

ROLE OF DYNAMIC POSTURAL CONTROL USING FUNCTIONAL MOVEMENT  
ASSESSMENTS IN INDIVIDUALS WITH CHRONIC ANKLE INSTABILITY:  
SYSTEMATIC REVIEW AND MATCHED CASE-CONTROL STUDY

by

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## TABLE OF CONTENT

	Page
ACKNOWLEDGEMENT .....	iv
LIST OF TABLES .....	vii
LIST OF FIGURES .....	viii
LIST OF ABBREVIATIONS .....	ix
ABSTRACT .....	x
 CHAPTER	
I. INTRODUCTION .....	1
II. SYSTEMATIC REVIEW OF LITERATURE .....	9
Abstract .....	9
Introduction .....	10
Methods .....	13
Results .....	14
Ankle Brace Device .....	14
Ankle Tape Devices .....	16
Discussion .....	20
Conclusion .....	21
References .....	22
III. MANUSCRIPT .....	31
Abstract .....	31
Introduction .....	32
Design .....	38
Methods .....	39
Participants .....	39
Instrumentation .....	41
Experimental Procedures/Protocol .....	43

Pilot Study .....	47
Statistical Analyses.....	47
Results .....	50
Pilot Study Results .....	50
ANOVA Results .....	50
Binary Logistic Regression Results .....	54
Discussion .....	55
Limitations .....	61
Conclusion .....	62
References .....	62
IV. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS FOR FUTURE STUDY .....	70
APPENDIX SECTION .....	72

## LIST OF TABLES

Table	Page
2.1. Inclusion and Exclusion Criteria .....	13
2.2. Search terms .....	14
2.3. CEBM Grades of Recommendation .....	21
2.4. PEDro Scores for Included Studies .....	28
2.5. Characteristics of Included Studies .....	29
3.1. Experimental Parameters and Outcome Measures .....	39
3.2. Participant Inclusion/Exclusion Criteria .....	41
3.3. Pilot Study Results for Intra-rater Test-Retest Reliability for All Clinical Outcome Measures .....	51
3.4. Summary of Participant Demographic Data .....	52
3.5. Two Way ANOVA Comparisons between and within CAI/matched (N = 7) and Control/matched (N = 16) groups .....	54
3.6. Classification Accuracy Table .....	55

## LIST OF FIGURES

Figure	Page
2.1. PRISMA flow chart of study selection .....	27
3.1. Functional Movement Screen (FMS) Scoring Sheet .....	48



## LIST OF ABBREVIATIONS

Abbreviation	Description
CAI	Chronic Ankle Instability
FMS	Functional Movement Screen
FMS-LE	Functional Movement Screen-Lower Extremity
FMS-CS	Functional Movement Screen-Composite Score
AROM	Active Range of Motion
OSI	Overall Stability Index
APSI	Anterior-posterior Stability Index
MLSI	Medio-lateral Stability Index
CAIT	Cumberland Ankle Instability Tool

## ABSTRACT

**Context:** Worldwide, more than 700,000 individuals sprain their ankle each day, with instability and recurrent ankle sprains reported in 40% to 70% of patients. Chronic ankle instability (CAI) is a term that describes the structural changes at the ankle joint due to recurrent ankle sprains and presence of residual symptoms such as pain, swelling, “giving way”, and loss of motion occurring long after an initial lateral ankle sprain. Previous studies have identified kinematic and kinetic changes in walking and running gait among individuals with CAI. The Functional Movement Screen™ (FMS) is a tool used to assess the quality of human movement, and there are limited research investigations that have examined the relationship between postural stability control and the FMS scores. Additionally, no previous systematic review of literature has evaluated the evidence that exists related to biomechanical changes in gait among individuals with CAI while wearing ankle support devices. **Objective:** For the systematic review, our objective was to evaluate the effects of ankle support devices on kinematic and kinetic characteristics during walking and running in people with CAI. For the case-control study, the primary purpose was to identify differences among measures of active range of motion (AROM), dynamic postural stability, and FMS-lower extremity scores in physically-active persons with and without CAI. A secondary purpose was to identify risk factors that predispose individuals to CAI. **Design:** Systematic review and case-control study. **Setting:** Laboratory based study. **Participants:** Prior to a university-mandated

moratorium on face-to-face human data collection due to the COVID-19 pandemic, we recruited 23 participants (age,  $22.3 \pm 2.1$  yrs) who completed all aspects of the study. From these participants' data we were able to create 7 triads ( $N = 21$ ) using a 2:1 ratio of persons without a previous history of ankle injury ( $n = 14$ ) to those with CAI ( $n = 7$ ) and triple matched them on sex, age ( $\pm 5$  yrs), and BMI category, e.g., underweight, normal, overweight **Interventions:** We searched electronic databases from January 2000 to March 2020 for relevant studies related to the purpose of our systematic review. During a one-time visit to the laboratory, we obtained both disease-oriented and patient-oriented measures of lower extremity function and postural control. **Main Outcome Measures:** In the case-control study we obtained talocrural dorsiflexion and plantar flexion active range of motion (AROM), subtalar inversion and eversion AROM, FMS composite score (FMS-CS), FMS lower extremity subscore (FMS-LE), the Athlete Single Leg Stability Test (ASLST), and the Foot and Ankle Disability Index-Sport (FADI-Sport) measures. **Statistical Analyses:** In the case-control study we calculated a Pearson product moment intercorrelation matrix from our 10 outcome measures to identify the presence of multicollinearity ( $r \geq 0.80$ ) and eliminated one redundant variable from further analysis. We employed both 1-way and 2-way ANOVAs to identify differences between the CAI and control groups, and the involved and uninvolved limbs of the CAI group ( $\alpha \leq 0.05$ ). We used an unconditional binary logistic regression approach to calculate odds ratios to determine the extent to which postulated risk factors increased

the risk of developing CAI. **Results:** A total of 77 articles were identified in our database search for the systematic review, and eight articles qualified for inclusion. Moderate evidence exists that semi-rigid ankle braces, closed-basketweave, KinesioTape™ and high-dye ankle taping have positive effects on correcting walking and running gait biomechanics in a CAI population. In the case-control study, 1-way ANOVA results indicated the case group scored significantly lower on the FADI-Sport ( $26.7 \pm 4.1$  points) than the control group ( $31.0 \pm 2.7$  points) [ $F = 9.30$ ,  $p = 0.006$ ,  $\eta^2 = 0.529$ ]. The case group had significantly worse (higher) ASLST level 4 scores ( $1.58 \pm 0.35$  deg,  $F = 4.14$ ,  $p = 0.045$ ,  $\eta^2 = 0.172$ ) compared to their matched controls ( $1.05 \pm 0.35$  deg). The unconditional logistic regression analysis indicated that for every 1 point decrease in FADI-Sport score, the odds of being diagnosed with CAI increased by a factor of 1.5 ( $p = 0.042$ ). Conversely, for every 1 point increase in OSI-CAI Level 4 scores from the ASLST, the odds of being diagnosed with CAI increased by a factor of 0.03 ( $p = 0.045$ ).

**Conclusions:** The collective evidence contained in the systematic review indicated that semi-rigid ankle braces, closed-basketweave, KinesioTape™ and high-dye ankle taping had positive effects on correcting walking and running gait biomechanics in a CAI population. Our case-control study results indicated that a lower FADI-Sport and a higher ASLST level 4 score can classify individuals as being more at risk for developing CAI.

## I. INTRODUCTION

Worldwide, approximately 700,000 individuals suffer ankle sprains each day.<sup>1</sup> Lateral ankle sprains account for 14% of all injuries recorded among all National Collegiate Athletic Association athletes.<sup>2</sup> In the United States, 23,000 ankle sprains occur each day, representing 20% of all treated joint injuries.<sup>2-4</sup> An estimated 2 million acute ankle sprains occur each year in the United States, resulting in an estimated annual aggregate health care cost of \$2 billion.<sup>2, 5</sup> Ankle sprains account for up to 40% of all athletic injuries, and are most common among athletes participating in basketball, volleyball, soccer, running, and ballet/dance.<sup>6-8</sup>

Lateral ankle sprains have one of the highest recurrence rates of all lower extremity musculoskeletal injuries.<sup>9-12</sup> Recurrent lateral ankle sprains often cause ongoing problems including residual symptoms of instability, decreased function and activity restrictions.<sup>12,13</sup>

Movement at the ankle involves the talocrural, subtalar, and transverse tarsal articulations.<sup>14, 15</sup> These three articulations work together to allow coordinated movements of the rearfoot.<sup>15</sup> Rearfoot motion occurs in all the cardinal planes, specifically plantar and dorsiflexion in the sagittal plane, inversion and eversion in the frontal plane, and internal and external rotation in the transverse plane.<sup>15</sup> Muscles that control the movements of these articulations must also work around changing axes of motion associated with the biomechanics of the lower limb.<sup>14-15</sup> In this kinematic chain, a limitation at one articulation may have a negative effect on the surrounding structures.<sup>14</sup>

Dynamic joint stabilization is achieved by contracting muscles surrounding a joint.<sup>14</sup> During activities such as running, jumping, and cutting, the person relies on muscular eccentric co-contraction to minimize mediolateral and anteroposterior forces between the ground and the ankle-foot complex.<sup>14-15</sup> Therefore, individuals who lack muscular co-contraction ability may be susceptible to injury due to the loss of muscular ability to dissipate these forces.<sup>14</sup>

More than a half century ago, Freeman, Dean and Hanham<sup>16</sup> described a dichotomy of mechanical instability and functional instability that followed ankle sprains and attributed the functional instability that was often present to a proprioceptive deficit caused by “articular deafferentation”. Many individuals who have sustained lateral ankle sprains have ongoing pain, giving way, and feelings of instability in their ankles. These continuing symptoms associated with recurrent ankle sprains are characteristic features of a condition that is now referred to as chronic ankle instability (CAI).<sup>9, 17</sup>

In 1967, Freeman and Wyke<sup>18</sup> investigated the influence of articular mechanoreceptors during reflex activity in the lower limb. They measured limb-muscle activity in cats under general anesthesia, inserting needle electrodes into the lower limb and passively moving the lower limb into full plantarflexion to dorsiflexion. The results of their study showed an increase in motor unit activity in the ipsilateral gastrocnemius muscle when moving into full dorsiflexion, with increased tibialis anterior motor activity when moving into full plantarflexion. These findings indicate that stretching the

posterior joint capsule of the ankle during passive dorsiflexion activated mechanoreceptors located within.<sup>18</sup>

The central nervous system mediates the perception and execution of musculoskeletal control and movement.<sup>12</sup> Muscular activity and joint motion are the products of multisite sensory input that is received and processed by the brain and spinal cord.<sup>12</sup> The somatosensory system functions to detect sensory stimuli from peripheral mechanoreceptors located within the skin, musculotendinous junction, joint ligaments and joint capsules.<sup>12</sup> Muscle spindles provide afferent neural signals to the central nervous system in response to changes in muscle length and contribute to joint proprioception.<sup>12,13</sup> Conversely, Golgi tendon organs, although capable of responding to changes in muscle length, are primarily responsible for detecting changes in muscle tension and are considered to signal muscle contraction.<sup>13</sup>

Chronic ankle instability has been defined as structural changes of soft tissues around the ankle joint due to repetitive ankle sprains and the presence of residual symptoms such as pain, swelling, “giving way”, and loss of motion occurring long after the initial lateral ankle sprain.<sup>17, 18</sup> The International Ankle Consortium identified two inclusion criteria that categorize an individual as having CAI: a medical history of at least one ankle sprain within the past 12 months, and a history of a previously-injured ankle joint “giving way”, and/or feeling of instability.<sup>9</sup>

