

DETECTING MOVEMENT ERRORS IN CHRONIC ANKLE INSTABILITY PATIENTS:  
COMPARING FUSIONETICS TO THE LESS

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## **ABSTRACT**

Julie Harriss: Detecting Movement Errors in Chronic Ankle Instability Patients: Comparing Fusionetics to the LESS  
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Lateral ankle sprains are the most common injuries in sport, and many who have an initial lateral ankle sprain go on to experience recurrent sprains and instability; defined as chronic ankle instability (CAI). The purpose was to determine whether Fusionetics or the Landing Error Scoring System (LESS), movement efficiency exams, are able to detect differences between collegiate athletes with and without CAI. Lower extremity Fusionetics tests (overhead squat, overhead squat with heel lift, and single limb squat) and the LESS were performed. Nonparametric analyses found no differences between groups for any of the five outcome measures. Further, no correlations were found between injury characteristics (questionnaires and number of sprains) and outcome measures within the CAI group. The results indicate that Fusionetics and LESS exams are not able to detect differences between those who have CAI and healthy controls. Neither task are likely ankle specific enough to detect differences.

## TABLE OF CONTENTS

LIST OF TABLES .....	vi
LIST OF ABBREVIATIONS.....	vii
CHAPTER I: INTRODUCTION.....	1
CHAPTER II: REVIEW OF LITERATURE .....	4
Epidemiology .....	4
Risk factors .....	4
Dynamic tasks in chronic ankle instability .....	9
Drop and Jump Landings .....	9
LESS .....	14
CHAPTER III: METHODS .....	16
3.1 Research design .....	16
3.2 Participants.....	16
3.3 Instruments.....	17
3.4 Procedures.....	17
3.5 Statistical Analysis.....	19
CHAPTER IV: RESULTS.....	22
Demographics .....	22
Normality .....	23
Group differences.....	23
Correlations.....	24

CHAPTER V: DISCUSSION.....	26
Sample Comparison.....	26
Group Differences.....	27
Individual Variability.....	29
Limitations.....	31
Clinical implications.....	32
Conclusions.....	32
APPENDICES.....	34
APPENDIX 1: FUSIONETICS SCORING.....	34
APPENDIX 2: LANDING ERROR SCORING SYSTEM DEMONSTRATION.....	34
APPENDIX 3: SCORING FOR THE LANDING ERROR SCORING SYSTEM.....	35
APPENDIX 4. FUSIONETICS SCORING ERRORS.....	36
APPENDIX 5: FOOT AND ANKLE ABILITY MEASUREMENT.....	36
APPENDIX 6: IDENTIFICATION OF FUNCTIONAL ANKLE INSTABILITY.....	37
REFERENCES.....	38

## LIST OF TABLES

Table 3-1 – Independent and dependent variables.....	23
Table 3-2 – Research aims.....	23
Table 4-1 – Number of participants by sport.....	24
Table 4-2 – Means and standard deviations.....	25
Table 4-3 – Correlations between injury characteristics and movement assessments.....	26

## LIST OF ABBREVIATIONS

ATFL	Anterior Talo-Fibular Ligament
CAI	Chronic Ankle Instability
CFL	Calcaneofibular Ligament
EMG	Electromyography
FAAM	Foot and Ankle Ability Measure
FAI	Functional Ankle Instability
FMS	Functional Movement Screen
GRF	Ground Reaction Force
IdFAI	Identification of Functional Ankle Instability
LAS	Lateral Ankle Sprains
LESS	Landing Error Scoring System
SEBT	Star Excursion Balance Test

## CHAPTER I: INTRODUCTION

Lateral ankle sprains (LAS) are one of the most common injuries in sport,<sup>1</sup> accounting for 40% of lower extremity injuries.<sup>2</sup> The anterior talofibular ligament (ATFL) is the most commonly injured ligament followed by the calcaneofibular (CFL) and the posterior talofibular ligament (PTFL). It is estimated that 2 million ankle sprains occur every year in the United States<sup>3</sup> costing an average of 2 billion dollars annually.<sup>4</sup> Acute ankle sprains are common, but up to 73% of subjects have recurrent sprains<sup>5</sup> and up to 74% report at least one symptom 1.5 to 4 years later.<sup>6</sup> Delahunt et. al.<sup>7</sup> conducted a review of the literature and recommended the definition of CAI include the presence of recurrent symptoms for a minimum of one year after initial LAS.

Chronic ankle instability is defined in many different ways, however, most agree that it has two subsections, mechanical instability and functional instability. Mechanical instability is defined as talocrural joint laxity due to damage to the lateral ankle ligaments.<sup>8</sup> Functional instability is defined as feelings of instability and feelings of giving way.<sup>8</sup> There are multiple theories about the causes of functional instability including disruption of proprioceptors, mechanoreceptors, neuromuscular control, and postural stability.<sup>8</sup> The link between mechanical and functional instability is not fully understood, mechanical instability rarely accounts for functional instability.<sup>9</sup>

General risk factors of lateral ankle sprains are well documented, such as increased BMI, participation in a cutting sport, and previous injury, which is the highest predictor.<sup>10</sup> Strength deficits, especially a decrease in plantarflexion and inversion eccentric strength have been shown to increase risk of injury.<sup>11</sup> Similarly a decrease in dorsiflexion has been shown to be a strong

predictor of sustaining a lateral ankle sprain.<sup>12,13</sup> Poor dynamic and static postural stability have also been shown to increase likelihood of injury, although there are conflicting studies.<sup>12 14-17</sup> More recently, functional tests have been studied to look at risk factors of ankle sprains, including the SEBT, jump stabilization tasks, the BESS and modified BESS, and weight bearing lunge test (WBLT). The SEBT, WBLT, and the BESS were shown to not have an association with increased risk of ankle sprain<sup>18</sup> while the hop test and the modified BESS found those who scored poorly were at greater risk of sustaining an ankle sprain.<sup>19 20</sup> These studies show promise that functional risk factors are predictive of ankle sprain risk but many use laboratory equipment that is not available to the vast majority of athletic trainers.

While few studies have been done to look at risk factors, many functional tasks have been done to look at the difference between those with CAI and healthy controls. The SEBT has been shown to have conflicting results with several showing differences in at least one direction<sup>21 22</sup> with several others showing no differences in reach distance.<sup>23-25</sup> SEBT research has not proven consistent enough to show it is a capable tool of detecting differences between those who have CAI and healthy subjects. The Functional Movement Screen deep squat has been used to look at differences between CAI and healthy controls, with no differences found between the groups.<sup>26 27</sup> Other functional studies include drop and jump landings where time to stabilize, ground reaction forces, and kinematics have been shown to be different between the groups.<sup>28-44</sup> Higher or more posteriorly directed GRFs have been shown in those with CAI along with more anterior shear at the talocrural joint upon landing, both causing more stress to be placed on the stabilizing ligaments.<sup>28-31 42 41</sup> Other research shows that those that have CAI require a longer time to stabilize after hopping tasks<sup>33-38</sup>, which is attributed to a decrease in dynamic stability. Although there are studies that show no difference in groups<sup>32 39 44</sup> an overwhelming majority found differences in at least one area. If there are differences in groups, it is hypothesized that there

could be a difference pre-injury that makes the subjects more likely to sustain a LAS, however, more research needs to be completed to support this theory.

The most promising functional task appears to be related to jump landing; however, many of the functional risk factors studied have used laboratory equipment, which is not readily available in a clinical setting to determine who is at risk of sustaining a LAS. The LESS has been proven to be reliable between users and valid at detecting movement errors.<sup>45</sup> The LESS does not require laboratory equipment and has been associated with other lower extremity injuries at the knee and stress fractures.<sup>45 46</sup> Fusionetics is a movement assessment that has three different tests looking at the lower extremity quality of movement, the overhead squat, the overhead squat with heel lift, and the single leg squat, and it provides total scores, individual test scores, and specific joint scores. Therefore, the purpose of this study is to determine if the LESS or the lower extremity Fusionetics screening is sensitive enough to detect differences in scores in those who have CAI and those who do not. We hypothesize that those who have CAI will have higher (worse) LESS and Fusionetics scores than healthy controls. Worse scores on the movement assessments may indicate that those with CAI are at an increased risk of lower extremity injuries.

