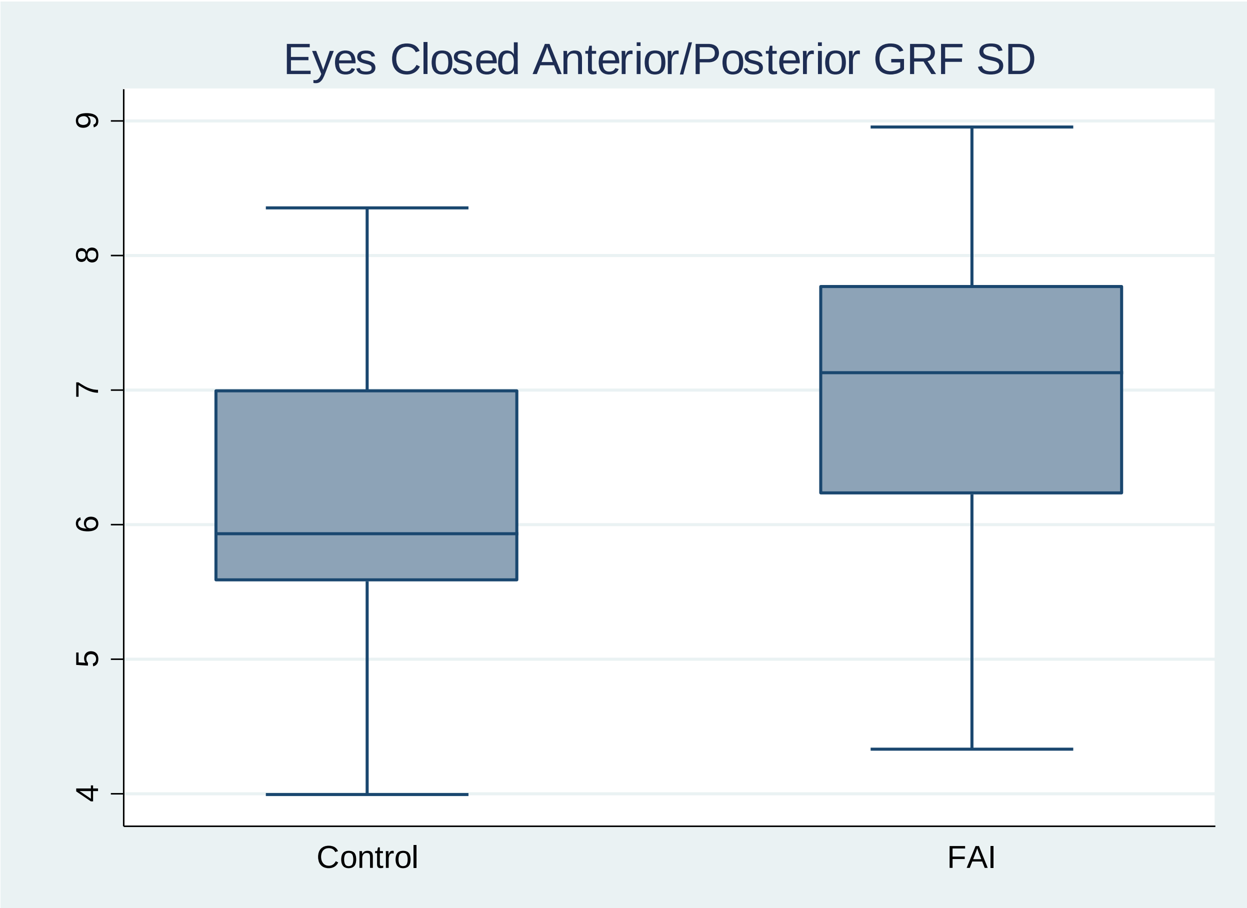

Figure 4. Eyes Closed A/P GRF SD Raw Data

APPENDIX G

[INDIVIDUAL SUBJECT DYNAMIC POSTURAL STABILITY SCORES]

	Subject	Anterior Jump MLSI	APSI	VSI	DPSI	Lateral Jump MLSI	APSI	VSI	DPSI
Control	1	0.03	0.15	0.37	0.40	0.14	0.04	0.32	0.35
	2	0.03	0.13	0.31	0.34	0.12	0.04	0.29	0.32
	3	0.02	0.13	0.38	0.40	0.12	0.04	0.42	0.44
	4	0.02	0.15	0.39	0.41	0.13	0.04	0.38	0.40
	5	0.05	0.14	0.37	0.40	0.12	0.04	0.37	0.40
	6	0.03	0.13	0.29	0.32	0.11	0.03	0.26	0.28
	7	0.02	0.14	0.30	0.33	0.13	0.03	0.22	0.25
	8	0.02	0.13	0.28	0.31	0.12	0.03	0.28	0.30
	9	0.03	0.12	0.31	0.34	0.12	0.03	0.29	0.31
	10	0.03	0.14	0.30	0.33	0.11	0.02	0.28	0.30
	11	0.03	0.13	0.30	0.33	0.12	0.04	0.28	0.31
	12	0.02	0.14	0.31	0.34	0.11	0.04	0.28	0.31
FAI	1	0.03	0.17	0.38	0.42	0.14	0.04	0.35	0.38
	2	0.05	0.13	0.35	0.37	0.12	0.04	0.34	0.36
	3	0.03	0.15	0.40	0.43	0.13	0.03	0.37	0.39
	4	0.03	0.15	0.40	0.42	0.13	0.03	0.33	0.36
	5	0.03	0.13	0.36	0.38	0.13	0.04	0.35	0.38
	6	0.03	0.14	0.33	0.36	0.12	0.04	0.33	0.35
	7	0.03	0.13	0.40	0.43	0.12	0.04	0.35	0.38
	8	0.03	0.13	0.40	0.42	0.15	0.04	0.37	0.4
	9	0.03	0.12	0.40	0.42	0.12	0.05	0.39	0.41
	10	0.03	0.13	0.34	0.37	0.11	0.03	0.34	0.36
	11	0.04	0.13	0.39	0.41	0.12	0.03	0.37	0.39
	12	0.03	0.14	0.31	0.34	0.13	0.03	0.29	0.31

MLSI = medial lateral stability index
APSI = anterior posterior stability index
VSI = vertical stability index
DPSI = composite score