Chronic ankle instability is created by recurrent ankle sprains, which account for 55% to 72% of all cases.<sup>7</sup> One associated component of CAI is the loss of neuromuscular control, specifically, postural control.<sup>11</sup> Chronic ankle instability has been categorized

into mechanical and functional instability.<sup>20</sup> Mechanical instability refers to excessive rearfoot laxity or excessive talocrural joint laxity that results in physiologic or accessory range of motion beyond what is expected from the ankle joint.<sup>20, 21</sup> Functional instability is typically self-reported, and involves episodes of giving way and feelings of instability of the ankle joint.<sup>20</sup>

Postural control can be grouped into static, functional, and dynamic categories.<sup>22-24</sup> Static postural control requires the individual to establish a base of support and maintain the position while minimizing body movement.<sup>22, 23</sup> Functional stability is the ability to produce and maintain a balance between mobility and stability throughout the kinetic chain while performing fundamental patterns with accuracy and efficiency.<sup>24</sup> Dynamic postural control involves a level of expected movement around the base of support.<sup>22</sup>

The ankle plays a vital role in posture and locomotion.<sup>23</sup> Weakness in the ankle stabilizing musculature is a major cause of postural instability.<sup>25, 26</sup> Factors that contribute to the development of CAI have been dichotomized into mechanical and functional impairments.<sup>26</sup> Mechanical impairments involve range of motion deficits, ligamentous laxity and arthrokinematic alterations; on the other hand, functional impairments include sensorimotor deficits that impair stability during functional motion.<sup>26</sup> Freeman et al suggested alterations in postural control could be caused from deficits in afferent input of mechanoreceptors in the ankle capsule and ligaments (articular deafferentation).<sup>27-28</sup> Functional instability may result in mechanoreceptor damage in lateral ankle ligaments,<sup>16</sup> with subsequent partial deafferentation of the



proprioceptive reflex.<sup>16, 29</sup> Konradsen<sup>30</sup> identified neural, muscular and mechanical deficits as contributors to functional ankle instability.

When discussing postural control, there are three different types of strategies for maintaining anteroposterior stability: an ankle strategy, a hip strategy, and a stepping strategy.<sup>31</sup> The ankle strategy is employed first to combat small amplitude anteroposterior perturbations of postural control and restore the center of mass to a position of stability through the ankle joints and activation of the gastrocnemius to produce plantarflexion that slows and reverses the body's forward motion.<sup>31</sup> If the ankle strategy is unsuccessful, hip flexion is initiated in effort to control motion of the center of mass within the base of support.<sup>53</sup> When the ankle and hip strategies are insufficient to recover balance, a stepping strategy (a step or hop) is used to bring the support back into alignment under the center of mass.<sup>31</sup> Individuals with CAI tend to have a greater dependence on the hip strategy to maintain balance due to a diminished capacity for postural control.<sup>32</sup> Disruptions in the central pathways for neuromuscular control are thought to occur from damage to peripheral mechanoreceptors.<sup>11</sup>

Webster and Gribble<sup>33</sup> reported decreased gluteus maximus activity in people with CAI during single leg squat exercises. Some individuals with CAI also display a delay in onset of muscle activation around the ankle, knee, and hip during the transition from bilateral to unilateral stance, indicating the involvement in multiple neural pathways.<sup>8, 11</sup>

Patient-reported outcome questionnaires are an important and cost-effective tool of assessing symptoms that help in determining whether an ankle sprain patient has developed CAI. The results of patient-reported outcome questionnaires, such as the

the Foot and Ankle Ability Measure, the Foot and Ankle Outcome Score and the Functional Ankle Disability Index (FADI), have shown disability differences between individuals with and without CAI.<sup>34, 35</sup> The FADI-Sport is a version of the FADI that is a more appropriate outcome measure for the physically-active population, and assesses more difficult tasks that are essential for physical activity.<sup>36</sup>

Postural control assessments can be conducted with valid and reliable instrumentation such as the Biodex Balance System.<sup>37-39</sup> This device provides repeatable objective measures of an individual's ability to balance on stable and unstable surfaces.<sup>37</sup> Mechanically, the Biodex system consists of an elevated, circular platform that can be programmed to allow 0 to 20 degrees of surface tilt in a 360 degree range.<sup>40</sup> The platform is free to move in anterior-posterior (AP) and medial-lateral (ML) axes simultaneously.<sup>37-40</sup> The degree to which the platform tilts during an assessment indicates the individual's ability to maintain static or dynamic balance.<sup>37, 41</sup> One of the tests available with this device, the Athlete Single Leg Stability Test (ASLST),<sup>28</sup> is used to assess dynamic postural stability by calculating three separate measures: Antero-Posterior Stability Index (APSI), Medio-Lateral Stability Index (MLSI), and Overall Stability Index (OSI).<sup>19</sup> The APSI and MLSI values assess the fluctuations along the sagittal and frontal planes, respectively. Instead of measuring the center of gravity during static conditions, the Biodex system measures the degree of tilt about each axis during dynamic movements.<sup>40</sup> The OSI is calculated from the indices APSI and MLSI values, which makes it sensitive to changes in both directions.<sup>40</sup> A higher indices (OSI further

away from 0.0) reflects the platform is further away from the center target, indicative of a poorer balance performance.<sup>28, 41</sup>

Currently, there is no gold standard test for the evaluation of human movement capacity. The Functional Movement Screen™ (FMS), however, has been recommended as a screening tool for movement pattern limitations and side-to-side movement asymmetries.<sup>11</sup> Purposes of a screening tool, such as the FMS, are to identify body asymmetries, assess mobility and stability within the kinetic chain of whole-body movements, and detect poor-quality movement patterns.<sup>42, 43</sup> The FMS is comprised of seven fundamental movements that require balance of mobility/stability as well as neuromuscular and motor control.<sup>42-44</sup> The seven movement patterns of the FMS are the deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise, trunk stability pushup, and rotary stability.<sup>43-48</sup> Of these, the deep squat, hurdle step, and inline lunge, and the active straight leg raise are the only FMS tests that isolate lower extremity function. Each FMS test is scored based on the degree of compensatory movements required to complete each test and then summed to determine an overall FMS composite score (FMS-CS).<sup>44-47</sup> Previous studies have determined that a person receiving an FMS-CS of  $\leq 14$  points out of a possible 21 points is classified as having a “high risk” of injury.<sup>44, 45, 48</sup>

Choi and Shin<sup>24</sup> evaluated postural control for the deep squat and hurdle step of the FMS in persons with and without CAI. Center of pressure displacements were also compared between groups. These authors found a significant difference in center of pressure path length and velocity between groups for the hurdle step with the non-

affected limb.<sup>24</sup> Their results indicated that there was a difference in the hurdle step with the non-affected limb in persons with CAI compared to healthy individuals.<sup>24</sup> These findings reveal that impairments in feedback sensorimotor function in the involved limb also affects the contralateral lower limb in individuals with CAI.<sup>24</sup>

In summary, lateral ankle sprains can lead to neuromuscular and functional deficits and eventually cause individuals to have CAI. Chronic ankle instability can cause individuals to have difficulty with static, dynamic, and functional postural control. The FMS and Biodex Balance System™ are tools commonly used to assess dynamic and functional postural stability. The FADI-Sport™ is an appropriate health quality questionnaire for the physically-active population to assess if an individual has developed CAI or not.

Following the successful completion of this master's thesis, an abstract of the primary findings from this study will be submitted for presentation at the 72<sup>nd</sup> Annual Meeting of the National Athletic Trainers' Association to be held in Orlando, Florida in June 2021. Both manuscripts from this thesis will be submitted for publication in the *Journal of Athletic Training*.

## II. SYSTEMATIC REVIEW OF LITERATURE

### ABSTRACT

**Background:** Previous research has identified kinematic and kinetic changes that occur during walking and running in individuals wearing an ankle support device. No review, however, has systematically identified the various kinematic and kinetic changes to gait brought about by the wearing of ankle support devices by persons with chronic ankle instability (CAI). **Purpose:** To evaluate the effects of ankle support devices on kinematic and kinetic characteristics during walking and running in people with CAI. **Study Design:** Systematic review. **Methods:** Electronic databases were searched for relevant English-language studies. MEDLINE, PubMed, EBSCO, CINAHL, Science Direct, and SPORTDiscus were included in the electronic database search. Additional hand-search of references was also completed. Included studies were searched from January 2000 to March 2020. **Results:** A total of 77 articles were identified from the database search. After implementing the inclusion and exclusion criteria and removal of duplicated studies, eight articles were selected for this review. All included studies evaluated the kinematic and kinetic changes in gait in persons with CAI wearing either an ankle brace or applied support tape. The experimental methodologies of the included studies were quite varied, with investigators performing gait analyses using 3-dimensional motion analysis systems and force plates to evaluate kinematic and kinetic parameters of walking and running gait. **Conclusion:** Semi-rigid ankle braces, closed-basketweave, KinesioTape™ and high-dye ankle taping procedures are shown to have positive effects on correcting

gait biomechanics in a CAI population. Health-care professionals should evaluate if their patients who may suffer from CAI have altered gait and apply the appropriate ankle support device that will give the best support. **Clinical Relevance:** Evidence from this systematic review gives healthcare providers knowledge that external ankle devices can help change altered gait patterns that are associated with the CAI population.

**Key words:** ankle biomechanics, gait kinematics, gait kinetics, ankle braces, ankle tape

## **INTRODUCTION**

Ankle sprains are the most common injury among the general population, and the most frequently reported injury by athletes.<sup>1</sup> Worldwide, approximately 712,000 individuals suffer ankle sprains each day.<sup>2</sup> About 23,000 ankle sprains occur each day in the United States, representing 20% of all injuries that are seen daily in emergency departments.<sup>3</sup> Many individuals who sprain their ankles do not seek or participate in rehabilitative treatment, with incomplete recovery leading to repeated ankle sprains.<sup>1-4</sup> Recurrent lateral ankle sprains frequently cause ongoing orthopedic problems that include residual symptoms of instability, decreased function, and activity restrictions.<sup>4</sup>

Rearfoot motion occurs in all three cardinal planes; specifically, plantar and dorsiflexion at the talocrural joint occurs in the sagittal plane; inversion and eversion at the subtalar joint occurs in the frontal plane, while internal and external rotation at the transverse tarsal joints occurs in the transverse plane.<sup>5</sup> In this, as in any kinematic chain, a limitation of motion at one articulation may have a negative effect on the surrounding structures.<sup>5</sup> Individuals who have sustained lateral ankle sprains may have ongoing pain, giving way, and feelings of instability in their ankles.<sup>4</sup> These continuing symptoms

associated with recurrent ankle sprains are characteristic features of a condition that is now referred to as chronic ankle instability (CAI).<sup>4</sup>

Chronic ankle instability has been defined as structural changes of soft tissues around the ankle joint due to repetitive ankle sprains with concomitant residual symptoms such as pain, swelling, “giving way”, and loss of motion occurring long after the initial lateral ankle sprain.<sup>4,7,8</sup> Mechanical instability refers to excessive rearfoot laxity or excessive talocrural joint laxity that results in physiologic or accessory range of motion beyond what is expected from the ankle joint.<sup>9</sup> Functional instability is typically self-reported, and involves episodes of giving way and feelings of instability of the ankle joint.<sup>9</sup>