## CHAPTER II: REVIEW OF LITERATURE

### Epidemiology

Lateral ankle sprains (LAS) are one of the most common musculoskeletal injuries,<sup>1</sup> which accounts for 40% of lower extremity injuries.<sup>2</sup> Of the lateral ligaments, the anterior talofibular ligament (ATFL) is the most frequently injured. The calcaneofibular ligament (CFL) is injured fairly frequently but mostly in concurrently with an ATFL injury. The posterior talofibular ligament (PTFL) is rarely injured. It is estimated that 2 million ankle sprains occur every year in the United States alone<sup>3</sup> and 5600 incidences per day in the UK<sup>47</sup>. Incidence rates have been listed as 2.15 to 7 per 1000 person-years,<sup>3 4</sup> although females showed a higher incidence of ankle sprains compare with males with one study showing a incidence rate of 13.6 in females.<sup>47</sup> LASs have a high initial health care cost ranging from \$318-\$941 per visit to an emergency room.<sup>48</sup> Given the volume of acute ankle sprains seen, healthcare costs can reach 2 billion dollars annually.<sup>4</sup> Average time lost due to LAS is  $7.1 \pm 6.5$  days.<sup>14</sup>

Acute ankle sprains are a common problem in athletic population; however, many of those with a first time ankle sprain incur recurrent sprains or symptoms that lead to more time lost. Up to 73% of athletes who initially have a LAS have recurrent sprains.<sup>5</sup> Residual symptoms also occur frequently following a LAS. For example, Konradsen et al.<sup>49</sup> found that 32% of patients who had inversion ankle sprains had pain, swelling, or recurrent sprains, while 11% had 3 or more severe sprains a year. Anandacoomarasamy et al.<sup>6</sup> reported that 74% of patients complained of at least one symptom when asked between 1.5 and 4 years following injury. Similarly, 59-72% of LAS patients reported residual disability or recurring symptoms that functionally impaired them during athletic participation.<sup>5 49</sup>

Most importantly, acute LAS and recurrent ankle sprains have been linked to posttraumatic ankle osteoarthritis. Hinterman et al.<sup>50</sup> found that 66% of subjects with lateral ankle ligament injuries had cartilage damage predominately in the medial talus. Sugimoto et al.<sup>51</sup> and Valderrabano et al.<sup>52</sup> found similar results, with 73% and 85% of ankles with instability displaying articular degeneration respectively. Lee et. al.<sup>53</sup> found a significantly greater percentage of those with CAI had osteochondral lesions of the tip of the medial malleolus compared to those without CAI. Using MRI, as opposed to arthroscopic visualization, Golditz et. al.<sup>54</sup> found that an ankle instability group showed greater T2 relaxation times (worse cartilage health) on the medial talar dome relative to copers and uninjured controls; however, copers showed greater changes than the control group. The changes are believed to be a strong predictor of osteoarthritis, showing the presence of an early structure modification.<sup>54</sup>

CAI is a continuum that includes mechanical instability and functional instability.<sup>55 56</sup> However, the link between mechanical and functional instability has not been clearly demonstrated. Mechanical instability is defined as laxity of the talocrural joint caused by damage to the ligaments.<sup>8</sup> Functional instability is defined as recurrent lateral ankle instability due to the disruption of proprioception, postural stability, and neuromuscular control in the ankle.<sup>8</sup> Freeman<sup>9</sup> found that mechanical instability and adhesion formation rarely accounts for functional instability. Hertel<sup>8</sup> suggests that when ankle ligaments are torn, the sensory mechanoreceptors in the ankle are damaged. While the body lays down scar tissue and laxity is often reduced, it does not appear that the body is able to regain the mechanoreceptors which provide proprioception to allow the body to know joint position. Functional instability and mechanical instability do not occur together in many cases. Mechanical instability results from damage to the lateral ankle ligaments that predispose ankle to future instability by impairing arthrokinematics, pathological laxity, and static stability.<sup>55</sup> Pathologic laxity refers to the

increased amount of joint laxity in triplanar directions. Absence of the ATFL allows more anterior movement of the talus whereas damage to the CFL allows the talus to tilt more towards inversion.<sup>55</sup> Functional instability has been related to impaired postural control and other dynamic functional tasks, and chronic ankle instability has been shown to influence feedback and feed-forward mechanisms of motor control.<sup>57</sup> Studies have been able to show what percentages of first time ankle sprains develop chronic ankle instability; however, the link between why certain patients develop recurrent problems is still unknown.

Hertel<sup>55</sup> in a later article described chronic ankle instability as recurrent lateral ankle instability that results in recurrent ankle sprains. Hiller et al.<sup>56</sup> advanced the model by describing CAI as symptoms ranging from giving way of ankle, loss of strength, recurrent sprains, pain, and swelling. Although there are many definitions of ankle instability, Delahunt et. al.<sup>7</sup> conducted a review of the literature and recommended the definition of CAI to include the presence of recurrent symptoms for a minimum of one year after initial LAS. Most recently, the International Ankle Consortium, determined inclusion criteria of CAI as at least one ankle sprain, a history of previously injured ankle giving way or recurrent sprains, and a function questionnaire such as the Foot and Ankle Ability Measure or the Foot and Ankle Outcome score.<sup>58</sup> Subjects with multiple sprains complain of more symptoms than those who have had only a single sprain.<sup>5</sup>

It is unknown why some individuals become a copers versus developing CAI, and more research is needed to see if there are indeed differences in copers and subjects with CAI. It has been shown that copers have better postural control than subjects with CAI, and it is believed that copers have compensatory strategies that allow them to prevent recurrent sprains.<sup>59</sup> However, these compensatory strategies are not fully understood. Copers are referred to those who have a have had an initial lateral ankle sprain but do not have recurrent sprains following a period of time after injury.<sup>59</sup> Copers do not experience recurrent sprains or symptoms after an

initial LAS like those with CAI do and report limited or no self reported disability and better function than those with CAI. Studies have found no differences in laxity, talar position, and fibular position in copers when compared to those with CAI.<sup>59</sup>

Wikstrom and Brown<sup>59</sup> report minimum inclusionary criteria should include an ankle sprain that is severe enough to warrant immobilization for one week or non-weight bearing for minimum of three days, return to moderate activity for 12 months without a recurrent ankle sprain, and minimum disability reported on a questionnaire. Copers report better overall ankle function than those with chronic ankle instability.<sup>59</sup> Research has not been able to distinguish why certain patients develop chronic ankle instability and why some become copers and have no recurrent problems following an acute sprain.

### **Risk factors**

Ankle sprains are a common injury and because they often result in long term instability. In order to understand how to prevent them, there needs to be a general understanding of risk factors. General risk factors have been found, including BMI, previous injury, and ankle strength. Studies have been done to look at intrinsic risk factors for first time ankle sprains and chronic ankle instability; however, not much consistency has been found among the results of those studies. The most common risk factors include previous injury, BMI, increased body weight, and asymmetry between eccentric ankle plantar flexion and ankle dorsiflexion.<sup>10</sup> Previous injury has been shown to be the most consistent and important risk factor.

Ekstrand and Gillquist<sup>60</sup> found that the dominant limb was sprained 92% of the time and that 47% of the ankles had been previously injured. They concluded that a lateral ankle sprain is significantly more common in a previously injured ankle than those without a history of ankle sprains. De Noronha et al.<sup>15</sup> study also found that those with previous history of ankle sprains

were 2x as likely to suffer an ankle sprain. They found that previous injury was the strongest predictor of ankle injury.

Two studies looked at deficits in range of motion, and both found that less dorsiflexion increased risk of ankle sprains.<sup>12 13</sup> Subjects with less dorsiflexion than average were at a 5x greater risk of an ankle sprain, which is considered a strong predictor of ankle sprains.<sup>12</sup> Baymhauer et al.<sup>13</sup> found that muscle strength imbalances increased risk of ankle injuries. Peak torque and average torque were measured of lower-leg musculature to determine if the risk of ankle sprains is related to isotonic or isokinetic strength.<sup>11</sup> Subjects with lower eccentric plantar flexion were 10.8x more likely to sustain a lateral ankle sprain and those with lower inversion eccentric strength were 4.4x more likely to sustain a ankle sprain.