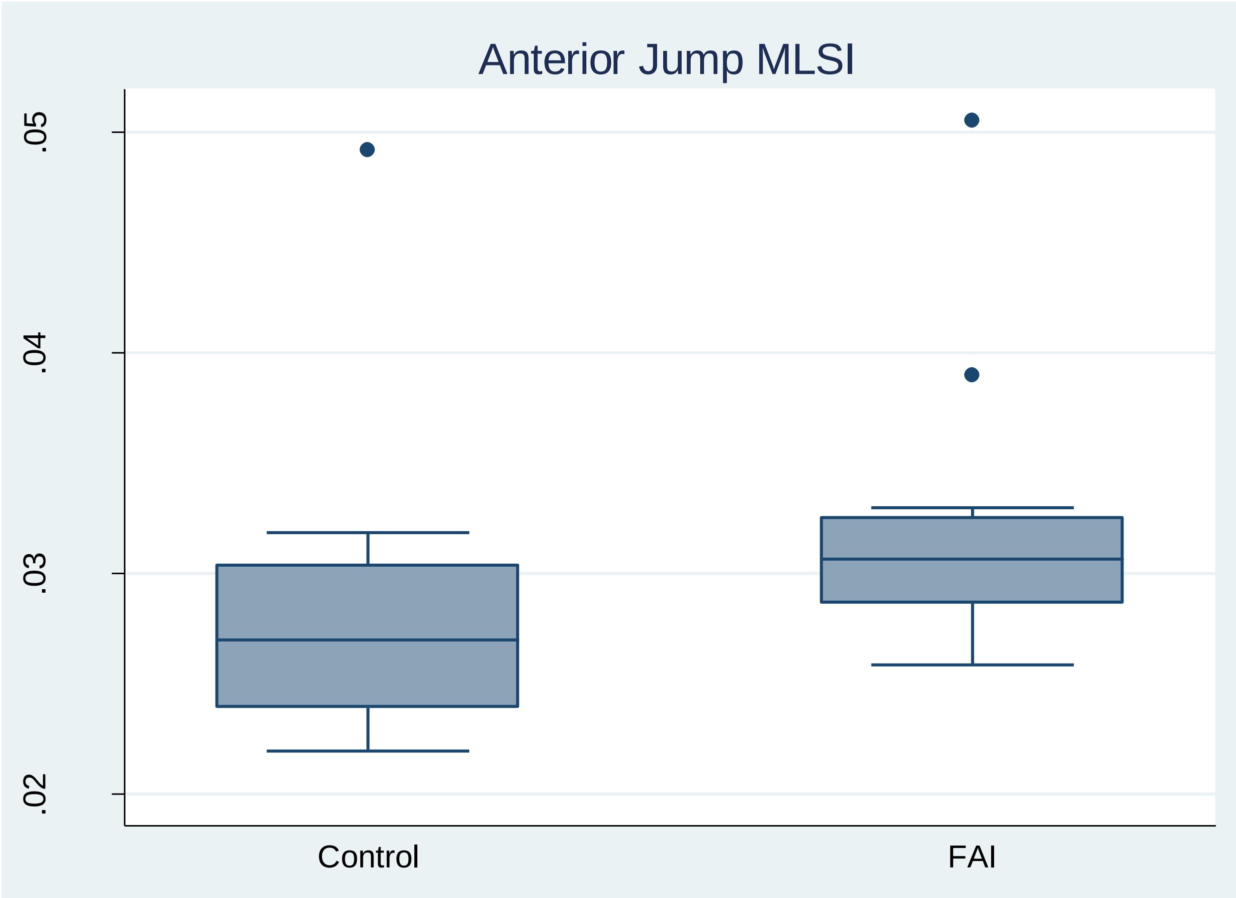

Figure 5. Anterior Jump MLSI Raw Data

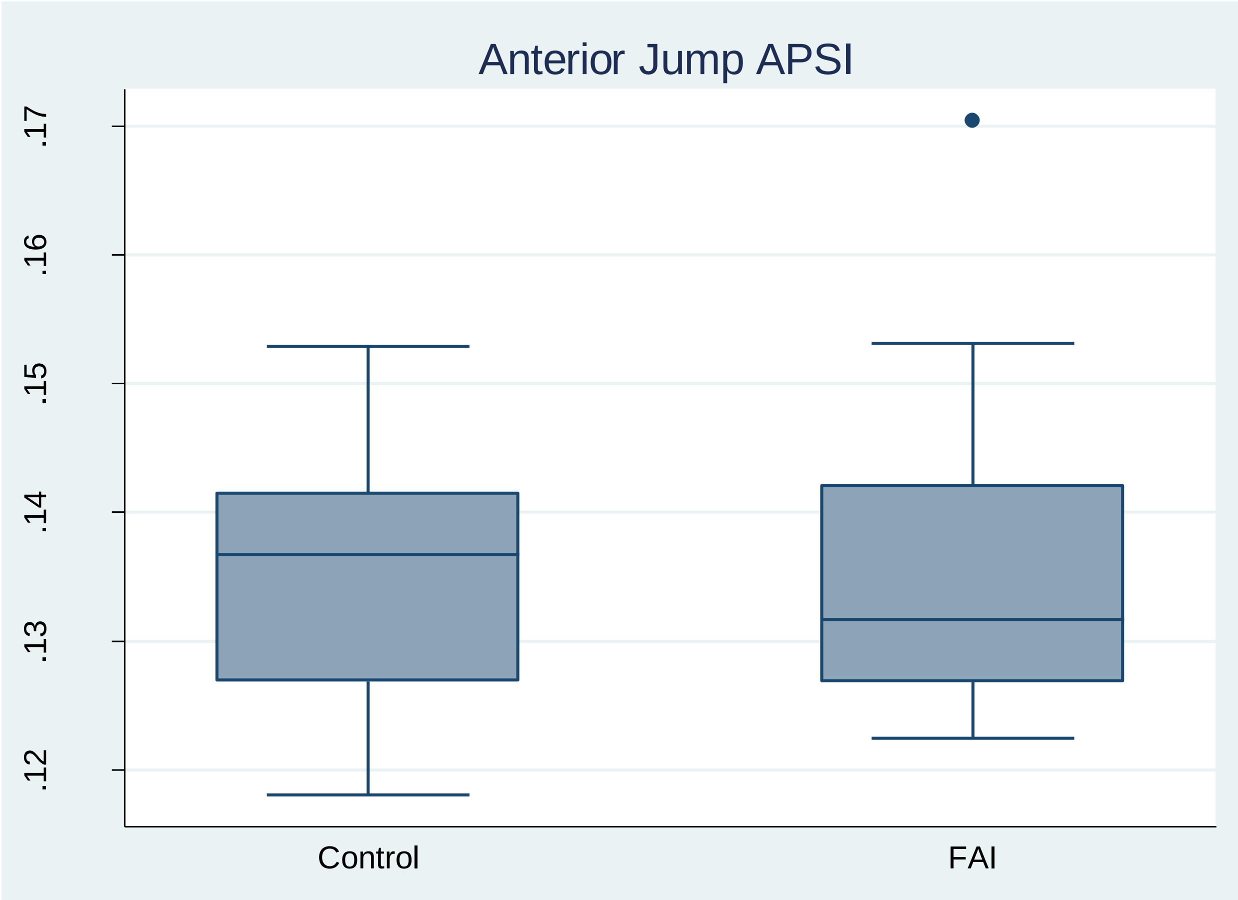

Figure 6. Anterior Jump APSI Raw Data

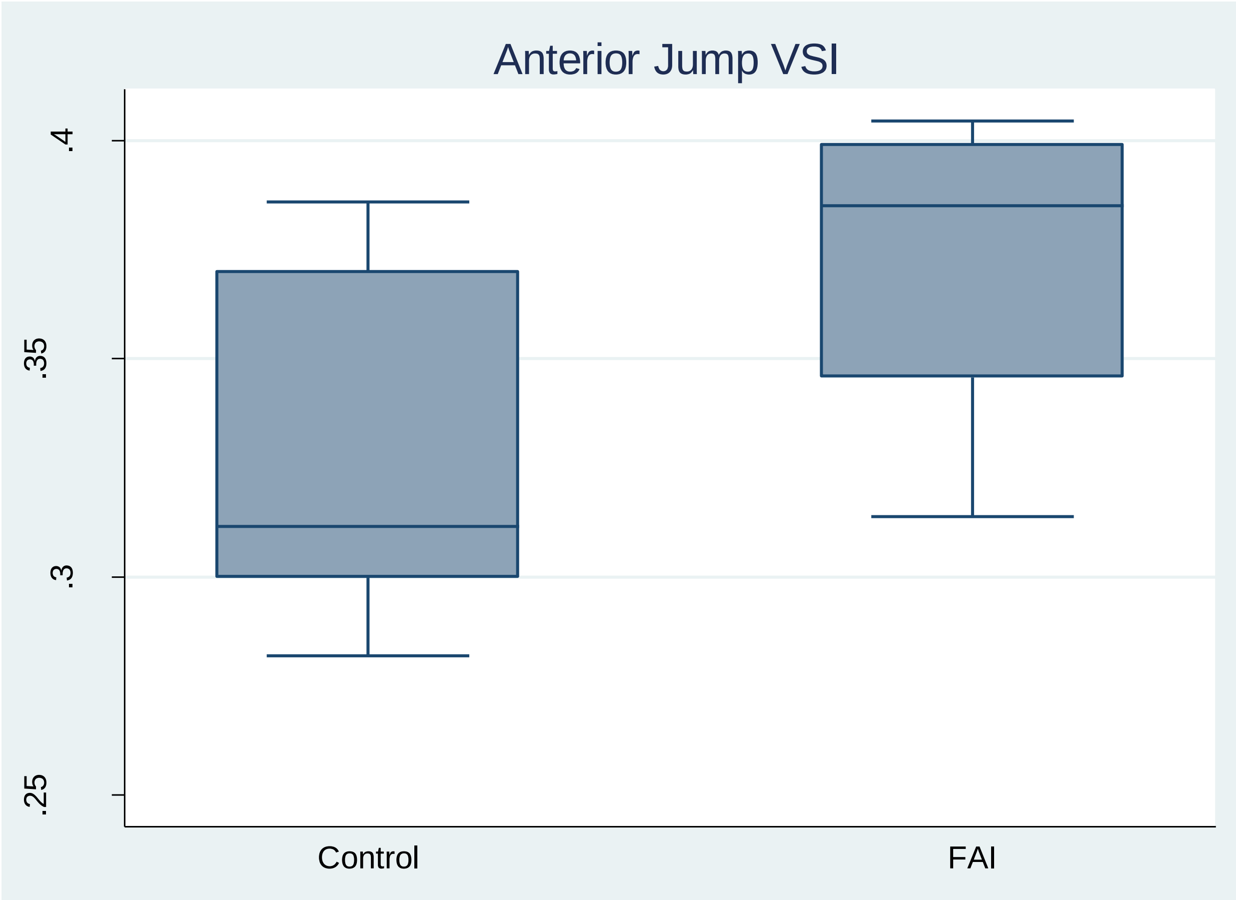

Figure 7. Anterior Jump VSI Raw Data

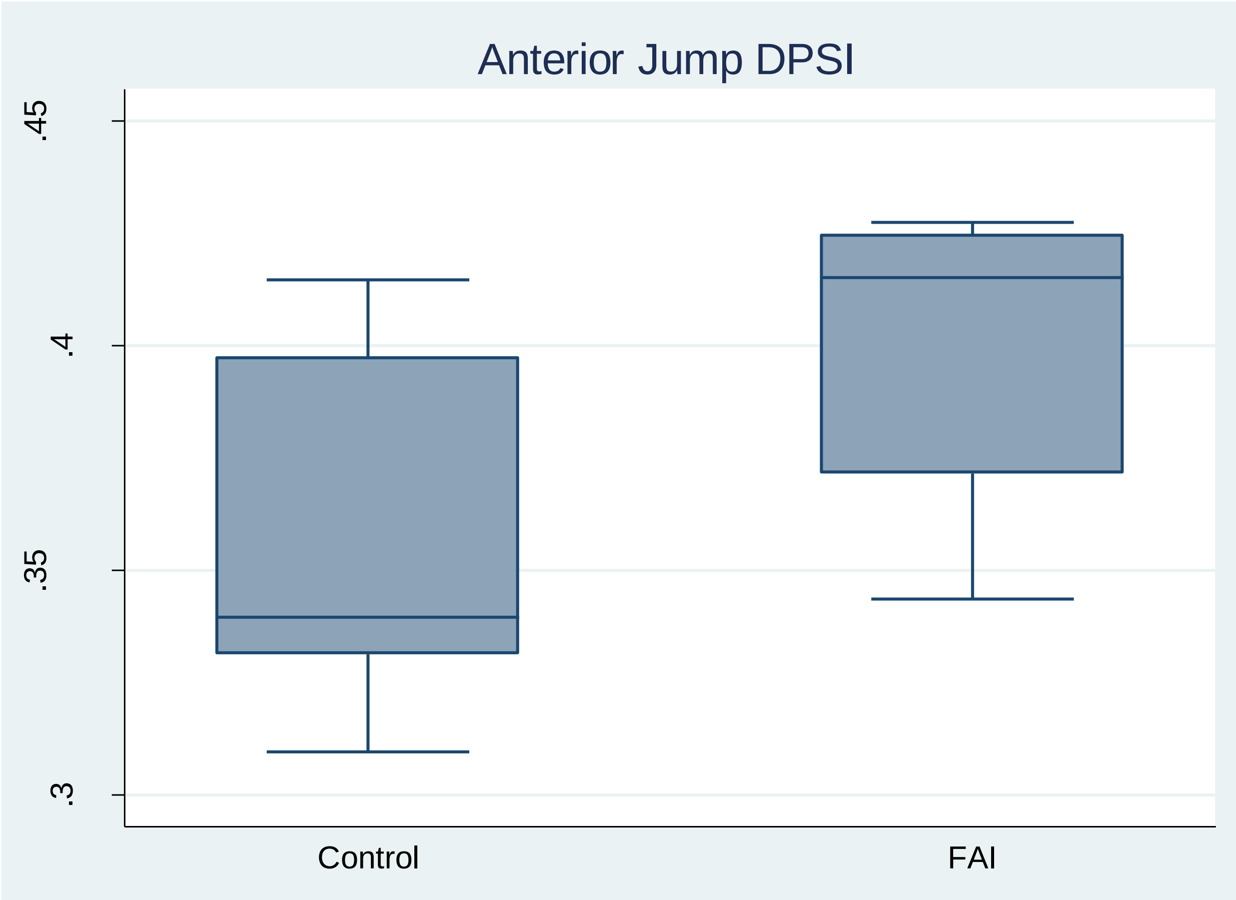

Figure 8. Anterior Jump DPSI Raw Data

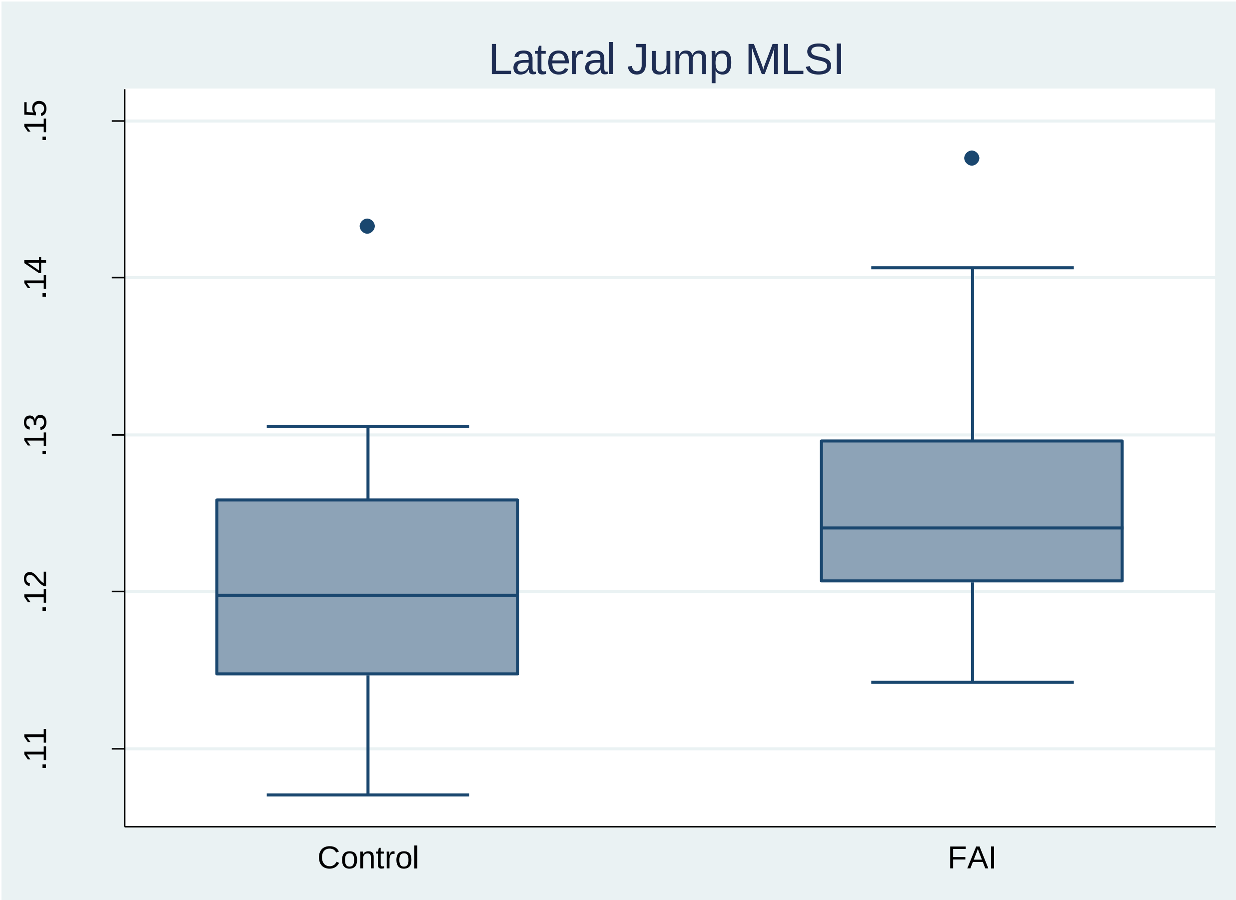