Previous investigators have identified specific deficits in muscle strength, force production, proprioception, fibularis muscle reaction time, gait kinematics, and postural control among individuals with CAI.<sup>10-15</sup> Midfoot ligamentous injury and tibial and fibular nerve injury are common following a lateral ankle and may contribute to changes in ankle-foot function during gait.<sup>10</sup> Decreased ability to use afferent input, deficits in reflexive responses, and reduced efferent motor control may produce alterations in responsive muscle activity before and after ground contact during walking.<sup>12</sup> Individuals with CAI have demonstrated a more inversion foot position before and after heelstrike,<sup>12</sup> as well as increase rate of change in inversion during the same point in the gait cycle.<sup>12</sup>

Because the foot tends to be more inverted during the midswing phase of gait in patients with CAI, the fibularis muscles must activate during late swing to actively move

the foot into eversion in preparation for initial contact.<sup>1</sup> This activation is associated with medial displacement of the center of pressure (COP) as the foot everts. <sup>1</sup> If the fibularis longus muscle is already active before initial contact, it cannot be contracted again to plantar flex during the loading phase of gait.<sup>1</sup>

Decreased ability to use afferent input, deficits in reflexive responses, and reduced efferent motor control may result in alterations in normal muscle activity responsiveness before and after ground contact during walking.<sup>12</sup> Individuals with CAI demonstrate a more inverted foot position before and after heel strike,<sup>16, 17</sup> causing a larger concentric evtor moment in CAI patients. In contrast, an eccentric evtor moment is present in individuals with healthy ankles.<sup>16, 17</sup> A more inverted foot position results in increased neuromuscular activity of the fibularis longus in individuals with CAI during the first 80 milliseconds after heel strike as a protective effort.<sup>17</sup>

Patients with CAI suffer from higher levels of gait disturbances, defined by alterations in walking speed and reduced stride time variability.<sup>18-20</sup> These gait changes have been hypothesized to be due to less adaptability of sensorimotor system in response to task constraints.<sup>18</sup> Springer et al<sup>18</sup> compared the effects of dual-task and walking speed on gait variability in individuals with and without CAI. For dual task, participants recited out loud serial subtraction by 7 while walking on the treadmill. Results showed a decrease in stride time using the dual-task performance in CAI participants.<sup>18</sup> Biomechanical alterations in jogging and running usually mirror the same alterations during walking.<sup>1</sup> Recent research has suggested that using ankle support devices, such as bracing or taping, can improve foot and ankle biomechanics during gait



and reduce excessive inversion during walking in CAI patients.<sup>19, 20, 23-28</sup> Therefore, the purpose of this study was to evaluate the available evidence regarding the effects of ankle support devices on kinematic and kinetic characteristics during walking gait among individuals with CAI.

## METHODS

A systematic review of the literature from January 2000 to March 2020 was conducted to examine if ankle support devices had a positive effect on walking kinematics in a CAI population. Ankle support devices included ankle brace or a tape application. The databases searched were MEDLINE, PubMed, EBSCO, CINAHL, Science Direct, SPORTDiscus, and hand-searched resources. The inclusion and exclusion criteria for this systematic review are summarized in Table 2.1, while Table 2.2 contains a list of the search terms used.

**Table 2.1. Inclusion and Exclusion Criteria**

Inclusion Criteria	Exclusion Criteria
<ul style="list-style-type: none"> <li>• Studies that were CEBM* level 3 or higher</li> <li>• English language</li> <li>• Studies that investigated the biomechanical alterations of gait patterns in CAI patients.</li> <li>• Studies that included ankle bracing or tape application</li> <li>• Studies that were published within the last 20 years (January 2000-March 2020)</li> </ul>	<ul style="list-style-type: none"> <li>• Studies that investigated jump landing or other functional movements</li> </ul>

\*CEBM = Centre of Evidence Based Medicine

**Table 2.2. Search terms**

- |   |
|---|
| <ul style="list-style-type: none"><li>• Chronic ankle instability <b>OR</b> CAI</li><li>• Biomechanics <b>OR</b> kinematics <b>OR</b> kinetics</li><li>• Ankle brace <b>OR</b> tape</li></ul> |
|---|

## **RESULTS**

A total of 77 articles were identified through database searching, from January 1, 2000 to March 31, 2020, with no additional articles found using a hand-searching method. After removing duplicate and excluded articles, eight articles were assessed and included in this systematic review. All included studies employed cross-sectional experimental designs and were ranked as Centre for Evidence Based Medicine level 3 evidence.<sup>29</sup> A PRISMA flow chart of the identification and removal process of articles for this systematic review is presented as Figure 1. The eight articles selected for this systematic review had an average PEDro score of 5.36 (Table 2.3).

### **Ankle Bracing Devices**

The use of ankle braces has been shown to be beneficial to the prevention of recurrent ankle sprains, and some braces exert a pronounced effect on the dynamic balance of CAI patients.<sup>19</sup> That said, the mechanism by which ankle braces prevent recurrent ankle sprains and facilitate balance remains unknown.<sup>19,20</sup>

Cao et al<sup>19</sup> recently conducted a study involving 11 CAI patients (6 women, 5 men) to evaluate the effects of a semi-rigid ankle brace on the gait kinematics of patients with CAI. Dual fluoroscopic imaging system and computed tomography (CT)

scans captured joint position and kinematics of talocrural and subtalar joints as their participants first walked on a level platform, and then on a 15° inversion platform with and without the semi-rigid ankle brace. Results show the tibiotalar joint was more inverted, and subtalar joints were more anteriorly translated during walking without a brace on the inverted platform compared to a level platform. Subtalar inversion decreased when wearing the brace while walking on the inverted platform. The clinical significance of this study is that a semi-rigid brace can be beneficial in decreasing subtalar inversion in CAI population; however, the semi-rigid brace caused an increase in subtalar joint anterior translation and plantarflexion.

In contrast, previous research has also suggested that ankle brace application does not alter selected gait parameters in individuals with CAI.<sup>20</sup> Spaulding et al<sup>20</sup> conducted a study to determine if orthotic ankle devices effected gait patterns in CAI patients. Twenty participants, 10 with history of CAI were matched and compared with 10 healthy controls. Their participants all performed 3 functional movement tasks: walking on a level surface, walking up a step, and walking on an instrumented ramp. All participants performed each task with no brace, a lace-up brace and a semi-rigid brace. Three-dimensional kinematic data were collected using a Northern Digital Optotrak™ system, and ground reaction forces were measured using force plates imbedded in the walkway. Statistical analysis showed differences in kinematic and kinetic gait parameters between groups on walking up the step and ramp, suggesting varied gait patterns between the groups; however, there were no obvious differences found in gait pattern between the two groups with the brace application.

Two previous studies have reported that the application of ankle braces was beneficial in improving eversion velocity, reducing ground reaction force peak vertical measurements and plantarflexion during jump landing tasks<sup>21, 22</sup> but not the dynamic stability<sup>23</sup> in individuals with CAI. Future research should conduct prospective studies investigating the kinematic and kinetic effects of ankle brace application during functional movement and sport specific tasks.

### **Ankle Taping Techniques**

When compared to healthy individuals, persons with CAI displayed greater ankle inversion throughout the majority of the gait cycle.<sup>19, 22</sup> Greater inversion during walking and running gait increases the chances of recurrent ankle sprains in CAI individuals.<sup>24</sup> There are several different applications of athletic adhesive tape that can be used to assist in walking for CAI patients, such as fibular repositioning tape,<sup>24</sup> high-dye taping,<sup>25,26</sup> closed-basket weave taping,<sup>27, 28</sup> and KinesioTape™.<sup>30</sup>

McCleave et al<sup>24</sup> investigated the extent to which fibular repositioning taping affected lower extremity kinematics and kinetics during walking gait in individuals with CAI. Twenty physically active persons (age =  $21.5 \pm 4.1$  yrs, hgt =  $170.0 \pm 7.5$  cm, mass =  $81.8 \pm 22.0$  kg) with CAI participated in this study. Biomechanical data were collected using electromagnetic motion analysis systems and embedded force plates. Participants walked along a walkway platform with and without the fibular repositioning tape. Results from this study revealed there were no significant differences between groups for transverse, frontal or sagittal GRFs of the ankle; therefore, the application of fibular

repositioning tape had no significant effects on lower extremity kinematics and kinetics during gait in CAI patients.

Dingenen et al<sup>25</sup> and Deschamps et al<sup>26</sup> investigated the influence of high-dye taping and low-dye taping on kinematic patterns during gait in a CAI population. In the Dingenen et al study 27 participants (15 CAI group, 12 healthy controls) had their walking gait measured using a three-dimensional motion analysis system. Each participant was tested in three conditions: barefoot, high-dye taping, and low-dye taping. High-dye taping includes both the ankle and lower limb and its main purpose is to reduce ankle plantarflexion and inversion.<sup>25</sup> The low-dye taping procedure use in the Dingenen study involved the rearfoot, midfoot and forefoot. Results from Dingenen show that low-dye taping can cause the metatarsals to stay in an inverted position, as high-dye taping positions the ankle in a more close-packed position. The high-dye tape application was more effective in restricting plantarflexion in CAI patients. From the Dingenen study, we can conclude that high-dye tape for the ankle can create positive biomechanical changes to help prevent re-injury in CAI individuals.

Deschamps et al<sup>26</sup> investigated the difference in rigid foot kinematics between non-injured and CAI participants during running. The second aim was to determine the effectiveness of low-and high-dye taping on foot kinematics in CAI patients. Using similar methods and procedures as Dingenen,<sup>25</sup> Deschamps et al found that high-dye taping targets shank-rearfoot and forefoot kinematics, leading to decreased plantarflexion and a less loose-packed position of the ankle joint.<sup>26</sup> According to

Deschamps et al,<sup>26</sup> high-dye taping has better therapeutic features with respect to low-dye taping in running biomechanics in a CAI population.

Herb et al<sup>27</sup> and Chinn et al<sup>28</sup> both investigated the effects of traditional ankle taping on kinematics during walking and jogging in individuals with CAI. Herb et al<sup>27</sup> had a total of 26 participants (15 CAI patients; 11 healthy controls). Walking and running kinematics were captured using a 12-camera motion captured system and kinetics via force plates in the bed of a custom-built treadmill. Participants walked on the treadmill for 5 minutes and then jogged at two different speeds (4.83 km/h and 9.66 km/h, respectively). After performing the first walking and running trials without ankle taping, each participant had his/her ankle taped using a standard closed-basket weave taping method applied by the same clinician. Participants then repeated the walking and running trials. Their results indicated that the magnitude of both coupled motion and stride-to-stride variability during walking and running were significantly lower in a taped condition than non-taped in both groups. Decrease in joint-coupling variability may indicate a protective mechanism by altering intersegmental coupling at the ankle joint, creating consistent stride-to-stride patterns in individuals with CAI.

Chinn et al<sup>28</sup> had a total of 15 participants (8 men, 7 women) with CAI; these individuals reported an average of  $5.3 \pm 3.1$  ankle sprains per person. Participants walked and jogged on a treadmill with and without a closed-basket weave, traditional ankle tape application. Gait kinematics data were obtained using a 12-camera motion analysis system, while frontal and sagittal-plane kinetics were measured with force plates embedded in a custom-made treadmill. Participants walked on the treadmill for

three minutes, and then progressed to jogging at two pre-determined speeds (1.34 km/h and 2.68 km/h, respectively). After completing walking and jogging trials with no tape, participants were taped and repeated the treadmill walking and running trials. Results showed that participants had less plantarflexion and inversion during walking with the tape application. During jogging, participants showed less dorsiflexion and inversion with the tape application.<sup>28</sup>

In a recent pilot study Yen et al<sup>30</sup> compared the effects of KinesioTape™ (KT) with closed-basket weave taping on ankle motion in the frontal plane, and tibial motion in the transverse plane during the stance phase of walking gait in individuals with CAI. Convenience sampling methods were used to assign 10 participants with CAI to the KT group (8 women, 2 men; age,  $22.8 \pm 1.3$  yrs) and 10 participants with CAI to the closed-basket weave group (7 women, 3 men; age,  $23.0 \pm 2.3$  yrs). Each participant walked at a self-selected comfortable speed on a treadmill for one minute in both a no tape and a taped condition based on experimental group assignment. The KT application significantly reduced foot inversion (or increased foot eversion) by  $1.67^\circ$  ( $p = 0.049$ ) immediately after foot contact. Participants in the closed-basket weave procedure were found to have increased tibial internal rotation during late stance ( $p \leq 0.03$ ). The authors concluded that KinesioTape™ may provide a “flexible pulling force” that increased foot eversion during early stance in walking, whereas athletic tape helps restrict tibial external rotation during terminal stance.