McGuine et. al.<sup>14</sup> looked at balance as a predictor of ankle sprains, and found that those who sustained injuries had higher preseason compilation (COMP) scores, indicating worse postural stability, compared to those who did not suffer sprains. COMP scores where assessed by looking at postural sway while balancing on a single limb with eyes open and eyes closed.<sup>14</sup> McGuine et al.<sup>14</sup> found that an increase in COMP scores correlated with increased rates of ankle sprains thus leading them to the conclusion that poor balance may predispose athletes to ankle injuries. Beynnon et al.<sup>16</sup> also looked at postural sway differences in healthy athletes but did not find a relationship between COMP scores and the risk of initial ankle sprains. However, De Noronha<sup>12</sup> found postural sway to be a moderate predictor of ankle sprains, and in a later study, he found that those who scored below an 80% on the SEBT in the postereolateral direction were at 48% greater risk of suffering an ankle sprain.<sup>15</sup> Those with abnormal postural stability have a significant increase in the risk of sustaining an ankle injury.<sup>17</sup>

A study looking at four way hops over a hurdle onto a force plate found a difference in dynamic postural stability, measured by looking at stability index and GRF.<sup>61</sup> The study found

that subjects were 4-13x more likely to sustain a lateral ankle sprain if they were unable to control their momentum during the forward hop, and they were 2x more likely to sustain an ankle sprain if they could not control their landing during a backwards hop. This study showed the ability to predict ankle sprains by using a forward and backwards hop. Another study found that the weight-bearing lunge test, BESS, and SEBT scores were not associated with sustaining a lateral ankle sprain.<sup>18</sup> Again, showing the SEBT is not as consistent in being an ankle sprain injury risk test. Finally, a study found that using a modified BESS test, scoring above the median for the foam tests were 70% more likely to sustain a lateral ankle sprain.<sup>19</sup> Based on the above research, some risk factors are more functional in nature and can be used in a clinical setting to look at biomechanical differences in those that suffer injuries and those that do not. However, other functional movement patterns should be investigated, especially those that can be incorporated into a clinical setting, without the use of laboratory equipment given the inconsistencies noted in the literature.

### **Dynamic tasks in chronic ankle instability**

There are functional tasks that have been studied to determine differences between those with CAI and healthy controls, one of which being the Star Excursion Balance Test (SEBT). The SEBT is a non-instrumented test that is used to measure dynamic postural stability by having a patient stand on one leg while reaching in eight different directions. Anterior, posteromedial, and posterolateral directions are commonly used to measure reach distance and normalized by leg length. All eight directions are not needed for the SEBT to be used as a clinical test for functional deficits. Two studies show that the posteromedial component is representative of all eight components in subjects with or without CAI and show that the other seven directions do not need to be tested to show deficits.<sup>62,21</sup>

Several studies found no significant difference in reach difference when comparing healthy controls to those with CAI or copers.<sup>23,24,25</sup> Hertel et. al.<sup>21</sup> found significant deficits in subjects with CAI compared to healthy in the anteromedial, posteromedial, and medial directions. Another study found significant differences in performance in all eight directions in those with CAI compared to healthy controls and their uninjured limb.<sup>22</sup>

While some studies found no difference in reach distance, one study looked at trunk rotation, pelvic rotation, and hip flexion and found all three were greater in those with CAI with the anteromedial reach, and an increase in just trunk flexion in the medial reach in those with CAI.<sup>24</sup> Changes in trunk and pelvic motion may be a compensatory movement to increase deficits in reach distance or a risk factor of initial sprains or CAI.

While the SEBT is a non-instrumented test, occasionally EMG activity of muscles like the tibialis anterior and peroneus longus are measured and studied to see differences in groups. EMG results showed greater activity of the tibialis anterior and the peroneus longus of copers compared to healthy controls which may be a compensatory strategy to improve stability while performing the SEBT.<sup>25</sup> However, the study did not find a significant difference in EMG activity of the copers compared to those with CAI.

The SEBT can be used as a predictor of lower extremity injuries, with girls who have composite scores less than 94% of leg length were 6.5 times more likely to sustain a lower extremity injury.<sup>63</sup> The same study found boys who had right and left leg reach distances different than 4 cm were 2.5 times more likely to sustain a lower extremity injury. While lower extremity injury is not specific to the ankle, a functional test that can predict injury without the use of laboratory instruments is an important clinical tool. The SEBT is a clinical tool that can be used without equipment; however, the research has not been developed to show that it is a capable tool of detecting differences in those with CAI and those healthy subjects.

Only two previous articles have looked at differences between those with CAI and healthy controls performing another functional movement, the squat. Both previous articles used the Functional Movement Screen (FMS) lower extremity assessment. One study included the deep squat and the hurdle step over<sup>26</sup> while the other included all three exercises: hurdle step over, deep squat, and the in-line lunge.<sup>27</sup> For the deep squat, the FMS scores the test 0-3. A 3 is achieved if the subject can perform a deep squat keeping their heels on the floor, head and chest facing forward, and does not have valgus collapse of either knee with feet shoulder width apart. If any compensation is noted, the FMS board was placed under the heels. If the subject is able to complete the test with no compensations with their heels raised, a score of 2 is given. If the subject is still unable to perform the test, a score of 1 is given. A score of zero is achieved if the subject has any pain with testing. Both previous tests found no differences in deep squats between groups.<sup>26 27</sup>

### **Drop and Jump Landings**

It is hypothesized that differences in jump or drop landings between those with CAI and healthy controls may increase risk of ankle sprains. Studies have investigated biomechanical differences in sagittal and frontal plane kinematics, ground reaction force (GRF), and time to stabilization during drop landing in those with CAI compared to healthy controls or copers.<sup>28-44</sup> Some studies found that those with CAI have higher GRFs during single leg drop landing compared to healthy individuals.<sup>28 29</sup> Increased GRFs are often attributed the known dorsiflexion deficit seen in those with CAI. These DF deficits are thought to limit the ability to absorb shock or dissipate force.<sup>28</sup> Stiffer landings may predispose subjects to ankle instability or recurrent sprains.<sup>29</sup> Individuals with CAI also showed altered ankle displacement with an increase in peak anterior and lateral forces occurring earlier than in healthy individuals during jump landing.<sup>31</sup> These earlier forces during landing can cause an increase in the stress on the ankle and the risk of

re-injury. They are theorized to be attributed to altered feed-forward mechanics.<sup>31</sup> Caulfield et al.<sup>30</sup> found differences between CAI and healthy control groups in pre-landing angles of the knee and ankle that are attributed to differences in feed forward motor control. A decrease in angular displacement does not allow shock absorption and increases the risk of injury.<sup>30</sup>

Lateral and forward hops have also been used to look at differences in landing kinematics between CAI and controls. De Ridder et al.<sup>32</sup> found no differences in lower limb kinematics when comparing CAI to controls in lateral and forward jumps, while recently his work found an increase in GRF in those with CAI causing them to have a stiffer landing in a side jump test.<sup>29</sup> Other jumping tasks have found that those with CAI, functional instability, or mechanical laxity need a longer time to stabilize after landing than healthy controls.<sup>33-38</sup> Gribble et. al.<sup>34</sup> also found a decrease in pre-landing knee flexion that may contribute to a decrease in the dynamic stability of the ankle; subsequently causing an increased time to stabilize. Knee flexion upon impact helps dissipate forces and control ground reaction forces. In addition, more knee flexion lowers the center of gravity, which improves postural stability. Only one study found no difference in dynamic postural stability during jump landings between CAI, copers, and healthy controls.<sup>39</sup>

Stop jump landings are another form of functional testing. By having subjects land and then jump to maximum height, these tests mimic more of a functional movement performed in sports that have high incidences of ankle injuries. Studies found differences in EMG activity of the peroneals and/or tibialis anterior between those with CAI and control subjects.<sup>40 43 42</sup> Two studies<sup>40 43</sup> found a decreased EMG activity of co-contraction of the peroneus longus and tibialis anterior pre-landing which decreases the ability of dynamic stabilizers of the ankle to provide joint stability and potentially prevent injury. Decreased preparatory muscle activity could allow landing in a more plantar flexed and inverted position, a common mechanism for lateral ankle sprains.

Lin et. al.<sup>40</sup> hypothesized that an alteration in muscle feed-forward activation, can increase risk of re-injury. This could also increase injury risk as plantar flexion is an open packed position that decreases bony congruence of the ankle. Participants with functional instability had a longer time to reach a closed packed, dorsiflexed position of the ankle joint. Limited dorsiflexion range of motion can increase the likelihood of a lateral ankle sprain.<sup>42</sup> A decrease in dorsiflexion at initial contact during single leg jump landing may explain an increase in posterior GRF which can cause a higher transmission of force to the stabilizing ligaments and joint articular surfaces which could explain the high incidence of OA and ligament injuries in those with ankle instability.<sup>42</sup> A delay or decrease in dorsiflexion may result in the posterior GRF due to the changes in the position of body mass and center of gravity, causing an increase of stress on the articular surfaces.