Figure 9. Lateral Jump MLSI Raw Data

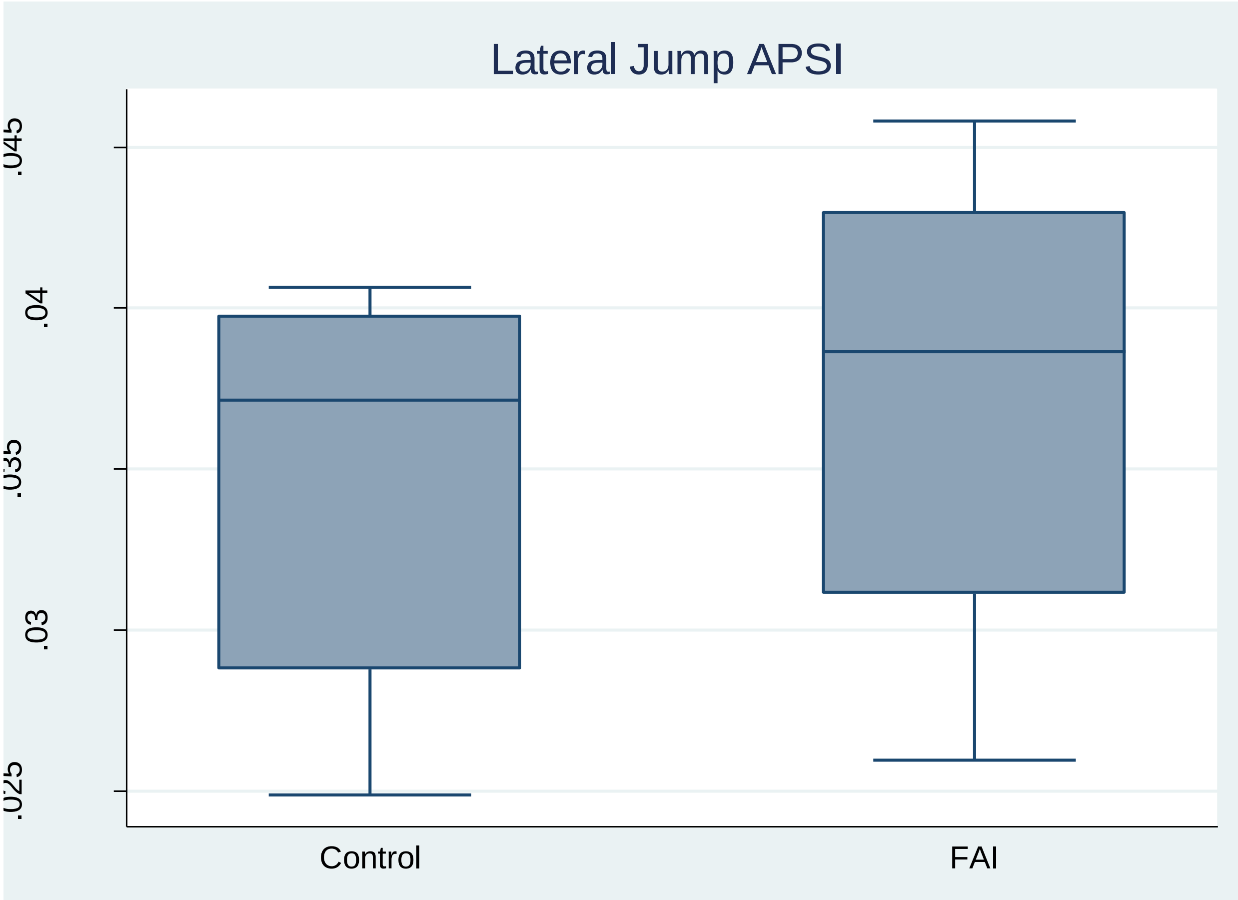

Figure 10. Lateral Jump APSI Raw Data

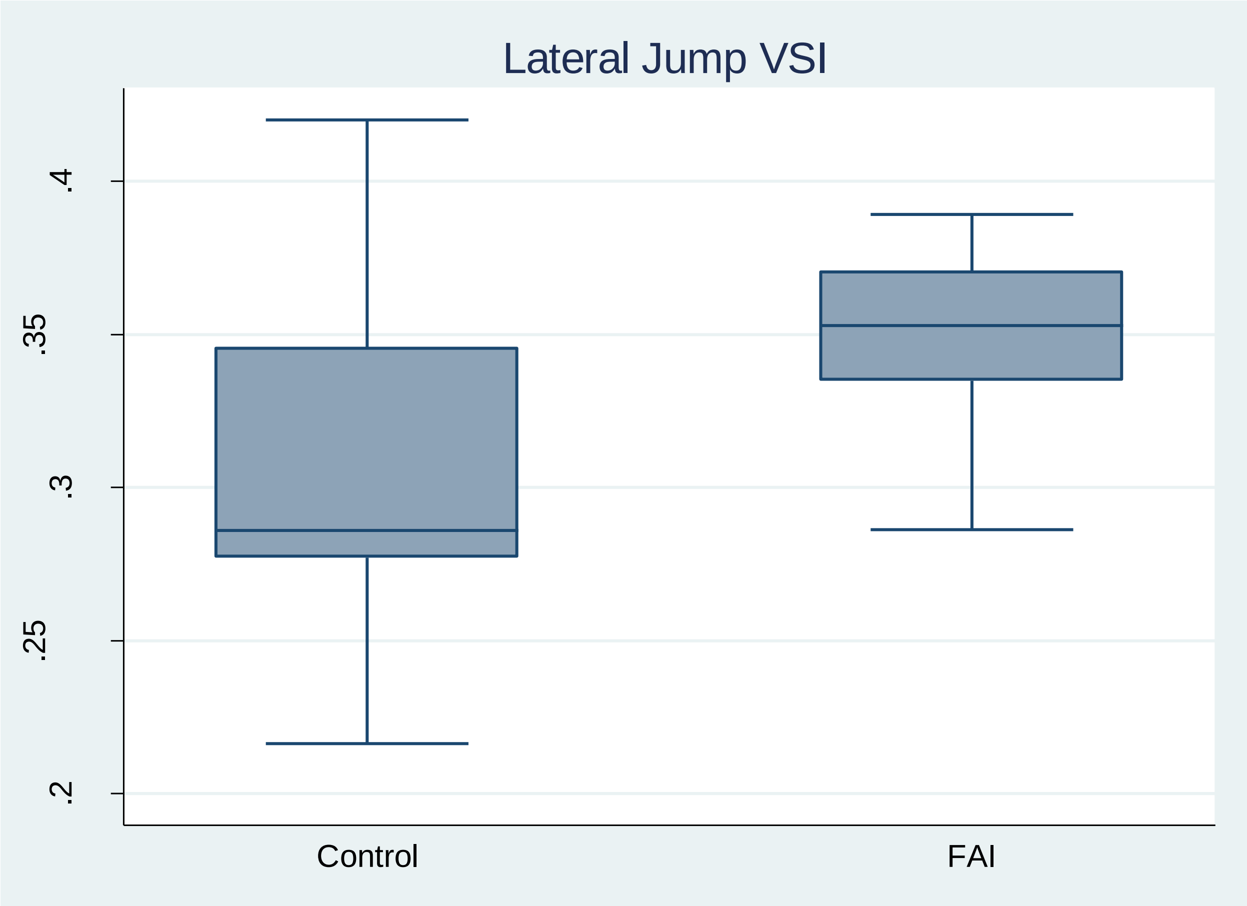

Figure 11. Lateral Jump VSI Raw Data

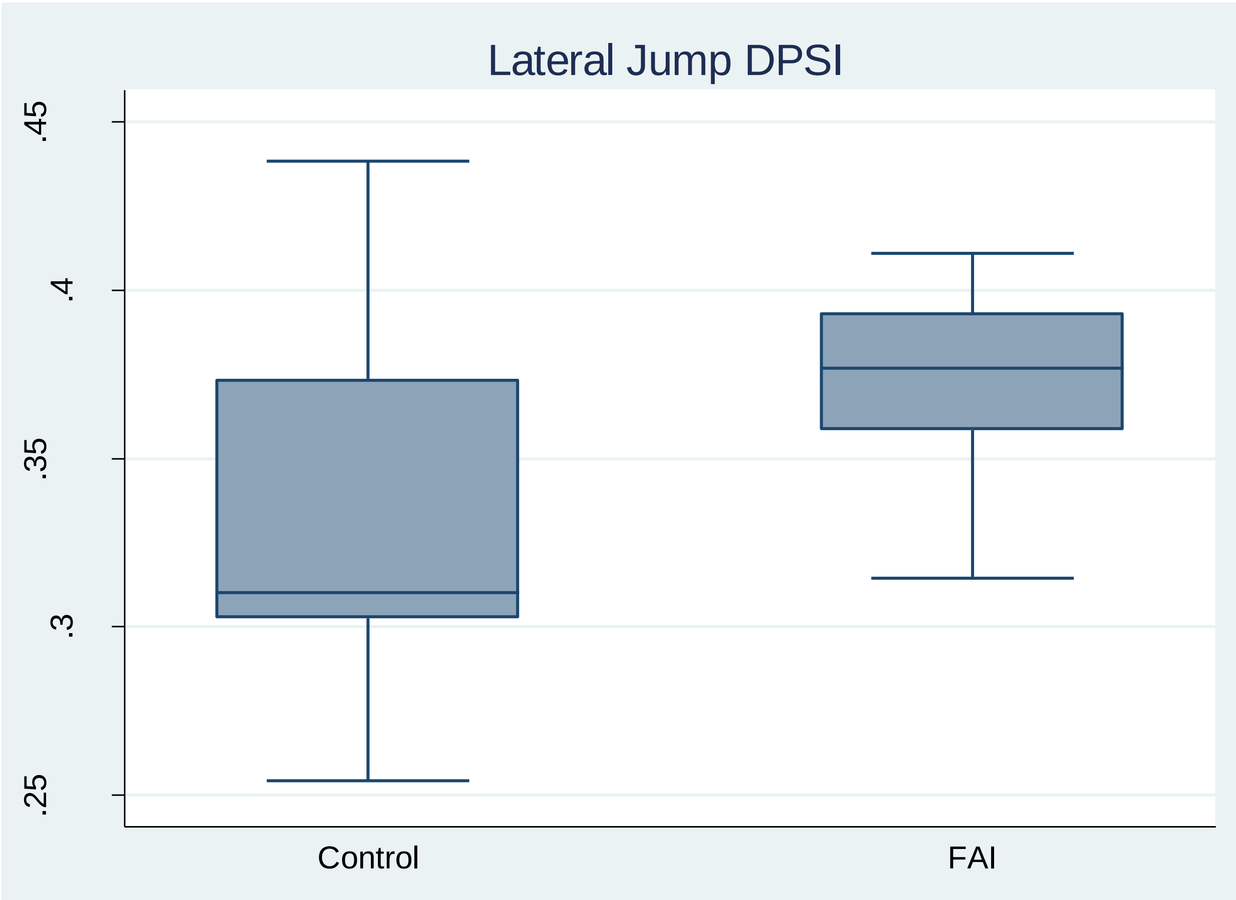

Figure 12. Lateral Jump DPSI Raw Data

APPENDIX H

[INDIVIDUAL SUBJECT FAI ANKLE QUESTIONNAIRE SCORES]

	Subject	FADI	FADI-S	AII	AJFAT	CAIT
Control	1	100%	96%	0	27	30
	2	100%	100%	0	26	28
	3	100%	100%	0	26	28
	4	100%	97%	0	27	30
	5	100%	100%	0	26	30
	6	100%	100%	0	26	30
	7	100%	100%	0	26	30
	8	100%	100%	0	27	30
	9	100%	100%	0	26	30
	10	100%	97%	0	26	30
	11	100%	97%	0	26	30
	12	99%	97%	0	26	30
FAI	1	97%	90%	4	16	24
	2	89%	84%	6	16	16
	3	94%	90%	3	24	26
	4	100%	100%	2	25	30
	5	95%	94%	5	20	24
	6	78%	47%	8	10	19
	7	98%	91%	4	18	21
	8	98%	97%	5	19	27
	9	96%	91%	3	17	21
	10	96%	91%	4	14	23
	11	95%	75%	5	14	20
	12	99%	94%	3	19	25

FADI = Functional Ankle Distability Index
FADI = Functional Ankle Distability Index -Sport
AII = Ankle Instability Instrument
AJFAT = Ankle Joint Functional Assessment Tool
CAIT = Cumberland Ankle Instability Tool