## DISCUSSION

Individuals who suffer from CAI often experience functional instability symptoms of giving way during physical activity.<sup>6,9</sup> Mechanical instability mostly involves a lack of inversion strength and damage to local proprioceptors.<sup>9</sup> According to the International Ankle Consortium,<sup>31</sup> individuals who suffer from CAI experience altered gait biomechanics and are at high-risk of re-injuring their ankle. Based on the available evidence, health-care professionals should consider advising their CAI patients to wear an ankle brace or apply support tape to help counterbalance the altered kinematics during physical activity.

Previous research has shown consistent evidence that the support of an ankle brace or taping technique improves biomechanical alterations in CAI patients during other functional tasks, such as drop landing techniques.<sup>21,22</sup> Zhang et al<sup>21</sup> reported that the ground reaction forces during landings improved when CAI participants wore a semi-rigid ankle brace compared to wearing a soft-rigid ankle brace. Kuni et al<sup>22</sup> conducted a study on 20 CAI and 20 healthy control participants and measured their drop landing kinematics in four conditions: barefoot, with KT, with non-elastic tape and with a soft-rigid brace. Results showed the non-elastic tape application stabilized the midfoot the best in the CAI group.

This systematic review is not without limitations. The most notable limitation of this review is the lack of high-quality studies, e.g., randomized controlled trials, to be reviewed. Seven of the eight included studies used cross-sectional experimental



designs, with no studies employing clinical interventions for more than one day. The effectiveness of ankle taping on walking kinematics may have greater significance if the participants were tested during multiple rounds of walking. Ankle tape is known to rapidly lose its initial level of restraint to motion during exercise, which makes generalizing the results of several of the ankle taping studies that were cited difficult.<sup>32-</sup>

<sup>24</sup> Lastly, the use of different operational definitions for CAI in the studies cited makes the comparison of the results of this research difficult, at best.

## CONCLUSION

The evidence cited in this systematic review indicates that the application of a semi-rigid ankle brace, closed-basket weave taping, KT, and high-dye taping is effective in making corrections to the altered gait patterns present among CAI patients. During gait, CAI patients may experience excessive inversion, which may increase the risk of re-injury. Therefore, it is beneficial for CAI patients to use ankle support devices, if available, to reduce the risk of re-injury. Further research, specifically, randomized controlled trials, is needed to determine the biomechanical effectiveness of ankle bracing and taping on the kinematics and kinetics of walking and running in CAI patients.

**Table 2.3. CEBM Grades of Recommendation**

Clinical Statements/Questions	Grade of Recommendation
Application of an ankle brace has positive kinematic effects on correcting altered gait patterns in a CAI population	B
Application of a supportive ankle tape technique has positive kinematic effects on correcting altered gait patterns in a CAI population.	B

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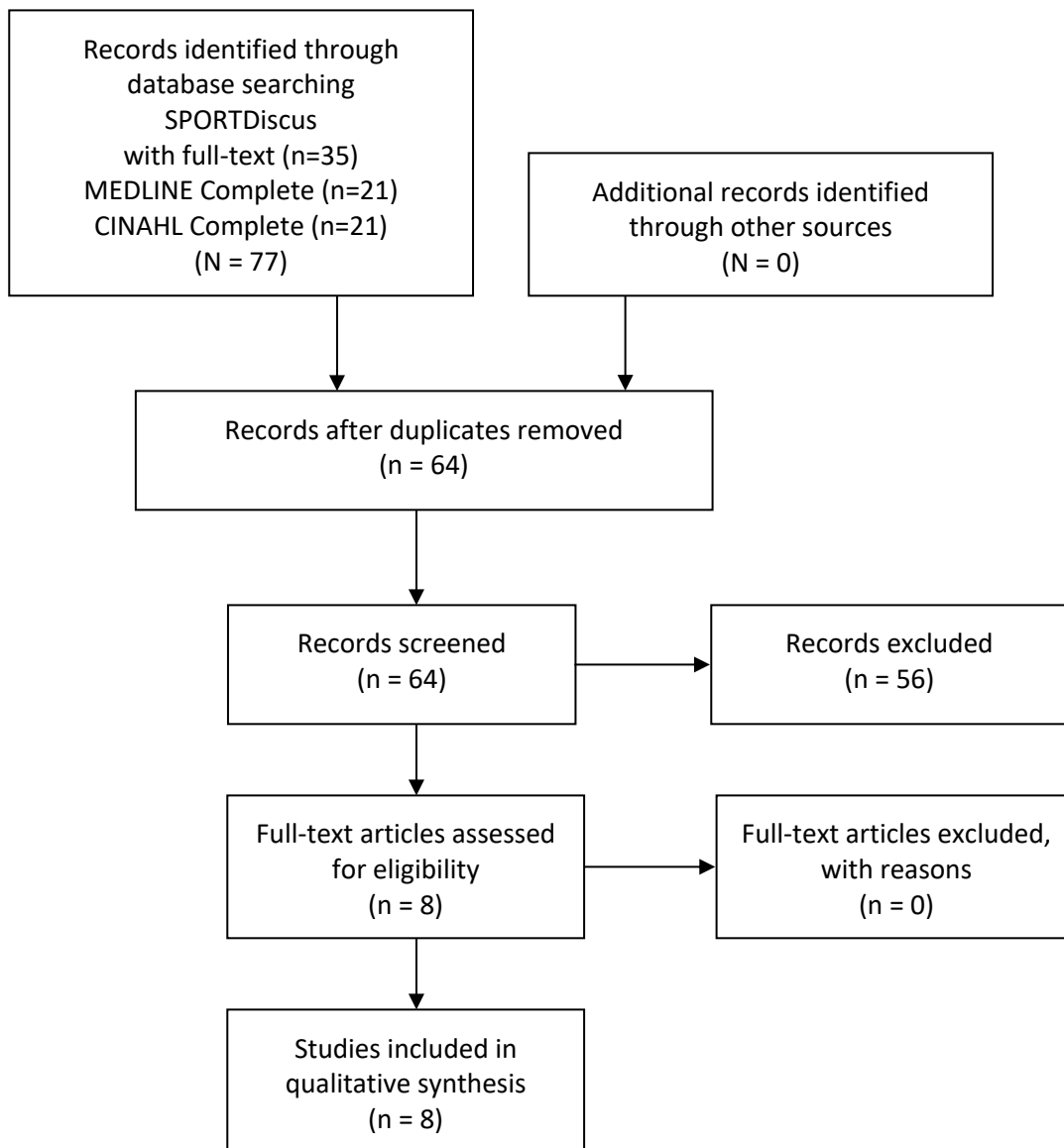
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**Figure 2.1: PRISMA flow chart of study selection**

**Table 2.4.** PEDro Scores for Included Studies (N = 8)

<b>Author/Year</b>	<b>1</b>	<b>2</b>	<b>3</b>	<b>4</b>	<b>5</b>	<b>6</b>	<b>7</b>	<b>8</b>	<b>9</b>	<b>10</b>	<b>11</b>
Spaulding et al (2003)	×			×				×	×	×	×
Chinn et al (2016)	×			×				×	×	×	×
Deschamps et al (2016)	×			×				×	×	×	×
Herb et al (2016)	×			×				×	×	×	×
Dingenen et al (2017)	×			×				×	×	×	×
Yen et al (2018)	×	×		×				×	×	×	×
Cao et al (2019)	×			×				×	×	×	×
McCleve et al (2019)	×			×				×	×	×	×

1: Eligibility criteria and source of participants. 2: random allocation. 3: concealed allocation. 4: baseline comparison. 5: blinded participants. 6: blinded therapists. 7: blind assessors. 8: adequate follow-up. 9: intention-to-treat analysis. 10: between-group comparisons. 11: point estimates and variability.

*\*NOTE: Item 1 does not contribute to the total PEDro score*



Table 2.5. Characteristics of Included Studies

Author/Year	CEBM Level of Evidence/Study Design/Participants	Intervention and Control Groups	Outcome Measures	Results	PEDro Score
Spaulding et al (2003) <sup>20</sup>	Level 3 Cross-sectional study Intervention: 10 participants (24.3 + 5 years) with CAI Control: 10 healthy participants (27.3 + 4 years)	Intervention and control group: walk on 30-meter level walkway, up a step and on a ramp with no brace, a flexible brace and a semi-rigid brace	Ground reaction force (GRF); step length and timing of gait, and angle of foot contact during gait	The absolute angle of foot at foot contact showed greatest difference between groups during level walking with no brace and walking on ramp with a semi-rigid brace (F1,6 =12.27, p<0.01).	5
Chinn et al (2016) <sup>28</sup>	Level 3 Controlled laboratory study Intervention: 15 participants (men=8, women=7; age=26.9+6.8 years; height=171.1+6.3 cm) with self-reported CAI	Intervention group: walked and jogged at pre-determined speeds on a treadmill with and without tape. Three 15-second trials were conducted for each participant.	Frontal and sagittal-plane ankle and sagittal-plane knee kinematics.	During walking, participants were less plantar flexed from 64% to 69% (mean difference =5.73+0.54 degrees), and less inverted from 51% to 61% (mean difference =4.34+0.65 degrees) when taped	5
Deschamps et al (2016) <sup>26</sup>	Level 3 Cross-sectional study Intervention: 15 CAI participants (6 men, 9 women) Control: 12 non-injured participants (5 men, 7 women)	Intervention group: CAI patients ran on a 10-m walkway embedded with force plates in 3 conditions (barefoot, high-dye and low-dye taping) Control group: barefoot trials only.	Walking speed, stride time, stance time and swing time.	Increased inversion decreased dorsiflexion angle during terminal swing and early stance in barefoot group. High-dye tape group had more rear-foot	5
Herb et al (2016) <sup>27</sup>	Level 3 Observational laboratory study Intervention: 15 CAI patients Control: 11 healthy participants	Both groups performed walking and jogging at pre-determined speeds on a treadmill with custom running shoes with and without a standard closed-basket weave tape job. Each participant completed 1 trial of 15 seconds in time, extracting 15 strides used for statistical analysis.	Magnitude to coupled motion, ratio of coupled motion, and variability of shank-rear-foot joint coupling.	Magnitude of coupled motion and variability differences were significantly lower in taped conditions than non-taped conditions in both groups. Magnitude differences and variability were found near initial contact during walking in both groups.	5