Studies also looked at the frontal plane motion upon landing and found a greater variability in ankle frontal plane motions in those with FAI. Due to the laxity in the ATFL, the ligament is not able to limit anterior translation which can increase risk of injury as the motion exceeds safe movement patterns, and may explain the increase in variability in GRF.<sup>41</sup> In contrast, Terada et. al.<sup>44</sup> found no significant difference in peak anterior tibial shear force between those with CAI and the control group. Peak anterior tibial shear force had a moderate inverse correlation with knee flexion and was strongly correlated with posterior GRF; however neither outcome was significantly different between groups.<sup>44</sup>

Overall dynamic functional tests have shown differences in those with chronic ankle instability and healthy controls. Many of these functional tests require lab equipment including force plates and 3-dimensional motion capture systems. Since they are not available in many clinical settings, other clinical assessment tools may be needed.

## LESS

The Landing Error Scoring System (LESS) is a functional movement screen that can be used with or without laboratory equipment. The test involves a horizontal jump off of a 30-cm box placed 50% of the subject's height from a landing target followed by an immediate maximum vertical jump. Keys to the test are instructing subjects to jump with both feet simultaneously, not jumping vertically off the box, and completing the motions in a fluid manner. Standard video cameras, to capture the frontal and sagittal planes, help ensure valid scoring. Scoring consists of counting landing errors, with higher scores indicating worse landing technique. Errors include positioning of lower extremity and trunk upon landing, positioning of the feet, positioning of the trunk during landing and amount of displacement of each joint in both sagittal and frontal plane. 3D motion analysis, the gold standard of kinematic and kinetic movements, showed the LESS to be valid and reliable at indicating movement errors.<sup>45</sup> Interrater reliability ranged from .72-.81 for the LESS scored in real time<sup>65</sup> and proved to have moderate to excellent interrater reliability between experts and novices.<sup>66</sup> Automatic scoring, via the Physimax system, has also been shown to have the same reliability as expert LESS raters.<sup>68</sup>

The LESS has shown that subjects with high LESS scores have significantly different landing kinematics compared to subjects with lower LESS scores.<sup>45</sup> Those with low LESS scores displayed good landing technique while those subjects with high LESS scores displayed poor landing technique, which has been shown to increase risk for a noncontact ACL injury.<sup>45</sup> Subjects who had noncontact ACL injuries had higher LESS scores than those that did not, showing the LESS has potential to be a screening tool for noncontact ACL injuries.<sup>46</sup> Poor less scores were associated with decreased knee and hip flexion angles, increased knee valgus and hip adduction, increased internal rotation of knee and hip, and anterior shear force. Decreases in knee flexion may be the most sensitive indicator in the LESS of those with CAI; however,

alternative kinematics and kinetics may need to be included to expand the LESS to be useful for looking at ankle instability.

While the LESS can be used to identify those with poor landing biomechanics that put them at risk for an ACL injury, limited data is available regarding jump landing biomechanics as a predictor of injury. While some landings biomechanics appear capable of predicting ankle injury risk, they have not used a clinically available tool like the LESS. To date, only one other non-instrumented functional task, the SEBT, has been shown to predict ankle sprain injury risk. Worse scores on the Fusionetics and LESS tests may indicate that those with CAI are at an increased risk of lower extremity injury. Thus, identifying another functional task that is easily deployed in clinical settings would be valuable.

Previous studies have found previous injury to be the biggest and most consistent risk factor for a lateral ankle sprain. Several previous studies have looked at balance tasks as a predictor of injury, but the results have been inconclusive. Additionally, more functional tasks have been used to look at differences in those who have already developed CAI and healthy controls and have found differences in those groups. However, all of these significant findings with functional tasks have used laboratory equipment. There is no functional task that can be completed without laboratory use used to look at differences between the groups or injury risk. Fusionetics and the LESS are clinically applicable tests and this study will look to prove they are capable of detecting differences in movement quality and efficiency between healthy controls and CAI.

## CHAPTER III: METHODS

### 3.1 Research design

This case-control study sought to identify if the LESS and/or Fusionetics was sensitive enough to identify those who have CAI compared to controls. The independent variable was group, CAI and control. The dependent variables were the overall scores and the overall Fusionetics as well as the individual Fusionetics scores for the overhead squat, overhead squat with heel lift, and the single leg squat with a max possible score of 100 for each (appendix 1). Outcomes were compared between groups at one time point during preseason screenings.

### 3.2 Participants

Ninety-nine participants were used in this study. These participants were varsity athletes at the University of North Carolina at Chapel Hill. Physically active individuals participated in at least three thirty minute sessions of sporting activity a week. The inclusion and exclusion criteria for the CAI group was determined by the International Ankle Consortium.<sup>58</sup> The inclusion criteria for CAI group consisted of a history of at least one significant ankle sprain that occurred at least 12 months prior to enrolling in the study and was associated with inflammatory symptoms and interrupted at least one day of physical activity. Inclusion criteria also included at least 2 episodes of giving way in the six months prior to the study and scoring above a 10 on the Identification of Functional Ankle Instability (IdFAI). Inclusion criteria for the control group included no previous ankle sprain. IdFAI and FAAM-s were collected on control group but was not included in the inclusion criteria. Exclusion criteria for both groups included a history of previous surgery to either lower extremity, a history of lower extremity fracture requiring realignment, and an acute lower extremity joint injury in the previous 3 months resulting in an

interruption of one day of physical activity. Participants could be between 18-35 years old. This study was approved by the Institutional Review Board (IRB) of the University of North Carolina at Chapel Hill.

### **3.3 Instruments**

Fusionetics is a movement efficiency screen that is broken up into seven specific components, three for the lower body. The lower extremity Fusionetics<sup>64</sup> score was determined by performance on the un-weighted overhead squat, the overhead squat with heel lift, and the single leg squat tasks. Before conducting the squat assessments, verbal instructions were given to participants: “feet shoulder width apart, toes pointing straight ahead, and arms fully extended up by your ears. Squat down to the height of a chair seat.” The same instructions were given for the overhead squat with the heel lift except the heels were placed on a small weight plate (~3/4 inch).

For the single leg squats, “Stand on one leg with toes pointing straight ahead and hands on hips, squat down to the height of a chair seat.” The tester observed movements from the front and recorded the compensations that occurred at each checkpoint. The detail for movement compensations can be seen in appendix 4. Major themes that were noted in Fusionetics are any alterations in foot or knee positioning that occurred due to hip, knee, or ankle factors. Another major theme was asymmetry between sides, especially when looking at single leg squats.

A total Fusionetic score was calculated out of 100, the maximum score, with lower scores indicating worse movement. This was the first study to look at the Fusionetic scores on those with or without chronic ankle instability. Previous studies have used the deep squat of the Functional Movement Screen and have found no differences between a control and a CAI group on deep squat scores.<sup>26 27</sup> The FMS squat was scored on a scale of 0 to 3 based on how they performed correctly, which may not be sensitive enough to distinguish between the groups. In

the Fusionetics squat assessment, however, specific errors are noted at each joint and the errors are deducted from the total squat score based on computer scoring. There are 10 total errors for the overhead squat and the overhead squat with heel lift, and 5 errors for the single leg squats. Different errors are weighted differently. Appendix 4 shows specific errors for the Fusionetics squat tasks. Errors look at foot and knee positioning, arch collapse, lumbar spine arching or rounding. The single leg squat has fewer errors and also looks at foot and knee positioning as well as uncontrolled trunk flexion and loss of balance. The Fusionetics scoring should be able to pick up smaller differences in movement between participants than the FMS squat scores. The Fusionetics scores were calculated on the online portal by the proprietary Fusionetics software. The scores start at 100 and decrease with each error. The magnitude of reduction, depends on the error made. Fusionetics has developed cut off scores to separate participants into good, moderate and poor movers. Based on the Fusionetics algorithms, good movers score between 75-100, moderate score between 50-75, and poor movers score below 50.

The Landing Error Scoring System (LESS) was scored automatically using the PhysiMax software.<sup>67</sup> The detailed scoring criteria can be seen in Appendix 3. A Microsoft Kinect Camera was used to record the LESS which initiated by setting a 30cm box a distance of 50% the participants height away from the target landing area (Appendix 2). The participants were then instructed, “Starting with feet pointing straight ahead and feet shoulder width apart, jump out, not up, off of both feet, land in the landing area with both feet hitting at the same time and immediately jump up for maximal height.” The LESS is a valid and reliable movement assessment.<sup>45</sup> The Interrater reliability ranged from .72 to .81.<sup>65</sup> LESS errors are indicators of poor landing techniques and can predispose the participant to injuries. The PhysiMax software immediately scored the LESS and the scores were recorded for each participant. The PhysiMax software has been shown to have the same reliability as expert LESS raters<sup>68</sup>.