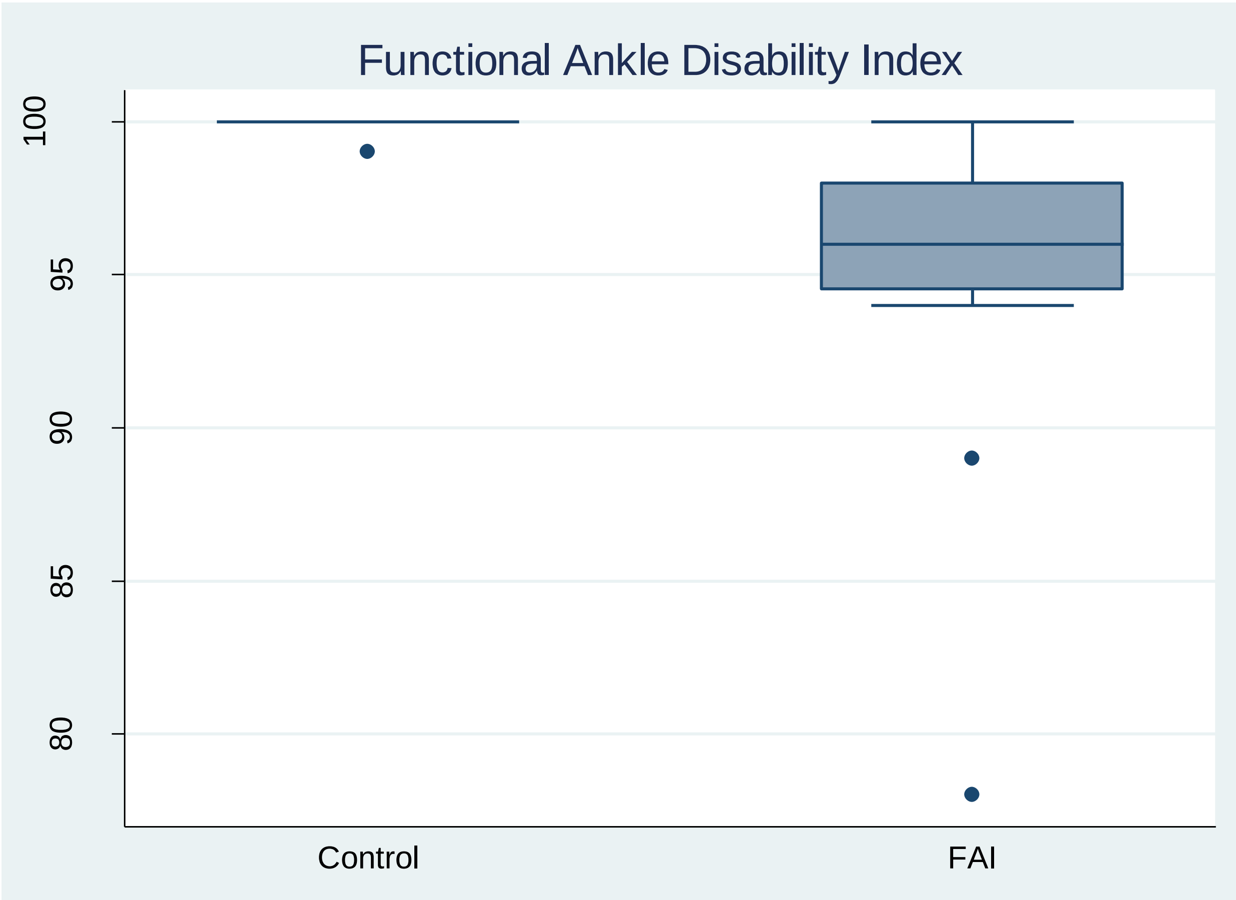

Figure 13. Functional Ankle Disability Index Data

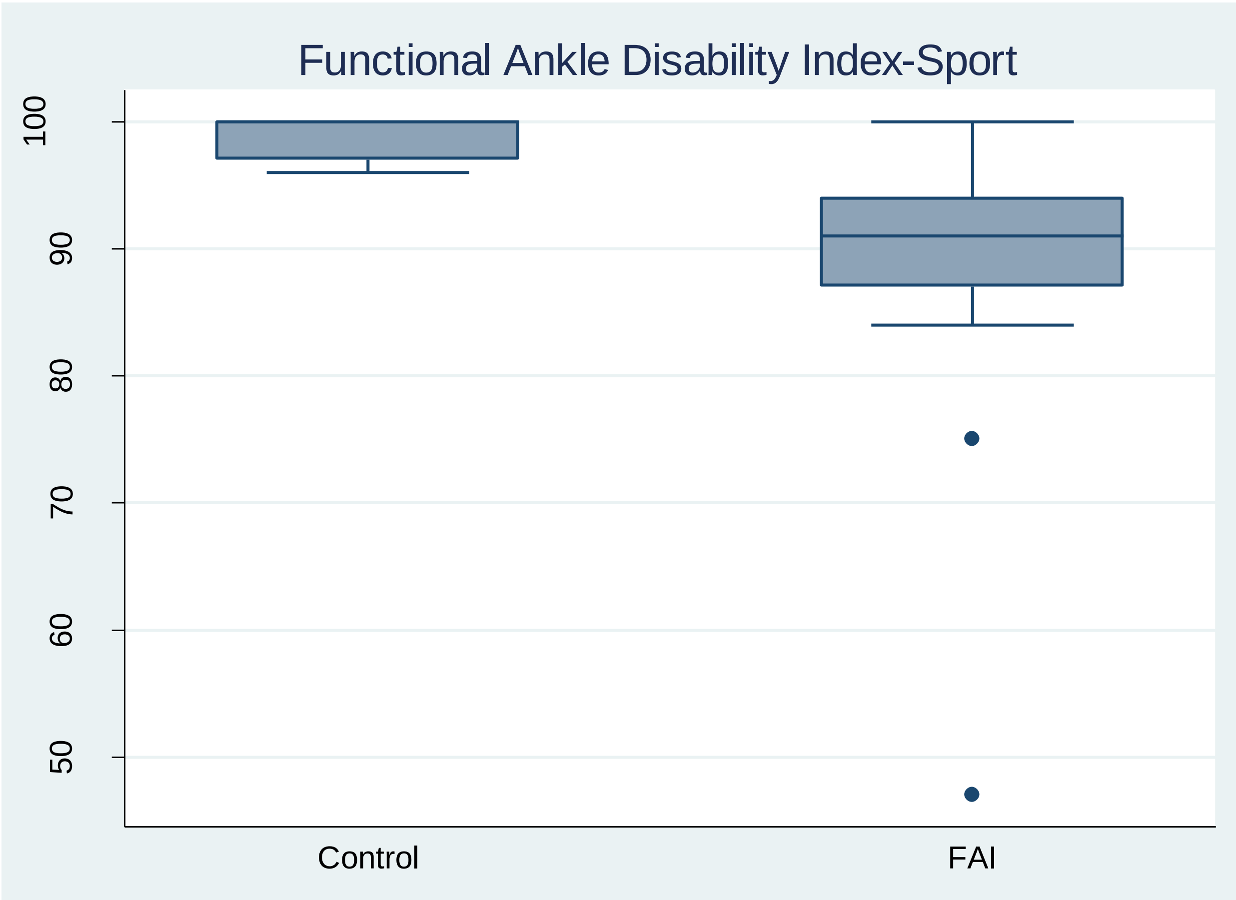

Figure 14. Functional Ankle Disability Index-Sport Data