Table 2.5. Characteristics of Included Studies—continued

Author/Year	CEBM Level of Evidence/Study Design/Participants	Intervention and Control Groups	Outcome Measures	Results	PEDro Score
Dingenen et al (2017) <sup>25</sup>	Level 3 Cross-sectional study Intervention: 15 CAI participants (6 men, 9 women) Control: 12 non-injured participants (5 men, 7 women)	Intervention group: walking on 10-m walkway embedded with force plates in 3 conditions (barefoot, high-dye and low-dye taping) Control group: barefoot trials only	Walking speed, stride time, stance time and swing time.	Significant decreased dorsiflexion found in CAI_BF group compared to controls (p=0.025) and calcaneus was more inverted (p=0.024). Metatarsus was significantly more inverted to mid-foot in CAI_LD compared to CAI_BF (p=0.017)	5
Yen et al (2018) <sup>30</sup>	Level 3 Case-control crossover design N=20 CAI (KT group: n=10; 2 men and 8 women; age 22.8 ± 1.3 years; AT group: n=10; 3 men and 7 women; age 23 ± 2.3 years)	Participants were randomized into the KT group or AT group. The KT application were 2 strips from medial calcaneus to the lateral leg. The AT application was a closed-basket weave technique. Each group walked on a treadmill for 1-minute with and without tape.	Frontal plane foot motion and transverse tibial plane motion in stance phase of gait.	KT demonstrated decreased inversion compared with non-taped condition (p=.03). The AT condition produced significant increase in tibial internal rotation compared to non-taped conditions (p ≤ .03).	6
Cao et al (2019) <sup>19</sup>	Level 3 Cross-sectional study N=11 participants with unilateral CAI	Intervention group: wore semi-rigid ankle brace and also barefoot while walking on 15-degree inversion platform and a level platform, performing 3 walking trials each condition	Subtalar and tibiotalar joint kinematics in vivo.	Inversion of subtalar joints decreased after the brace application at flatfoot to mid-stance (p=0.003), heel-off (p=0.004) and toe-off (p=0.016) of testing foot during stance phase of walking.	5
McCleve et al (2019) <sup>24</sup>	Level 3 Cross-sectional crossover study N=20 participants (age=21.5+ 4.1 years, height=170.0+7.5 cm) with CAI	Intervention group: walked on 20-foot force-plate embedded walkway in 3 conditions (no tape, FRT, and sham FRT). Each participant performed 10 trials.	Ankle, knee, and hip kinematics, kinetics, and ground-reaction force (GRF); full gait cycle	No significant difference in lower extremity kinematics, kinetics, or GRF's during gait between all groups.	5

### III. MANUSCRIPT

#### ABSTRACT

**Context:** Worldwide, more than 700,000 people sprain their ankle each day, with recurrent ankle sprains occurring in as many as 40% to 70% of these individuals. Chronic ankle instability (CAI) describes the structural changes at the ankle due to recurrent sprains and presence of residual symptoms such as pain, swelling, “giving way”, and loss of motion that occur long after the initial injury. Few research investigations have examined the relationship between Functional Movement Screen™ (FMS) and dynamic postural stability in persons with CAI. **Objective:** To identify differences among measures of active range of motion (AROM), dynamic postural stability, and FMS-lower extremity scores in physically-active persons with and without CAI. A secondary purpose was to identify risk factors that predispose individuals to CAI. **Design:** Cross-sectional case-control study. **Setting:** Laboratory based study. **Participants:** Twenty-three individuals (12 women, 11 men; age,  $22.3 \pm 2.1$  yrs) completed all aspects of the study. We subsequently created 7 triads using a 2:1 ratio of persons without a previous history of ankle injury ( $n = 14$ ) to those with CAI ( $n = 7$ ), and triple matched them on sex, age ( $\pm 5$  yrs), and BMI category. **Interventions:** We obtained disease-oriented and patient-oriented measures of lower extremity function and postural control. **Main Outcome Measures:** Talocrural joint dorsiflexion and plantar flexion active range of motion (AROM), subtalar joint inversion and eversion AROM, FMS composite score (FMS-CS), FMS lower extremity subscore (FMS-LE), the Athlete Single Leg Stability Test (ASLST) at level 4, and Foot and Ankle Disability Index-Sport (FADI-Sport) score. **Statistical Analysis:**

We employed both 1-way and 2-way ANOVAs to identify differences between the case and control groups, and the involved and uninvolved limbs of the participants with CAI ( $p \leq 0.05$ ). We used a binary logistic regression approach to calculate odds ratios to determine the extent to which postulated risk factors increased the risk of developing CAI. **Results:** One-way ANOVA results indicated the case group scored significantly lower on the FADI-Sport ( $26.7 \pm 4.1$  points) than the control group ( $31.0 \pm 2.7$  points) [ $F = 9.30$ ,  $p = 0.006$ ,  $\eta^2 = 0.529$ ]. The CAI group had significantly poorer ASLST level 4 scores in their injured ankles compared to their contralateral normal limbs ( $F = 4.14$ ,  $p = 0.045$ ,  $\eta^2 = 0.172$ ). Binary logistic regression analysis results indicated that for every 1 point decrease in FADI-Sport score, the odds of being diagnosed with CAI increased by a factor of 1.5 ( $p = 0.042$ ). Conversely, for every 1 point increase in OSI-CAI Level 4 scores from the ASLST, the odds of being diagnosed with CAI increased by a factor of 0.03 ( $p = 0.045$ ). **Conclusion:** The CAI group had significantly lower scores on the FADI-Sport than the Control group. The Biodex ASLST level 4 scores within and FADI-Sport were significantly worse in the injured ankle of the CAI group compared to the contralateral normal ankle, and matched ankles from the control group. A lower FADI-Sport and a higher Athlete Single Leg Stability Test level 4 score can classify individuals as being more at risk for developing CAI.

**Key Words:** FADI-Sport, Athlete Single Leg Stability Test, odds ratios

## INTRODUCTION

Worldwide, approximately 700,000 individuals suffer ankle sprains each day.<sup>1</sup> Lateral ankle sprains account for 14% of all injuries recorded among all National

Collegiate Athletic Association athletes.<sup>2</sup> In the United States, 23,000 ankle sprains occur each day, representing 20% of all treated joint injuries.<sup>2-4</sup> An estimated 2 million acute ankle sprains occur each year in the United States, resulting in an estimated annual aggregate health care cost of \$2 billion dollars.<sup>2,5</sup> Ankle sprains account for up to 40% of all athletic injuries, most commonly seen in athletes participating in basketball, volleyball, soccer, running, and ballet/dance.<sup>6-8</sup> Lateral ankle sprains have one of the highest recurrence rates of all lower extremity musculoskeletal injuries.<sup>9-11</sup> Recurrent lateral ankle sprains often cause ongoing problems including residual symptoms of instability, decreased function, and activity restrictions.<sup>9</sup> Lateral ankle sprains have one of the highest recurrence rates of all lower extremity musculoskeletal injuries.<sup>9-12</sup> Recurrent lateral ankle sprains often cause ongoing problems including residual symptoms of instability, decreased function and activity restrictions.<sup>12,13</sup>

Dynamic joint stabilization is achieved by contracting muscles surrounding a joint.<sup>14</sup> During activities such as running, jumping, and cutting, the person relies on muscular eccentric co-contraction to minimize mediolateral and anteroposterior forces between the ground and the ankle-foot complex.<sup>14-15</sup> Therefore, individuals who lack muscular co-contraction ability may be susceptible to injury due to the loss of muscular ability to dissipate these forces.<sup>14</sup>

More than a half century ago, Freeman, Dean and Hanham<sup>16</sup> described a dichotomy of mechanical instability and functional instability that followed ankle sprains and attributed the functional instability that was often present to a proprioceptive deficit caused by “articular deafferentation”. Many individuals who have sustained

lateral ankle sprains have ongoing pain, giving way, and feelings of instability in their ankles. These continuing symptoms associated with recurrent ankle sprains are characteristic features of a condition that is now referred to as chronic ankle instability (CAI).<sup>9, 17</sup>

Chronic ankle instability has been further defined as structural changes of soft tissues around the ankle joint due to repetitive ankle sprains and the presence of residual symptoms such as pain, swelling, “giving way”, and loss of motion occurring long after the initial lateral ankle sprain.<sup>17, 18</sup> The International Ankle Consortium has identified two inclusion criteria that categorize an individual as having CAI: a medical history of at least one ankle sprain within the past 12 months, and a history of a previously-injured ankle joint “giving way”, and/or feeling of instability.<sup>9</sup> Chronic ankle instability is created by recurrent ankle sprains, which account for 55% to 72% of all cases.<sup>7</sup> One associated component of CAI is the loss of neuromuscular control, specifically, postural control.<sup>11</sup>

Postural control can be grouped into static, functional, and dynamic categories.<sup>22-24</sup> Static postural control requires the individual to establish a base of support and maintain the position while minimizing body movement.<sup>22, 23</sup> Functional stability is the ability to produce and maintain a balance between mobility and stability throughout the kinetic chain while performing fundamental patterns with accuracy and efficiency.<sup>24</sup> Dynamic postural control involves a level of expected movement around the base of support.<sup>22</sup>

When discussing dynamic postural control, there are three different types of strategies for maintaining anteroposterior stability: an ankle strategy, a hip strategy, and a stepping strategy.<sup>31</sup> The ankle strategy is employed first to combat small amplitude anteroposterior perturbations of postural control and restore the center of mass to a position of stability through the ankle joints and activation of the gastrocnemius to produce plantarflexion that slows and reverses the body's forward motion.<sup>31</sup> If the ankle strategy is unsuccessful, hip flexion is initiated in effort to control motion of the center of mass within the base of support.<sup>53</sup> When the ankle and hip strategies are insufficient to recover balance, a stepping strategy (a step or hop) is used to bring the support back into alignment under the center of mass.<sup>31</sup> Individuals with CAI tend to have a greater dependence on the hip strategy to maintain balance due to a diminished capacity for postural control.<sup>32</sup> Disruptions in the central pathways for neuromuscular control are thought to occur from damage to peripheral mechanoreceptors.<sup>11</sup>

Patient-reported outcome questionnaires are an important and cost-effective tool of assessing symptoms that help in determining whether an ankle sprain patient has developed CAI. The results of patient-reported outcome questionnaires, such as the Foot and Ankle Ability Measure, the Foot and Ankle Outcome Score, and the Functional Ankle Disability Index (FADI) have shown disability differences between individuals with and without CAI.<sup>34, 35</sup> The FADI-Sport™ is a subscale of the FADI that is a more appropriate outcome measure for the physically-active population, and assesses more difficult tasks that are essential for physical activity.<sup>36</sup>

The Cumberland Ankle Instability Questionnaire (CAIT) <sup>38, 39</sup> is a valid and reliable patient-reported outcome used to measure severity of functional ankle instability.<sup>39</sup> The CAIT consists of 9 questions and is scored on a 30-point scale, with lower scores indicating decreased stability.<sup>38,39</sup> In 2006, Hiller et al<sup>38</sup> created the CAIT questionnaire to reliably determine if an individual has functional ankle instability and be able to grade the severity of their instability. These authors determined that 27.5 was the threshold score; if an individual scored below that threshold, she/he was likely to suffer from CAI.<sup>38</sup> In 2013, International Ankle Consortium adopted the CAIT questionnaire and defined the CAI threshold score as 24 points on the CAIT.<sup>39</sup>

Postural control assessments can be conducted with valid and reliable instrumentation such as the Biodex Balance System.<sup>37-39</sup> This device provides repeatable objective measures of an individual's ability to balance on stable and unstable surfaces.<sup>37</sup> Mechanically, the Biodex system consists of an elevated, circular platform that can be programmed to allow 0 to 20 degrees of surface tilt in a 360 degree range.<sup>40</sup> The platform is free to move in anterior-posterior (AP) and medial-lateral (ML) axes simultaneously.<sup>37-40</sup> The degree to which the platform tilts during an assessment indicates the individual's ability to maintain static or dynamic balance.<sup>37,41</sup> One of the tests available with the Biodex system, the Athlete Single Leg Stability Test (ASLST), <sup>28</sup> is used to assess dynamic postural stability by calculating three separate measures: Medio-Lateral Stability Index (MLSI), Antero-Posterior Stability Index (APSI), and Overall Stability Index (OSI).<sup>19</sup> The APSI and MLSI assess the fluctuations along the sagittal and frontal axes. Instead of measuring the center of gravity during static conditions, the