IdFAI is a self-reported questionnaire based on two previous FAI instruments, the Ankle Instability Index (AII) and the Cumberland Instability Tool (CAIT). The IdFAI is a ten-item questionnaire with a discrimination score of 10, meaning those scoring higher than a 10 are considered to have FAI (Appendix 6).<sup>69</sup> Gurav et al.<sup>70</sup> found the IdFAI to have excellent test-retest reliability ( $ICC_{2,1}=0.959$ ). Overall, the IdFAI was found to have an accuracy of 89.6%, which is higher than the accuracy of the CAIT and AII combined.<sup>69</sup> This questionnaire can be filled out quickly and easily and is an accurate and feasible way to determine whether participants have FAI.

The Foot and Ankle Ability Measurement-sport subscale (FAAM-s) is another self-reported foot and ankle function questionnaire about sport activities (Appendix 5). Each question has point values from 0 (unable to do) to 4 (no difficulty at all). The scores are then transformed into percentage scores with higher scores indicating higher levels of function.<sup>71</sup> The maximum score for the sports subscale is 32. The score is divided by the highest possible score and then multiplied by 100 to get a percentage. A higher percentage is a representation of higher function.<sup>71</sup> The FAAM test retest reliability was .87 for the sports subscale.<sup>72</sup> The FAAM sport allowed us a comparison between the CAI and control groups on the level of disability in sport activities.

### **3.4 Procedures**

After determining eligibility via the IdFAI score, participants completed the Fusionetics screening by completing five overhead squats, overhead squats with heel lift, and finally five single leg squats for both limbs. The Fusionetics data was collected on Fusionetics scoring sheets by the examiner. Participants then were given practice trials of the LESS until they were comfortable with the movement. Next, participants completed the FAAM-S questionnaires. Finally, participants completed three test trials of the LESS with the PhysiMax cameras on to

score the jump landings. Failed trials of the LESS were discarded and repeated. LESS jump landings were considered successful if the participants (1) jumped off of both feet from the box; (2) jumped forward, but not vertically, to reach the force plate below; (3) landed with the entire foot of the dominant lower extremity on the force plate; (4) landed with the entire foot of the non-dominant lower extremity off the force plate; and (5) completed the task in a fluid motion.<sup>45</sup> The test order was recorded.

### **3.5 Statistical Analysis**

Sample size estimates were based on sample sizes from pilot testing. A power analysis was conducted based on effect sizes. Calculated effect sizes from pilot testing of recreational athletes, indicate a total sample size of 174 was needed to observe significant differences in CAI and control for the total Fusionetics. A sample size of 70 was needed to observe significant differences in the LESS.

Komogorov-Smirnov normality tests were used to determine normality of dependent variables. Fusionetics, LESS, and individual component scores were assessed using separate nonparametric statistics to compare between the two groups, controls vs. CAI. Non-parametric statistics were used because four out of the five dependent variables indicated that the data was not normal distribution. A frequency distribution of movement quality (Good, Moderate, Poor) by group was analyzed with Chi Square. A Spearman Rho correlation was run on CAI cases only to determine correlations between IdFAI, FAAM-Sport, and number of ankle sprains and Fusionetics individual and total score, and LESS total score. An alpha level of 0.05 was used for all analyses and Statistical Product and Service Solutions (SPSS) programming was used to run all the statistics. The Hedges' g between group effect sizes with a 95% confidence interval were calculated.

**Table 3-1 Variables**

Independent Variables	Dependent Variables
<b>Group:</b> -CAI -Healthy controls	Total Fusionetics Overhead squat Overhead squat with heel lift Single leg squat LESS scores

**Table 3-2 Research Aims**

Aim	Description	Variables	Comparison	Outcome variable	Analyses
1	Differences in Fusionetics scores between CAI and healthy controls	<u>Dependent variables:</u> -Total Fusionetics scores -SL squat score -OH squat score -OH squat score with heel lift  <u>Independent variable:</u> -CAI group -Healthy control group	Total Fusionetics scores of CAI vs. total Fusionetics scores of healthy controls	Scores range 0-100	4 different independent samples t-tests for each of the 4 dependent variables
			SL Squat scores healthy vs. CAI	Scores range 0-100	
			OH Squat scores healthy vs. CAI	Scores range 0-100	
			OH Squat Heel lift scores healthy vs. CAI	Scores range 0-100	
2	Differences in LESS scores between CAI and healthy controls	<u>Dependent variables:</u> -Total LESS Scores  <u>Independent variable:</u> -CAI group -Healthy control group	Total LESS scores of CAI vs. total LESS scores of healthy controls	LESS scores 0-17	1 independent samples t-test

## CHAPTER IV: RESULTS

### Demographics

Ninety-nine subjects from six division one NCAA sports met the inclusion and exclusion criteria. Forty-nine of those participants were deemed to have CAI (M:20;F:29, age  $19.86 \pm 1.24$ , height  $68.59 \pm 3.14$ , weight  $159.41 \pm 25.67$ , IdFAI  $15.63 \pm 3.86$ , FAAM-S  $94.58 \pm 9.61\%$ ) and fifty participants were considered uninjured controls (M:26;F:24, age  $19.64 \pm 1.08$ , height  $69.82 \pm 3.54$ , weight  $159.82 \pm 25.94$ , IdFAI  $1.20 \pm 2.30$ , FAMM-S  $98.82 \pm 5.42\%$ ). Normality tests show that age ( $p < .01$ ) and height ( $p < .01$ ) are not normal therefore nonparametric statistics are used to compare age, height, and weight between groups. There were no differences in age ( $p = .356$ ), height ( $p = .244$ ), and weight ( $p = .937$ ). A breakdown of the participant's sport by Group can be seen in Table 4.1.

**Table 4-1** Number of participants by sport

	CAI	Control
<b>Women's Crew</b>	10	9
<b>Men's Soccer</b>	9	12
<b>Women's Soccer</b>	4	3
<b>Men's Lacrosse</b>	11	14
<b>Women's Lacrosse</b>	9	4
<b>Field Hockey</b>	6	8

## Normality

Komogorov-Smirnov normality tests were run on the five dependent variables. Four out of the five tests were significant: LESS  $p < .05$ , Fusionetics  $p = .20$ , DL squat  $p < .01$ , DL squat with heel lift  $p < .01$ , SL squat  $p < .01$  indicating the data is not normally distributed. Therefore, non-parametric statistics were used to compare the two groups.

## Group differences

No differences were found between groups for LESS score ( $p = .514$ ), total Fusionetics score ( $p = .491$ ), un-weighted overhead squat score ( $p = .814$ ), overhead squat with heel lift score ( $p = .725$ ), or the single leg squat score ( $p = .359$ ). Group means and standard deviations for each test can be seen in table 4-2 below. The Chi square results were not significant for each task, total Fusionetics ( $p = .715$ ), DL squat (.073), DL squat with heel lift ( $p = .681$ ), and single leg squat ( $p = .321$ ).

**Table 4-2** Means and standard deviations

	<b>LESS (0-17)</b>	<b>Fusionetics (0-100)</b>	<b>DL squat (0-100)</b>	<b>DL Squat HL (0-100)</b>	<b>SL Squat (0-100)</b>
<b>CAI</b>	4.94±1.93	65.39±12.33	66.41±18.22	82.38±13.61	49.20±21.91
<b>Control</b>	4.80±1.99	67.01±15.10	67.60±16.61	80.33±16.58	54.00±24.06
<b>Effect Sizes</b>	.05	-.08	-.05	.09	-.15
<b>95% CI of the effect size</b>	(-.34 to .44)	(-.48 to .31)	(-.44 to .35)	(-.3 to .49)	(-.54 to .25)

**Table 4-3** Cutoff score frequency for Fusionetics scores

		Total Fusionetics	DL squat	DL Squat with heel lift	SL Squat
<b>Good</b>	CAI	13 (26.5%)	20 (40.8%)	35	5 (10.2%)
	Control	17 (34%)	17 (34%)	32 (64%)	9 (18%)
<b>Moderate</b>	CAI	29 (59.2%)	20 (40.8%)	13	22 (44.9%)
	Control	27 (54%)	30 (60%)	16 (32%)	25 (50%)
<b>Poor</b>	CAI	7 (14.3%)	9 (18.4%)	1	22 (44.9%)
	Control	6 (12%)	3 (6%)	2 (4%)	16 (32%)

### **Correlations**

Within the CAI cases, no significant correlations between LESS or Fusionetics scores and injury characteristics associated with CAI (e.g. IdFAI, number of ankle sprains, etc.) were noted. However, significant correlations were noted among CAI participant's weight and height and total Fusionetics scores, double leg squat scores, and double leg heel lift squat scores. A table illustrating the relationships among these variables can be seen in table 4-4.