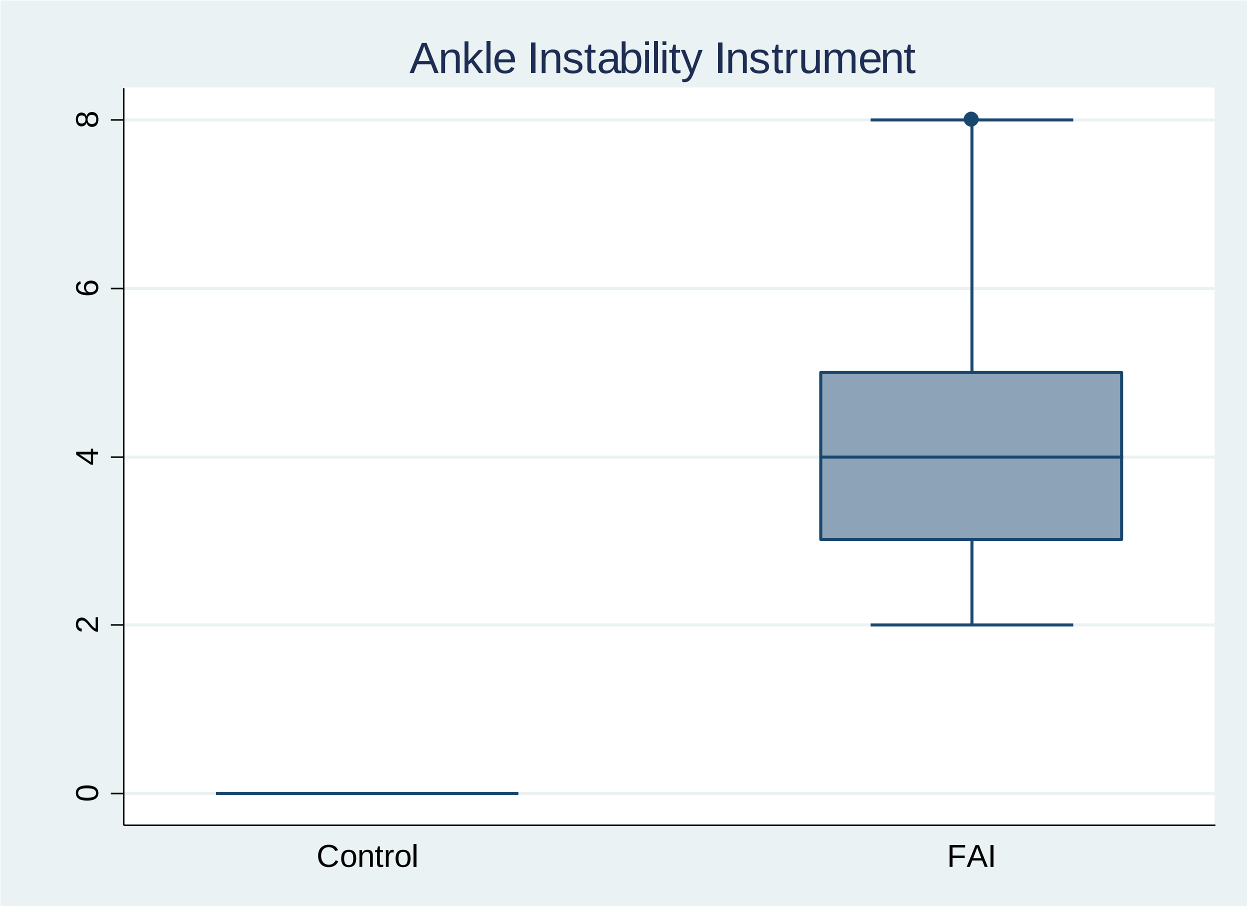

Figure 15. Ankle Instability Instrument Data

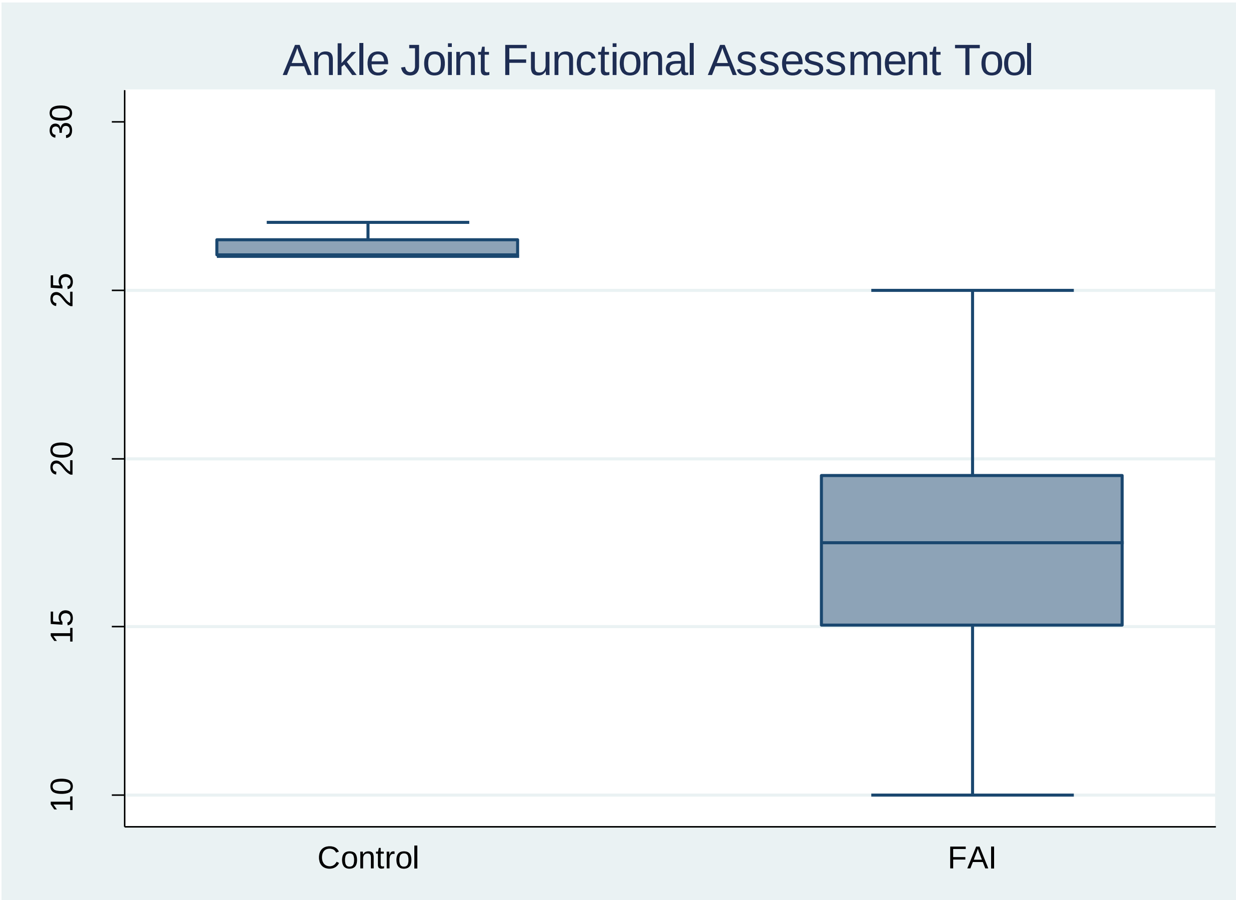

Figure 16. Ankle Joint