Biodex measures the degree of tilt about each axis during dynamic movements.<sup>40</sup> The OSI is a composite of the indices APSI and MLSI, which makes it sensitive to changes in both directions.<sup>40, 51, 52</sup> A greater the numerical index, e.g., the further away the subject's center of pressure is from the origin (0, 0) on the X-Y axes, the poorer the postural balance performance.<sup>28, 41</sup>

There is currently no gold standard test for the evaluation of human movement capacity. The Functional Movement Screen™ (FMS) has been recommended as a screening tool for movement pattern limitations and side-to-side movement asymmetries.<sup>11</sup> The purposes of a screening tool, such as the FMS, are to identify body asymmetries, assess mobility and stability within the kinetic chain of whole-body movements, and detect poor-quality movement patterns.<sup>42, 43</sup> The FMS is comprised of seven fundamental movements that require balance of mobility/stability as well as NMC and motor control.<sup>42-44</sup> The seven movement patterns of the FMS are the deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise (ASLR), trunk stability pushup and rotary stability.<sup>43-48</sup> The deep squat, hurdle step, and inline lunge, and the ASLR are the only FMS tests associated with the lower extremity. Each FMS test is scored based a degree of compensatory movements required to complete each test and summed to determine the overall FMS composite score.<sup>44-47</sup> Previous studies have determined that a person receiving an FMS composite score of  $\leq 14$  points out of a possible 21 points is classified as having a high risk of injury.<sup>44, 45, 48</sup>

Therefore, the primary purpose of this study was to identify interrelationships as well as differences among measures of ankle active range of motion (AROM), dynamic

postural stability, and FMS-lower extremity scores in physically-active persons with and without CAI. A secondary purpose was to identify risk factors that predispose individuals to developing CAI.

## **DESIGN**

This research study used a case-control design in effort to determine which of four categories of hypothesized risk factors play a significant role in developing CAI. Both one-way and two-way ANOVAs were employed to identify significant differences that may exist between groups and limbs. For outcome measures not measured bilaterally, e.g., FADI-Sport score, we employed one-way ANOVAs (Group) consisting of a case group (CAI participants) and a control group (healthy physically-active individuals). For outcome measures measured bilaterally, e.g., ankle AROM, Athlete Single Leg Stability Test, the group factor (case vs. control) remained the same as in the one-way ANOVA. The second factor, Limb (2) compared to the findings in the injured limb of a case group participant (right or left ankle), matched with the right or left limb of the 2 matched control group participants for statistical analysis. A similar procedure was followed to evaluate the uninjured limb data of the CAI participant with the right or left limb of the 2 matched control group participants.

For the binary logistic regression analysis, triads were created that triple matched two control group participants with a case group participant who had CAI on the basis of sex, age ( $\pm 5$  years) and BMI category (normal, overweight, obese). We used a binary logistic regression analysis to determine which of our outcome measures played a significant role in the development of CAI.

The experimental parameters and nine outcome measures included in this study are summarized in Table 3.1.

**Table 3.1: Experimental Parameters and Outcome Measures**

<b>Experimental Parameter</b>	<b>Outcome Measure</b>
Functional Movement Screen (FMS™)	<ol style="list-style-type: none"> <li>1. FMS Composite Score (FMS-CS)</li> <li>2. FMS Lower Extremity Score (FMS-LE)</li> </ol>
Talocrural and Subtalar Joint Active Range of Motion	<ol style="list-style-type: none"> <li>1. R &amp; L dorsiflexion AROM measured with digital goniometer</li> <li>2. R &amp; L plantar flexion AROM measured with digital goniometer</li> <li>3. R &amp; L inversion AROM measured with the Clarkson Method<sup>49</sup></li> <li>4. R &amp; L eversion AROM measured with the Clarkson Method<sup>49</sup></li> </ol>
Dynamic Postural Stability	<ol style="list-style-type: none"> <li>1. Athlete Single Leg Stability Test at level 4 – Overall Stability Index (OSI) Score</li> <li>2. Athlete Single Leg Stability Test at level 12 – Overall Stability Index</li> </ol>
Patient-Reported Outcome Measure of Current Ankle Disability	<ol style="list-style-type: none"> <li>1. Foot and Ankle Disability Index – Sport (FADI-Sport) subscore</li> </ol>

## **METHODS**

### **Participants**

A target population of 60 physically-active volunteers was to be recruited via email solicitation and flyers from the university student and faculty communities.

We planned to recruit and match 20 participants with CAI with 40 control group participants using a 1:2 ratio, based their sex, age, and BMI category. We were given

permission to use an IRB-approved recruitment email as our primary method of attracting participants for this study. All volunteers need to meet the inclusion and exclusion criteria for their respective group (case or control) in order to be eligible for this study (Table 3.2).

Inclusion criteria for the CAI group were if the volunteer had a medical history of ankle instability that is associated with an initial injury, has repeated episodes of lateral ankle instability, and a score of 24 points or less on the 30-point Cumberland Ankle Instability Tool (CAIT).<sup>39</sup> Exclusion criteria from the CAI group included if a volunteer had bilateral ankle instability, had suffered an ankle sprain within the past 3 months, undergone any orthopedic surgical procedure in the lower extremity, a history of ankle fracture, or a history of vestibular disorder.

To be eligible for participation in the control group, volunteers must of had no history of ankle sprains that results in recurrent sprains within past 18 months of when coming in for testing, participated in physical activity for at least 150 to 300 minutes a week of moderate-intensity.<sup>24</sup> Our operational definition of “physically-active individual” was adapted from the Centers for Disease Control and Prevention’s definition of at least 150 minutes (2 hours and 30 minutes) to 300 minutes (5 hours) a week of moderate-intensity, or 75 minutes (1 hour and 15 minutes) to 150 minutes a week of vigorous-intensity aerobic physical activity.<sup>38</sup>

Volunteers were excluded from participation in the Control group if they had previous lower extremity orthopedic surgery, trauma to the lower extremity for at least

3 months prior to this study, a lower extremity injury resulting in time off from work/activity, or a history of vestibular disorder.

**Table 3.2: Participant Inclusion/Exclusion Criteria**

<b>Group</b>	<b>Inclusion</b>	<b>Exclusion</b>
Chronic Ankle Instability (Case)	<p>Isolated ipsilateral ankle involvement</p> <p>Repetitive bouts of lateral ankle instability resulting in numerous ankle sprains<sup>35</sup></p> <p>Score of less than 24 on the 30-point Cumberland Ankle Instability Tool (CAIT) questionnaire.<sup>39</sup></p>	<p>Bilateral ankle sprains</p> <p>Suffered ipsilateral ankle sprain &lt;3 months before study</p> <p>History of lower extremity surgery, fractures, or balance disorder</p> <p>Score of 24 or higher on the 30-point Cumberland Ankle Instability Tool (CAIT) questionnaire</p>
Physically-Active (Control)	<p>No history of ankle sprains</p> <p>Physically active for 150 to 300 minutes a week</p> <p>Matched on sex, age and BMI to CAI participants.</p>	<p>Lower extremity surgery/trauma</p> <p>Injury resulting in time off from work/activity</p>

### **Instrumentation**

The Cumberland Ankle Instability Tool (CAIT)<sup>38, 39</sup> was used as a screening instrument to assess the level of ankle dysfunction for all volunteers, and to determine whether a volunteer with a medical history of unilateral ankle sprain had a level of disability to qualify for membership in this CAI group. Volunteers with previous ankle sprains who met all other inclusion criteria and scored less than 24 points on the CAIT

were eligible for membership in the CAI group.<sup>39</sup> Previous studies have reported the CAIT having acceptable construct validity and internal reliability, as well as excellent test-retest reliability scores ( $ICC_{2,1} = 0.96$ ).<sup>38</sup>

We used the Foot and Ankle Disability Index (FADI)-Sport™ to measure the amount of disability an individual has with specific daily activities.<sup>36</sup> With 8 questions evaluated on a 0 to 4 grading scale (32 points maximum), the lower the FADI-Sport score, the greater the difficulty performing physical activities.<sup>36</sup>

A digital goniometer (Baseline Evaluation Instruments, Fabrication Enterprises Inc. White Plains, NY) was used to measure and record each participant's ankle dorsiflexion, plantar flexion. Subtalar inversion and eversion AROM were measured by using the Clarkson method.<sup>49</sup>

The Biodex Balance System (Biodex Medical Systems, Shirley, NY) was used to assess participants' static and dynamic postural stability control through the Athlete Single Leg Stability Test. This device's strain gauges sample the displacement of the participant's center of pressure in the anteroposterior and mediolateral directions at 20 Hz, and the software combines these sway values to calculate an Overall Stability Index (OSI). Low OSI scores, measured in degrees, indicate that individuals have good postural stability control.<sup>37, 43</sup> Two of 12 different preset stability settings, level 12 and level 4, were used to measure the participant's ability to maintain dynamic postural stability. Of these two settings, level 4 is less stable than the level 12 (fixed platform) setting.

A Functional Movement Screen™ testing kit (Functional Movement Systems Inc., Chatham, VA) was used to determine the overall FMS composite score for each

participant. Subscores of the FME-LE include Hurdle Step, Deep Squat, and In-Line Lunge. The primary researcher (JWL), a Level 1 certified FMS administrator since 2016, collected all the FMS data.

### **Experimental Procedures/Protocols**

Prior to data collection, all eligible participants signed an informed consent form document approved by the University's IRB. All testing and data collection sessions were performed at the university's Biomechanics/Sports Medicine Laboratory. Participants were informed that their single experimental session would last approximately 50 to 60 minutes. Prior to range of motion assessments and functional testing, volunteers who met the requirements for inclusion criteria for this study were asked to complete the Foot and Ankle Disability Index (FADI)-Sport™ questionnaire.

Talocrural joint plantar and dorsiflexion were measured with the participant in a supine anatomical position on an examination table. To obtain plantar flexion and dorsiflexion values, the axis of the goniometer was placed over the lateral malleolus, stationary arm aligned with the fibular head, and the moving arm aligned with the fifth metatarsal. This procedure was repeated for both ankles.

Subtalar joint inversion and eversion was measured with the method developed by Clarkson.<sup>49</sup> Participants were barefoot in a long sitting position on an examination table, positioned with his or her natural neutral ankle position and centered on a 61.0 cm (length) x 45.7 cm (width) x 1.3 cm thick Plexiglas overlaid on a 21.6 cm x 28.0 cm blank sheet of paper. A second piece of Plexiglas was then placed against the plantar aspect of the foot to be measured, and a line was drawn on the paper that indicated the

subtalar neutral (starting) position. The participant was asked to actively invert her/his ankle maximally, and the end position of movement was recorded as a line drawn on the paper using the Plexiglas as a guide. Next, the participant was asked to evert her/his ankle maximally, and the end position of this movement was also recorded as a line drawn on the paper using the Plexiglas as a guide. This procedure was repeated on both ankles of the participant. To expedite the single data collection session, the primary researcher (JWL) waited until after the session was completed to record the inversion and eversion AROM values obtained with this

After completion of AROM measurement collection, participants were evaluated using the Athlete Single Leg Stability Testing with the Biodex Balance System (Biodex Medical Group, Shirley, NY). Each participant was barefoot and asked to perform the Athlete Single Leg Stability Test with their eyes open at two levels of platform stability (level 12 and level 4). Three trials of Athlete Single Leg Stability Test at level 12 (fully stable platform) were completed first. A mandatory 3-minute rest period was imposed prior to testing of Athletic Single Leg Stability Test at level 4 (a less stable platform setting). All participants were asked to perform 3 successful 20-second trials at each of the two platform stability settings during the Athlete Single Leg Stability Test testing.