**Table 4-4** Spearman correlations between injury characteristics and movement assessments in CAI participants.

	LESS	Fusionetics	DL Squat	DL Squat HL	SL Squat
Number of sprains	-.202 p=.164	-.279 p=.052	-.229 p=.114	-.138 p=.343	-.167 p=.251
IDFAI	-.154 p=.290	-.265 p=.066	-.211 p=.145	-.258 p=.073	-.121 p=.406
FAAM Sport	-.203 p=.161	.173 p=.234	.074 p=.612	.053 p=.717	.219 p=.130
Height	-.198 p=.172	-.346 p=.015	-.287 p=.046	-.356 p=.012	-.139 p=.339
Weight	-.105 p=.473	-.400 p=.004	-.284 p=.048	-.378 p=.007	-.201 p=.167

## CHAPTER V: DISCUSSION

The purpose of this study was to compare movement efficiency during four tasks (LESS, double limb squat, double limb squat with heel lift, single limb squat) between collegiate athletes with and without CAI. We hypothesized that collegiate athletes with CAI would score significantly higher (worse) on the LESS than healthy controls and that collegiate athletes with CAI would score significantly lower (worse) on Fusionetics total score for each task relative to healthy controls. The results of this study overall failed to support our a priori hypotheses for both research questions.

### Sample Comparison

The current sample of CAI athletes were required to have sustained at least one lateral ankle sprain and score  $\geq 10$  on the IdFAI. This differs from previous studies which have used a wide range of inclusion criteria. The majority required at least one previous lateral ankle sprain, although a few required at least two<sup>30-32 42</sup> or more<sup>36 40</sup> to be defined as having CAI. Similarly, most previous participants were recreationally active and completed cardiovascular exercise or recreational sports like intramural soccer or basketball and found sensorimotor differences between a CAI and uninjured control group. Only one other study included Division I athletes as participants<sup>38</sup> and in that investigation differences, relative to uninjured controls, in static postural control were not detected. However, the CAI group did take longer to stabilize after landing from a jump relative to the uninjured control group.<sup>38</sup> Thus, our lack of group differences may have been due to the highly developed sensorimotor system in college athletes,

regardless of the presence of CAI. However, only two studies have been done in collegiate athletes with CAI, more research is needed.

Our average FAAM-sport scores for the CAI participants would support this hypothesis. Despite being classified as having CAI, the average FAAM-Sport score was 94.58% whereas previous studies often report FAAM-Sport scores below 80%.<sup>34 37 44</sup> Despite high functioning in the CAI group, our sample was still significantly lower than the control group. However, it should be noted that many studies in the literature use FAAM-Sport scores as an inclusion criteria which may bias the comparison between the current sample and previous reports. Similarly, no other study used the IdFAI to determine CAI status, instead using the CAIT, FAAM/FADI, or the AII.<sup>25-28 33 34 37 38 40 43</sup> While our results could suggest that the IdFAI was not an appropriate tool to classify participants, it must be noted that the scale was developed from the CAIT and AII.<sup>69</sup> More specifically, the IdFAI was developed to eliminate the number of diagnostic questionnaires being used in the CAI literature and was found to have an accuracy of 89.6% in identifying participants with the minimally accepted criteria for CAI.<sup>69 73</sup> While, it is possible that using a different classification tool could have altered the results, we are confident that the IdFAI accurately identified NCAA Division 1 collegiate athletes with CAI.

## **Group Differences**

### **Jump landings**

Previous literature for functional tasks in those with CAI have looked at both single and double limb drop or jump landings. These studies examined: GRF, EMG, and kinematics between healthy controls and CAI patients. Previous studies have found higher GRFs in CAI compared to control groups, and stiffer landings are often attributed to the inability to absorb shock<sup>28</sup> and may predispose participants to ankle injuries.<sup>29</sup> While the LESS is able to detect

differences in landing stiffness, it is likely that detecting a single error out of 17 possible errors may not be enough to show significant differences between the groups.

Differences in CAI and control groups have been found in single limb time to stabilization following a jumping task.<sup>33-38</sup> This study used the LESS, a double limb drop landing task, therefore, it is not as posturally demanding as the single limb jump landings observed in studies above. Additionally, the LESS does not require stabilization but rather requires participants to immediately jump for maximum height after landing from the drop jump. This does not allow time to stabilization to be measured using the LESS and therefore makes direct comparisons difficult.

Stop jump tasks, similar to the LESS, have been studied to look for differences between groups as well. These tasks mimic functional activity more closely than other jumping tasks. Previous studies have looked at both biomechanical changes and EMG activity, whereas the LESS only detects biomechanical differences. Biomechanical differences have been noted in previous studies but not in the current study. The LESS may not be sensitive enough to detect ankle specific differences compared to 3D biomechanics. Deficits in EMG have been found in both the peroneus longus and tibialis anterior in CAI participants which causes a decreased ability of dynamic stabilizers to provide stability.<sup>40 42 43</sup> Previous stop jump studies have differed from the LESS by looking at feed forward activation and hypothesized that a decrease in feed-forward activity can increase risk of injury.<sup>40</sup> The LESS is able to detect foot positioning at initial contact and maximum joint displacement but muscle activation is typically not recorded during the LESS. While initial contact is an indicator of feed-forward activity it is not a direct measure of the amount of preparatory muscle activity present. EMG activity may be a better indicator of compensations present in CAI participants than biomechanics alone using the LESS.

Finally, studies have looked at frontal plane motion with jump landings between CAI and control participants. These studies show greater anterior tibial shear force which may explain greater GRF findings. However, these studies had mixed results with one showing a difference between FAI participants and healthy controls<sup>41</sup> and another showing no difference.<sup>44</sup> The LESS also looks at the frontal plane errors but these errors focus on knee valgus and hip adduction, not ankle specific frontal plane errors.

Cumulatively, laboratory instruments have identified kinematic, and kinetic differences between CAI and uninjured control groups. However, the current study looked at a non-laboratory based test that could be used in a clinical setting. The LESS has been shown to identify worse landing kinematics<sup>45</sup> in those at greater risk for ACL injuries.<sup>45 46</sup> Errors indicating joint positioning at initial contact, max displacement, and stiffness of landing are similar to findings in previous literature. However, without laboratory equipment, feed forward muscle activity and anterior tibial translation cannot be measured. As a result, the overall LESS score may not be sensitive enough to detect the changes associated with CAI. Jump landings may be an inappropriate clinical task, or because specific individual movement errors could mask errors that show differences in groups. For example, trunk flexion may not differ between groups but may overshadow a lack of dorsiflexion. We did not examine specific errors related to plantar flexion at landing, or landing stiffness. The presence of these specific errors in isolation may be more appropriate to examine in CAI participants than the overall LESS score.

## **Squat**

Previous literature looked at the deep squat task during the FMS test. Consistent with the current findings, no differences were found between CAI and healthy controls.<sup>26 27</sup> Because Fusionetics has a more robust scoring continuum (i.e. more possible errors), it was hypothesized

that Fusionetics would be better able to pick up CAI associated compensations than the FMS. For example, out of the ten possible errors for the double limb squat, foot flattening, foot external rotation, and heel lift are included. These specific adaptations are thought to be related to decreases in available dorsiflexion. Previous studies have attributed movement compensations and an increased risk of recurrent lateral ankle sprains to a decrease in dorsiflexion.<sup>42</sup>

While there are more possible movement errors that could be identified in the Fusionetics scoring algorithm, few look at the ankle specifically. Further, the proprietary algorithm or proposed movement quality cut points may not be appropriate for looking at ankle specific errors or CAI associated movement abnormalities. Examining the specific errors made by the CAI and uninjured control participants might be more appropriate for the CAI population. Additionally, the postural demands in the double limb task are minimal and may not detect differences associated with CAI.<sup>21-25</sup> Although the single limb squat task has a greater demand for postural stability, both limbs are included in one test. Therefore, if deficits are seen in the involved side, the effect may be minimized due to the score of the uninvolved limb being included with the involved limb.