Functional Assessment Tool Data

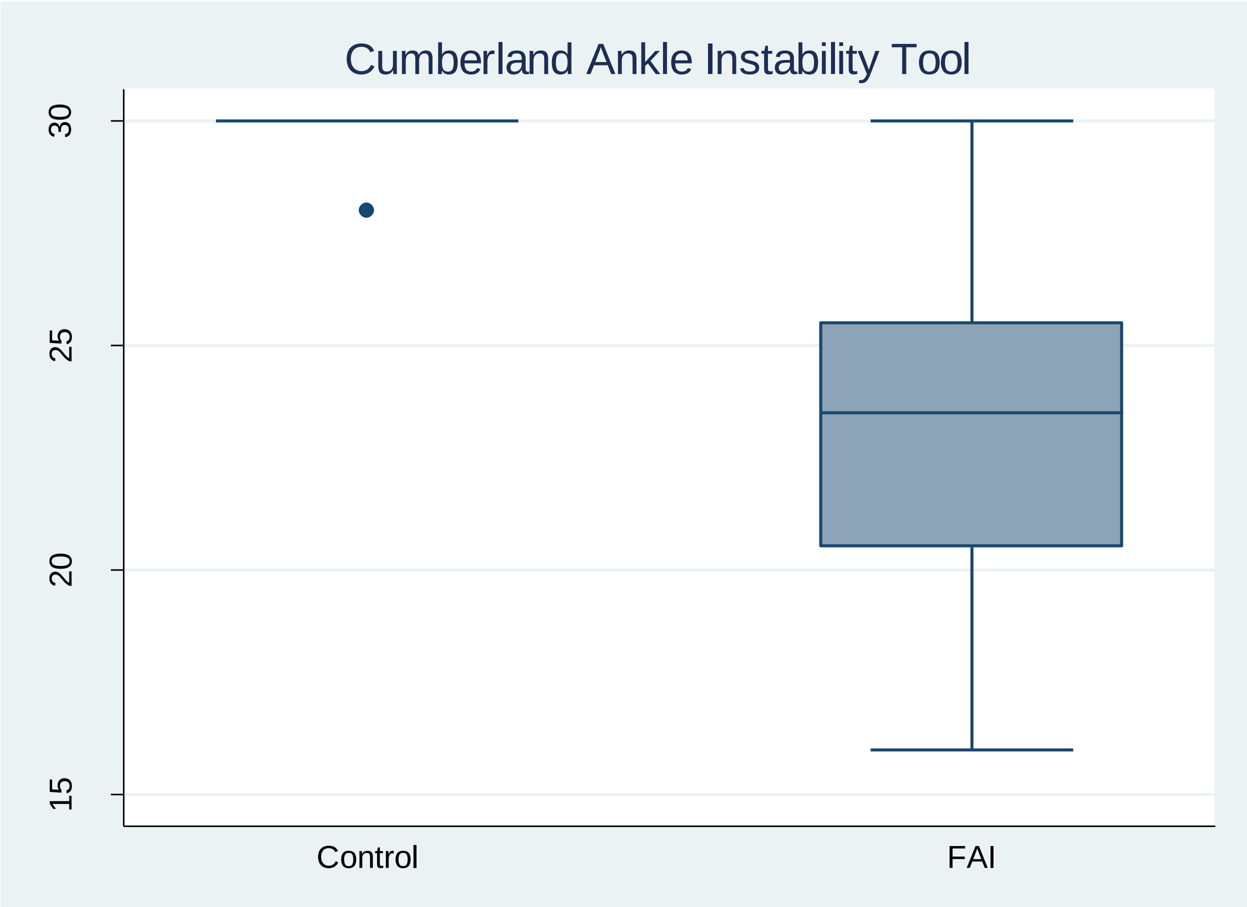

Figure 17. Cumberland Ankle Instability Tool Data

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