Participants were instructed to keep the black dot that appeared on the Biodex monitor, representing their center of pressure, in the middle of the bull's eye target as much as possible.<sup>36</sup> A three-trial average Overall Stability Index (OSI) score, expressed in degrees, represented the path of sway around the origin (0, 0) point at the center of the platform. The OSI is a measure of standard deviation that employs the Anterior-



Posterior Stability Index (APSI) and Medial-Lateral Stability Index (MLSI) values in its formula to represent dynamic postural stability.<sup>28, 40</sup>

After completion of Athlete Single Leg Stability Test testing, participants were moved to the area in the Biomechanics/Sports Medicine Laboratory where FMS testing was conducted. Participants were barefoot throughout FMS testing. Each participant was asked to complete all three FMS-lower extremity tasks in order as determined by the creators of this screen (Deep Squat, Hurdle Step, and inline lunge).<sup>47</sup>

Each participant was scored using the standard FMS scoring scale that ranges from “0” to “3” on each FMS-LE movement task.<sup>47</sup> To receive a score of “3”, the participant needed to perform the task completely correct with no errors. If the participant completed the movement with modifications, a score of “2” was assigned. If the participant could not complete the task with the modifications, a score of “1” was given, and if there was any pain elicited during the task, participants were assigned a score of “0”.

The purpose of the FMS deep squat activity is to assess bilateral, symmetrical, functional mobility of the hips, knees, and ankles.<sup>47</sup> The participants were instructed to stand with their feet shoulder width apart with feet aligned in the sagittal plane, holding a dowel rod overhead with their elbows in a 90-degree angle. The participant was then instructed to press the dowel rod above their head and perform their deepest squat possible. A score of “3” was awarded if they completed the full task with their heels touching the floor throughout the task, the femur was below horizontal, the knees were aligned over the feet and the dowel was aligned over the feet. A score of “2” was given

if participants completed this task with their heels raised on a 2" board. A score of "1" was given if the tibia and upper torso were not parallel, the femur was not below horizontal, the knees were not aligned over the feet, or lumbar flexion was observed while the heels were elevated off the floor.<sup>47</sup>

The FMS hurdle step begins with the examiner measuring the height of the participants' tibial tuberosity. The FMS kit was set up to create a hurdle, with the height of the hurdle at the height of the tibial tuberosity. Participants were instructed to hold the dowel on their posterior shoulders. Then participants were told to lift one leg, reach over the hurdle and tap their heel on the floor, then return to starting position. A score of "3" was given if participant's hips, knees, and ankles remain aligned in the sagittal plane, minimal to no movement was noted in the lumbar spine, and the dowel and hurdle remained parallel. A score of "2" was given if alignment was lost between hips, knees, and ankles, movement was noted in lumbar spine, or the dowel and hurdle did not remain parallel. A score of "1" was given if participants came in contact with the hurdle or a loss of balance was noted.<sup>47</sup>

The FMS inline lunge also used the participant's tibial tuberosity height to determine foot position. The toes of the trailing foot were placed on the start line on the FMS board, and the heel of the leading foot was placed at the line that correlates with the height of the tibial tuberosity. Participants were instructed to hold the dowel vertically behind their back, touching the back of their head, thoracic spine, and sacrum. The hand placement on the dowel was the hand opposite of the front foot grasps the dowel at the cervical spine level as the opposite hand holds the dowel at the lumbar

spine level. Instruction given to complete this task was to lunge down, touching their back knee to the beam and return to starting position. The dowel should remain as vertical as possible and be in contact with the body. A score of “3” was given if there are no errors throughout the task. A score of “2” was given if the dowel contacts were not maintained or did not remain vertical, movement was noted in the torso area, the dowel and feet did not remain in the sagittal plane, or the knee did not touch the board. A score of “1” was given if the participant demonstrated a loss of balance.<sup>47</sup>

### **Pilot Study**

Prior to formal data collection, we conducted a pilot study with 10 physically active volunteers to establish intrarater reliability of the primary investigator for all clinical outcome measures. Intraclass correlation coefficients (ICC) value categories were defined as follows: “Poor”, ICC < 0.40; “Fair”, ICC 0.40 to 0.59; “Good”, ICC 0.60 to 0.74; and “Excellent”, ICC 0.75 to 1.0.<sup>28</sup> To determine the intraclass reliability for our outcome measures (AROM, Athlete Single Leg Stability Test, and FMS Scores), we used the intraclass correlation coefficient fixed effect formula  $ICC_{(3,1)}$  with each participant measured by the main examiner, and reliability was calculated from a single measurement. All measurements were obtained by a single examiner (JWL).

### **Statistical Analyses**

To determine if multicollinearity ( $r \geq 0.80$ ) existed among our reported outcome measures, a Pearson product moment correlation matrix table was initially calculated,

## THE FUNCTIONAL MOVEMENT SCREEN

### SCORING SHEET

NAME _____	DATE _____	DOB _____
ADDRESS _____		
CITY, STATE, ZIP _____		PHONE _____
SCHOOL/AFFILIATION _____		
SSN _____	HEIGHT _____	WEIGHT _____
AGE _____		GENDER _____
PRIMARY SPORT _____		PRIMARY POSITION _____
HAND/LEG DOMINANCE _____		PREVIOUS TEST SCORE _____

TEST		RAW SCORE	FINAL SCORE	COMMENTS
DEEP SQUAT				
HURDLE STEP	L			
	R			
INLINE LUNGE	L			
	R			
SHOULDER MOBILITY	L			
	R			
IMPINGEMENT CLEARING TEST	L			
	R			
ACTIVE STRAIGHT-LEG RAISE	L			
	R			
TRUNK STABILITY PUSHUP				
PRESS-UP CLEARING TEST				
ROTARY STABILITY	L			
	R			
POSTERIOR ROCKING CLEARING TEST				
TOTAL				

**Raw Score:** This score is used to denote right and left side scoring. The right and left sides are scored in five of the seven tests and both are documented in this space.

**Final Score:** This score is used to denote the overall score for the test. The lowest score for the raw score (each side) is carried over to give a final score for the test. A person who scores a three on the right and a two on the left would receive a final score of two. The final score is then summarized and used as a total score.

**Figure 3.1: Functional Movement Screen (FMS) Scoring Sheet.**

and redundant outcome measures were eliminated from further analysis. A total of 10 outcome measures—ankle dorsiflexion, plantar flexion, inversion and eversion AROM, postural stability (Athlete Single Leg Stability Test results, specifically OSI), FMS-LE score, and FADI-Sport score—were analyzed for multicollinearity.

To identify significant differences in the outcome measures between physically active persons with CAI and healthy physically active individuals, and between the injured and non-injured limbs of the CAI group members, a series of Group (2) x Limb (2) 2-way ANOVAs were performed ( $p = 0.05$ ). We matched the injured and non-injured limbs of the case group with the dominant and non-dominant limbs of the control group, respectively. To determine which limb was dominant and non-dominant, we had all the case group participants provide us this information on our demographic questionnaire.

For outcome measures that were not measured bilaterally, e.g., FADI-Sport score, FMS-LE score, we employed 1-way ANOVAs with Group as the independent variable, consisting of a case (CAI participants) and a control (healthy physically active individuals) group.

To determine if CAI is associated with selected outcome measures obtained in this study, specifically, the FMS-LE score, FADI-Sport score, average bilateral ankle and hip AROM, and average Athlete Single Leg Stability Test level 4 and 12 scores, we calculated odds ratios using an unconditional logistic regression analysis. A binary logistic regression analysis was used to examine the relationship between the outcome variables and the presence of chronic ankle instability in participants. We ranked all

included outcome measures in order of significance and performed a stepwise process to find a risk factor with significant results ( $p \leq 0.05$ ). All statistical analyses were conducted with IBM SPSS software (v. 25, Armonk, NY).

## **RESULTS**

### **Pilot Study Results**

Prior to formal data collection, we conducted a pilot study with 10 physically active volunteers (7 men, 3 women; age,  $23.6 \pm 1.2$  yrs) to establish the intra-rater reliability of the principal investigator (JWL) for all the clinical outcome measures. Shrout and Fleiss,<sup>53</sup> have defined intraclass correlation coefficient (ICC) values that are  $\geq 0.75$  as indicative of “excellent” test-retest reliability; values between 0.40 and 0.74 are considered “good to fair” reliability, while values  $\leq 0.39$  represent “poor” reliability. Out of our 14 independent outcome measures, we had 12 dependent variables that achieved the “excellent” ICC value category. The pilot study ICC results for each outcome measure are summarized in Table 3.3.

### **ANOVA Results**

We originally sought 60 participants in this case-control study—20 physically-active individuals with chronic ankle instability and 40 physically-active individuals with mandatory shutdown of all interactive human research activities at our university during the spring of 2020, we modified the goals and scope of this study. Given those limitations, we were able to screen 40 volunteers between the ages of 18 and 35 years for eligibility in this study. We collected complete data sets from 23 participants (12

women, 11 men; age,  $22.3 \pm 2.1$  yrs) prior to being required to end all recruitment and data collection efforts on or about March 24, 2020.

<b>Table 3.3. Pilot Study Results for Intra-rater Test-Retest Reliability for All Clinical Outcome Measures</b>				
<i>Outcome Measures</i>	<i>Right (ICC<sub>2,1</sub>)</i>	<i>Left (ICC<sub>2,1</sub>)</i>	<i>Side N/A (ICC<sub>2,1</sub>)</i>	<i>Intraclass Correlation Coefficients Category</i>
FADI-Sport			1.0	Excellent
AROM Ankle Dorsiflexion	0.693	0.918		Excellent and Good and Fair
AROM Ankle Plantarflexion	0.981	0.978		Excellent
AROM Ankle Inversion	0.945	0.871		Excellent
AROM Ankle Eversion	0.771	0.733		Excellent and Good and Fair
ASLST OSI 12	0.730	0.842		Excellent and Good and Fair
ASLST OSI 4	0.814	0.793		Excellent
FMS Deep Squat			1.0	Excellent
FMS Hurdle Step			1.0	Excellent
FMS Inline Lunge			0.930	Excellent
FMS Shoulder Mobility			0.748	Good to Fair
FMS Active Straight Leg Raise			0.899	Excellent
FMS Trunk Stability Pushup			0.889	Excellent
FMS Rotary Stability			0.798	Excellent

The CAI (Case) group included 7 individuals with a medical history of at least one ankle sprain within the past 12 months, a previously injured ankle joint “giving way”, and/or feeling of instability, and scored less than 24 points on the 100-point Cumberland Ankle Instability Tool (CAIT).<sup>39</sup> The control group consisted of 14 volunteers who were triple matched with a case group participant at a 2:1 ratio on the basis of sex (male/female), age ( $\pm 5$  years) and BMI (same category, e.g., normal, overweight). The control group participants had no history of ankle sprains, never had lower extremity surgery, or any fractures in the lower leg. All participants self-reported being physically active for 150 to 300 minutes or more per week. A summary of participant demographic information is provided in Table 3.4.