Single limb balance tasks have been used as a predictor of ankle sprains; however, there are mixed results.<sup>15</sup> Several studies showing balance tests such as the SEBT and the BESS have mixed results in predicting ankle sprain risk<sup>14 18 39</sup> or lower extremity injuries in general.<sup>63</sup> There are also mixed results comparing CAI and healthy participants using the SEBT.<sup>21-25</sup> The Fusionetics single limb squat task was the only task that demanded a similarly challenging balance component (i.e. single limb stance) of the study participants. As stated above, there were no differences between groups, but it was the lowest (worse) scoring test for both groups (CAI 49.20±21.91, Control 54.00±24.06). Thus, the single leg squat may be too challenging for even

the control group. As a result, the SLS may not be able to pick up differences specific to the etiology of CAI. Future research should look at specific errors that CAI participants display during the SLS versus control participants.

### **Individual Variability**

CAI is a heterogeneous condition and thought to have a multi-factorial mechanism. As a result, everyone within the CAI group may move differently; therefore looking at group means may not be the most appropriate way to examine the data. With so much variability in the condition, looking at specific injury characteristics and how they influence sensorimotor function is key. Therefore, looking at group means and/or movement quality categories based on the Fusionetics recommendations may not be appropriate. For example, Choi et. al.<sup>27</sup> used a Spearman correlation to look at the relationship between FADI and FADI-s with the different FMS tasks. They found strong positive correlations between the FMS- Lower extremity score and FADI ( $r=.807$ ) and FADI-sport ( $r=.818$ ) but the FMS deep squat had no correlation with the FADI or the FADI-sport.<sup>27</sup> Similarly, Hubbard et. al.<sup>62</sup> found moderate negative correlations between self-reported function and static postural control with eyes open and closed ( $r=-.45$  to  $r=-.65$ ). These correlations indicate that as FADI and FADI-sport scores decrease, indicating worse ankle function, as postural control worsens. The current study found no correlations between injury characteristics and overall movement assessment scores (Table 4-3). This may be due to the use of high level athletes or the high average self-reported function in our CAI group. Additionally, the Hubbard study used postural control measures that have been proven in several studies<sup>11 14 16</sup> to identify differences between the groups. Postural control tests may be able to identify CAI differences better than Fusionetics or the LESS, which are unproven in their ability to identify ankle specific differences. Future research should focus on correlations between

injury characteristics (e.g. questionnaires of self-reported function, number of sprains, incidences of instability, severity of sprains, etc) and individual movement errors as well as other measures of sensorimotor function.

### **Limitations**

There were several limitations in this study. While we specifically targeted Division I athletes, the generalization of these results to other populations may be limited. This could also suggest that those with worse self-reported function may have worse movement quality relative to the current sample. Additionally, this current study used the Fusionetics platform, which has its own proprietary algorithm for scoring the different tasks. The limitation is that we only used this platform to score movement quality. There could be other more effective ways to score movement quality and identify group differences. Examining movement errors without the Fusionetics platform may be advantageous for CAI related research. Additionally, future research should focus on single limb tasks that increase postural demands like the SEBT or the Y-balance test. These balance tasks have been shown to detect differences in groups and are easily performed in a clinical setting.

### **Clinical implications**

This study was designed to test whether movement efficiency tasks that are clinically based, such as the LESS and Fusionetics, could detect differences in movement patterns of those with CAI in Division I athletes. However, this study shows that these tasks are not sensitive enough to CAI related movement alterations and therefore are likely not good candidates to determine risk of future ankle related injuries. However, differences or lack of differences between groups is different from identifying risk of injury. Based on the current results and previous literature, the Y-balance or SEBT appear to be the best clinician-oriented tools to predict ankle sprain risk.

## **Conclusions**

There was no difference between CAI subjects and healthy controls in Fusionetics total or individual task scores. Similarly, there was no difference between CAI subjects and healthy controls in LESS scores. Finally, despite CAI being a heterogeneous condition, there was no correlation among injury characteristics: number of sprains, IDFAI, or FAAM-S scores and movement assessment scores.

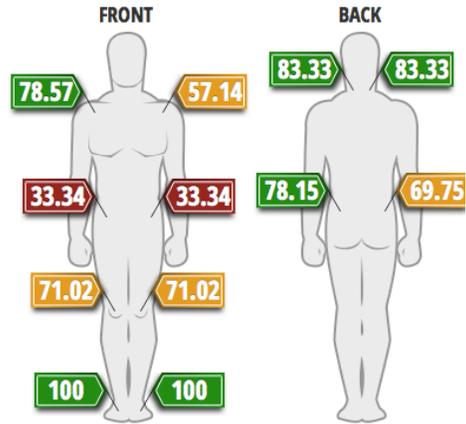
## APPENDICES

### APPENDIX 1: FUSIONETICS SCORING

#### MOVEMENT EFFICIENCY TEST SCORES

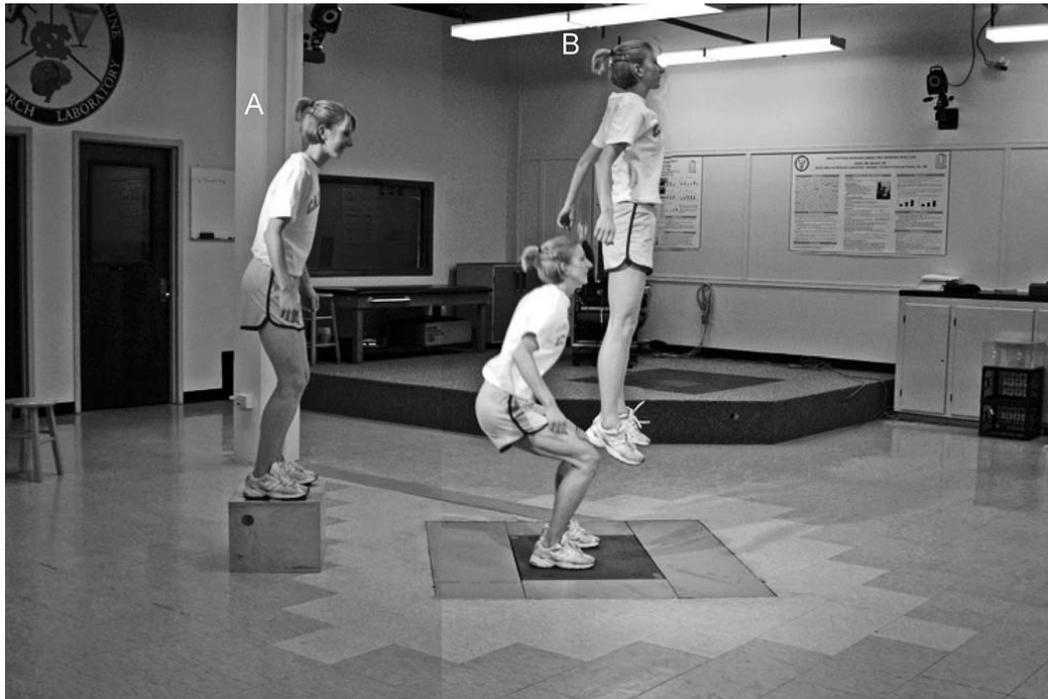
2-LEG SQUAT	83.33
2-LEG SQUAT WITH HEEL LIFT	100
1-LEG SQUAT	33.34
PUSH UP	60.00
SHOULDER MOVEMENT	62.50
TRUNK/LUMBAR SPINE MOVEMENTS	50.00
CERVICAL SPINE MOVEMENT	100

**ME SCORE** 69.39



Scores on the body flags represent movement efficiency at each checkpoint of the body assessed during the ME Test.  
Checkpoints tested: Foot/Ankle, Knee, Hips, Shoulders and Spine.

### APPENDIX 2: LANDING ERROR SCORING SYSTEM DEMONSTRATION



## APPENDIX 3: SCORING FOR THE LANDING ERROR SCORING SYSTEM

**Table 1. Operational Definitions for Individual Landing Error Scoring System Items**

Landing Error Scoring System Item	Operational Definition of Error	Scoring
Knee flexion: initial contact	The knee is flexed less than 30° at initial contact.	0 = Absent 1 = Present
Hip flexion: initial contact	The thigh is in line with the trunk at initial contact.	0 = Absent 1 = Present
Trunk flexion: initial contact	The trunk is vertical or extended on the hips at initial contact.	0 = Absent 1 = Present
Ankle plantar flexion: initial contact	The foot lands heel to toe or with a flat foot at initial contact.	0 = Absent 1 = Present
Medial knee position: initial contact	The center of the patella is medial to the midfoot at initial contact.	0 = Absent 1 = Present
Lateral trunk flexion: initial contact	The midline of the trunk is flexed to the left or the right side of the body at initial contact.	0 = Absent 1 = Present
Stance width: wide	The feet are positioned greater than shoulder width apart (acromion processes) at initial contact.	0 = Absent 1 = Present
Stance width: narrow	The feet are positioned less than shoulder width apart (acromion processes) at initial contact.	0 = Absent 1 = Present
Foot position: external rotation	The foot is externally rotated more than 30° between initial contact and maximum knee flexion.	0 = Absent 1 = Present
Foot position: internal rotation	The foot is internally rotated more than 30° between initial contact and maximum knee flexion.	0 = Absent 1 = Present
Symmetric initial foot contact: initial contact	One foot lands before the other foot or 1 foot lands heel to toe and the other foot lands toe to heel.	0 = Absent 1 = Present
Knee-flexion displacement	The knee flexes less than 45° between initial contact and maximum knee flexion.	0 = Absent 1 = Present
Hip-flexion displacement	The thigh does not flex more on the trunk between initial contact and maximum knee flexion.	0 = Absent 1 = Present
Trunk-flexion displacement	The trunk does not flex more between initial contact and maximum knee flexion.	0 = Absent 1 = Present
Medial-knee displacement	At the point of maximum medial knee position, the center of the patella is medial to the midfoot.	0 = Absent 1 = Present
Joint displacement	Soft: the participant demonstrates a large amount of trunk, hip, and knee displacement. Average: the participant has some, but not a large amount of, trunk, hip, and knee displacement.	0 = Soft 1 = Average
Overall impression	Stiff: the participant goes through very little, if any, trunk, hip, and knee displacement. Excellent: the participant displays a soft landing with no frontal-plane or transverse-plane motion. Average: all other landings. Poor: the participant displays large frontal-plane or transverse-plane motion, or the participant displays a stiff landing with some frontal-plane or transverse-plane motion.	2 = Stiff 0 = Excellent 1 = Average 2 = Poor

## APPENDIX 4. FUSIONETICS SCORING ERRORS

TEST / MOVEMENT	STARTING POSITION / MOVEMENT INSTRUCTIONS	CHECKPOINT EVALUATION / OBSERVATION CRITERIA FOR FAIL
<b>2-LEG SQUAT</b>  Click to Image to Play	✓ Feet shoulder-width apart ✓ Toes pointing straight ahead ✓ Arms extended <b>directly overhead</b> ✓ Perform 5-15 squats as if sitting into a chair ✓ Evaluate: Front, side, and back view	✓ <b>Foot Turns Out:</b> Any lateral deviation from starting position ✓ <b>Foot Flattens:</b> 5th Metatarsal is elevated and/or toes lift ✓ <b>Knee Moves In:</b> Mid-patella moves medial of 1st Toe ✓ <b>Knee Moves Out:</b> Mid-patella moves lateral of 5th Toe ✓ <b>Excessive Forward Lean:</b> Inability to maintain a torso parallel to the tibia ✓ <b>Low Back Arches:</b> Increased lumbar extension from starting position ✓ <b>Low Back Rounds:</b> Increased lumbar flexion from starting position (occurring before 90° of hip flexion) ✓ <b>Arms Fall Forward:</b> Inability to maintain a straight line as an extension of the torso ✓ <b>Heel of Foot Lifts (2-Leg Squat only):</b> Inability to keep heels in contact with floor ✓ <b>Asymmetrical Weight Shift:</b> Record the side shifting TOWARDS
<b>2-LEG SQUAT WITH HEEL LIFT</b>	✓ Elevate heels approximately 2" ✓ Feet shoulder-width apart ✓ Toes pointing straight ahead ✓ Arms extended <b>directly overhead</b> ✓ Perform 5-15 squats as if sitting into a chair ✓ Evaluate: Front, side, and back view	✓ <b>Foot Flattens:</b> 5th Metatarsal is elevated and/or toes lift ✓ <b>Knee Moves In:</b> Mid-patella is medial of 1st Toe ✓ <b>Knee Moves Out:</b> Mid-patella is lateral of 5th Toe ✓ <b>Uncontrolled Trunk:</b> Inability to maintain torso parallel to the tibia and/or any change from starting/neutral position ✓ <b>Loss of Balance:</b> Two or more touches with the non-involved foot and/or any hopping to retain balance
<b>1-LEG SQUAT</b>  Click to Image to Play	✓ Toes pointing straight ahead ✓ Athlete balances on 1-Leg ✓ Place hands on hips ✓ Perform 5 squats per leg ✓ Evaluate: Front view	✓ <b>Foot Flattens:</b> 5th Metatarsal is elevated and/or toes lift ✓ <b>Knee Moves In:</b> Mid-patella is medial of 1st Toe ✓ <b>Knee Moves Out:</b> Mid-patella is lateral of 5th Toe ✓ <b>Uncontrolled Trunk:</b> Inability to maintain torso parallel to the tibia and/or any change from starting/neutral position ✓ <b>Loss of Balance:</b> Two or more touches with the non-involved foot and/or any hopping to retain balance

## APPENDIX 5: FOOT AND ANKLE ABILITY MEASUREMENT

FAAM Sports Subscale						
Because of your <b>foot &amp; ankle</b> , how much <b>difficulty</b> do you have with:	No Difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable To Do	N/A
Running	0	1	2	3	4	<input type="checkbox"/>
Jumping	0	1	2	3	4	<input type="checkbox"/>
Landing	0	1	2	3	4	<input type="checkbox"/>
Starting & stopping quickly	0	1	2	3	4	<input type="checkbox"/>
Cutting/lateral movements	0	1	2	3	4	<input type="checkbox"/>
Low impact activities	0	1	2	3	4	<input type="checkbox"/>
Ability to perform activity with your normal technique	0	1	2	3	4	<input type="checkbox"/>
Ability to participate in your desired sport as long as you would like	0	1	2	3	4	<input type="checkbox"/>

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

\_\_\_\_\_ %

## APPENDIX 6: IDENTIFICATION OF FUNCTIONAL ANKLE INSTABILITY

### IDENTIFICATION OF FUNCTIONAL ANKLE INSTABILITY (IdFAI)

**Instructions:** This form will be used to categorize your ankle stability status. A separate form should be used for the right and left ankles. Please fill out the form completely and if you have any questions, please ask the administrator. Thank you for your participation.

Please carefully read the following statement:

***“Giving way” is described as a temporary uncontrollable sensation of instability or rolling over of one’s ankle.***

I am completing this form for my **RIGHT/LEFT** ankle (circle one).

1.) Approximately how many times have you sprained your ankle? \_\_\_\_\_

2.) When was the last time you sprained your ankle?

Never  > 2 years  1-2 years  6-12 months  1-6 months  < 1 month  
0 1 2 3 4 5

3.) If you have seen an athletic trainer, physician, or healthcare provider how did he/she categorize your most serious ankle sprain?

Have **not** seen someone  Mild (Grade I)  Moderate (Grade II)  Severe (Grade III)  
0 1 2 3

4.) If you have ever used crutches, or other device, due to an ankle sprain how long did you use it?

Never used a device  1-3 days  4-7 days  1-2 weeks  2-3 weeks  >3 weeks  
0 1 2 3 4 5

5.) When was the last time you had **“giving way”** in your ankle?

Never  > 2 years  1-2 years  6-12 months  1-6 months  < 1 month  
0 1 2 3 4 5

6.) How often does the **“giving way”** sensation occur in your ankle?

Never  Once a year  Once a month  Once a week  Once a day  
0 1 2 3 4

7.) Typically when you start to roll over (or ‘twist’) on your ankle can you stop it?

Never rolled over  Immediately  Sometimes  Unable to stop it  
0 1 2 3

8.) Following a typical incident of your ankle rolling over, how soon does it return to ‘normal’?

Never rolled over  Immediately  < 1 day  1-2 days  > 2 days  
0 1 2 3 4

9.) During “Activities of daily life” how often does your ankle feel **UNSTABLE**?

Never  Once a year  Once a month  Once a week  Once a day  
0 1 2 3 4

10.) During “Sport/or recreational activities” how often does your ankle feel **UNSTABLE**?

Never  Once a year  Once a month  Once a week  Once a day  
0 1 2 3 4

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