<b>Table 3.4. Summary of Participant Demographic Data</b>							
<i>Group</i>	<i>N</i>	<i>Age (yrs)</i>	<i>BMI Category</i>			<i>Sex</i>	
			Normal	Overweight	Obese	<i>Male</i>	<i>Female</i>
Case	7	21.9 $\pm$ 2.3	4	3	0	3	4
Control	16	23.5 $\pm$ 2.2	8	6	2	8	8
Total	21	22.7 $\pm$ 2.3	12	9	2	11	12

To determine the presence of multicollinearity<sup>54</sup> ( $r \geq 0.80$ ) among our outcome measures, we calculated a Pearson product moment intercorrelation matrix with our 15 outcome measures. Our matrix revealed high positive linear correlations between Athlete Single Leg Stability Test level 12 and level 4 scores on the CAI/matched ( $r = 0.944$ ,  $p = 0.001$ ), as well as the non-CAI/matched limbs ( $r = 0.918$ ,  $p = 0.001$ ). To decrease the chances of making a Type I error, the less challenging Athlete Single Leg



Stability Test level 12 outcome measures ( $n = 2$ ) were removed from further statistical analysis.

Three 1-way ANOVAs were used to measure the between group (case-control) differences of the FADI-Sport, FMS-CS, and the FMS-LE scores. As anticipated, our results indicated that the case group scored significantly lower on the FADI-Sport outcome measure ( $26.7 \pm 4.1$  points) than the control group ( $31.0 \pm 2.7$  points) [ $F = 9.303$ ,  $p = 0.006$ ,  $\eta^2 = 0.529$ ]. There were no significant differences between the CAI and control groups for FMS-CS scores (mean score,  $14.87 \pm 2.24$ ,  $F = 2.308$ ,  $p = 0.114$ ,  $\eta^2 = 0.686$ ) or the FMS-LE scores (mean score,  $6.0 \pm 1.5$ ,  $F = 2.889$ ,  $p = 0.105$ ,  $\eta^2 = 0.756$ ).

Five 2-way mixed ANOVAs (Group (2) x Limb (2)) were used to evaluate between and within group differences of four ankle AROM measures and the ASLST level 4 measurements. Results indicated a significant difference between groups for Athlete Single Leg Stability Test level 4 scores ( $F = 4.140$ ,  $p = 0.045$ ,  $\eta^2 = 0.172$ ), with the CAI group having worse scores compared to the control group. No significant differences were found between groups for any of the AROM measurements. The results also showed there is no significant difference ( $p > 0.05$ ) within groups, comparing the CAI/matched to the non-CAI/matched limbs, from any of the outcome measures. The “CAI” group involved the injured limb of the CAI participant with the two triple-matched control limbs. The “nonCAI” group involved the non-injured limb of the CAI participants matched to two control participants. The reported mean scores with standard deviation of each outcome measure are within group measurements. The statistical results for the five 2-way ANOVAs is summarized in Table 3.5.

<b>Table 3.5. Two Way ANOVA Comparisons between and within CAI/matched (N = 7) and Control/matched (N = 16) groups.</b>					
<b>Outcome measures</b>	<b>Mean scores + SD</b>	<b>Between Groups</b>		<b>Within Groups</b>	
		P Value	Effect Size	P Value	Effect Size
AROM_CAI_Dorsiflexion	10.56 ± 2.81 deg.	7.737	0.006	0.973	0.001
AROM_nonCAI_Dorsiflexion	11.12 ± 3.23 deg.				
AROM_CAI_Plantarflexion	51.55 ± 8.0 deg.	0.515	0.022	0.515	0.022
AROM_nonCAI_Plantarflexion	52.53 ± 6.45 deg.				
AROM_CAI_Inversion	39.26 ± 9.23 deg.	0.799	0.004	0.791	0.004
AROM_nonCAI_Inversion	39.65 ± 8.97 deg.				
AROM_CAI_Eversion	20.91 ± 6.1 deg.	0.304	0.053	0.454	0.028
AROM_nonCAI_Eversion	19.17 ± 6.56 deg.				
ASLST_OSI_CAI_4	1.29 ± 0.51 deg.	0.045*	0.172	0.328	0.048
ASLST_OSI_nonCAI_4	1.21 ± 0.5 deg.				

\*= p < 0.05

### Binary Logistic Regression Results

A binary logistic regression analysis was used to examine the relationship between the outcome variables and the presence of chronic ankle instability in participants. We excluded Athlete Single Leg Stability Test level 12 scores from this analysis, as it was too highly correlated with Athlete Single Leg Stability Test level 4 scores ( $r = 0.944$ ,  $p = 0.001$ ). The full model included all 13 outcome variables. The control group was used as the reference category. Variables were removed sequentially using manual removal until a parsimonious model was obtained. Variable removal from each iteration was determined based upon the variable that was least predictive of CAI. The order of variable removal was as follows: [1] AROM\_CAI\_Dorsiflexion ( $p=0.0786$ ); [2] AROM\_nonCAI\_Inversion ( $p= 0.0685$ ), [3] AROM\_nonCAI\_Dorsiflexion ( $p = 0.674$ ), [4] AROM\_CAI\_Inversion ( $p = 0.591$ ), [5] AROM\_CAI\_Eversion ( $p = 0.577$ ), [6] AROM\_nonCAI\_Eversion ( $p = 0.292$ ), [7] AROM\_nonCAI\_Plantarflexion ( $p = 0.286$ ), [8]

AROM\_CAI\_Plantarflexion ( $p = 0.280$ ), [9] FMS\_Total Score ( $p = 0.119$ ), [10]

ASLST\_OSI\_nonCAI\_4 ( $p = 0.098$ ), and [11] FMS\_Lower Extremity score ( $p = 0.051$ ).

The final reduced model indicated that both ASLST-CAI-4 ( $OR = 0.03$ ; 95% CI = 0.00 – 0.86) and FADI-Sport ( $OR = 1.54$ ; 95% CI = 1.01 – 2.34) were significantly associated with CAI (Cox & Snell  $R^2 = .45$ ). Compared to the control group those with CAI are likely to have lower FADI-Sport scores and greater Athlete Single Leg Stability Test level 4 scores. The classification accuracy of the final reduced model was 81% (95% CI = 58.09 – 94.55%) (see Table 3.6).

**Table 3.6. Classification Accuracy Table**

		Predicted Outcome		
		Case	Control	Percentage
Observed Outcome	Case	5	2	71.4
	Control	2	12	85.7
	Overall Percentage			81.0

*Note. The number of predicted cases of CAI was determined using a binary logistic regression model with FADI-Sport scores and ASLST Level 4 scores as predictor variables.*

## DISCUSSION

The primary purpose of this study was to identify differences among measures of active range of motion (AROM), dynamic postural stability, and FMS-lower extremity scores in physically-active persons with and without CAI. A secondary purpose was to identify risk factors that predispose individuals to CAI. Our study differs from others as we triple matched two healthy individuals for every 1 CAI individual by age ( $\leq 5$  yrs), sex, and BMI category. By using this method, it created a stronger analysis of the proposed

risk factors in CAI individuals. Our study differs from previous research, as Choi et al<sup>24</sup> evaluated the FMS deep squat, step over hurdle, and inline lunge with risk factors associated with CAI.<sup>24</sup> We included the use of the Biodex Balance System in searching for correlation between ankle range of motion and functional movement assessment scores.

The results from our study show that the FADI-Sport score is a significant factor in CAI. Unlike Choi et al,<sup>24</sup> we did not find the FMS lower extremity (FMS-LE) score (x/9) to have a significant difference between participants with CAI ( $5.28 \pm 2.1$ ) and between the healthy controls ( $6.31 \pm 1.1$ ). We also did not find a strong correlation between the FADI-Sport and FMS-LE scores ( $r = 0.333$ ,  $p = 0.140$ ,  $r^2 = 0.11$ ). Choi et al<sup>24</sup> also found a strong correlation between the FADI-Sport score and the Inline Lunge score on the FMS ( $r = 0.896$ ), as our results did have correlation between the two ( $r = 0.569$ ,  $p = 0.007$ ).

The binary logistic regression model was done in a stepwise process, evaluating each risk factor individually, and as a model based on the order of which they were entered. We started with the FMS-LE score first, as this was the primary focus of our study. Block 0 (beginning block) included 13 outcome measures, and the model had significance ( $p = 0.031$ ), and the only significant risk factors were FADI-S ( $p = 0.045$ ) and Athlete Single Leg Stability Test level 4 scores ( $p = 0.042$ ). The final reduced model showed only two variables that were significantly associated with CAI; Athlete Single Leg Stability Test OSI level 4 and FADI-S scores.

Choi et al<sup>24</sup> concluded that the FMS tool could detect functional limitations in CAI individuals. The overall intent of the FMS is to identify individuals who might be at risk

for injury.<sup>47</sup> The FMS targets observing for physical deficits, but it should also screen for neurologic deficits as well, as a decrease in postural stability is recognized as a risk factor for CAI.<sup>22-24</sup> The FMS is not injury specific.

A score of 14 or less on the FMS indicates that the tested individual is at a greater risk of injury,<sup>47</sup> which O'Connor et al used as their cutoff score when testing marine officer candidates.<sup>55</sup> O'Connor found that a FMS score  $\leq 14$  predicted risk of future injury with a sensitivity of 0.45 and a specificity of 0.71. These results indicate the FMS is 45% accurate in testing ability to identify those at risk, and 71% accurate to determine those who are not at risk of injury.<sup>58</sup> Currently, there is no cut-off score for individual FMS tasks. If an individual's score is less than 14 on the FMS, it does not mean they are guaranteed to get injured, or decreased ankle function means the ankle is pre-determined to be injured, but rather that individual is at an increased risk of an injury. Again, the FMS is not sufficiently specific to singly target a specific injury.

Active ankle dorsiflexion is known to have an important role in the lower extremity functional movement chain.<sup>26-28</sup> We found that dorsiflexion had a weak positive correlation with the FMS inline lunge ( $r = 0.320$ ), FMS overall score ( $r = 0.179$ ), and the FMS lower extremity score ( $r = 0.181$ ) [ $p > 0.05$ ].

The FMS overhead squat, step-over hurdle and inline lunge all require ankle dorsiflexion, as most of the other screening tasks require shoulder mobility and rotary stability. Therefore, it is not surprising that the correlation between ankle dorsiflexion and FMS overall score is very low, as the FMS includes only three lower extremity tasks out of the seven total movements.

From our Pearson product moment intercorrelation matrix table, we found two negative (inverse) correlations between the Athlete Single Leg Stability Test level 4 scores and FMS overhead squat ( $r = -0.311$ ), step-over hurdle ( $r = -0.700$ ,  $p = 0.001$ ,  $r^2 = 0.49$ ), inline lunge ( $r = -0.322$ ), FMS total score ( $r = -0.427$ ), and lower extremity score ( $r = -0.508$ ,  $p = 0.019$ ,  $r^2 = 0.251$ ). It is not surprising that the Athlete Single Leg Stability Test and FMS step over hurdle have a strong negative correlation, as the Athlete Single Leg Stability Test is a unipedal test of dynamic balance, and the step over hurdle involves single leg balance while performing a functional movement task. The 51% unexplained variance between Athlete Single Leg Stability Test and the FMS step-over hurdle, which suggests that about half of a change in Athlete Single Leg Stability Test score can be explained in a change in the FMS step-over hurdle score. As for the rest, these small correlations are due to the multifactorial nature of the FMS, as the overhead squat and inline lunge do not require single leg balance.

The FMS scores may be associated with multiple risk factors that have been identified as synonymous with CAI, but a single cut-off score cannot be suggested in this study. The FMS is not specific to screening individuals with chronic ankle instability, due to the general goal of singling out an individual being at higher risk of injury. An FMS score of 14 indicates a higher risk of suffering an injury, but does not specify the type of injury, to what part of the body is at risk of injury, or the severity of the injury. Future investigation is needed to break down individual movements of the FMS to determine what would be required to detect the root causing dysfunction if the individual did not score perfectly.

Other than the three lower extremity tasks involved in the FMS, the rest of the screening involves testing shoulder mobility, rotary stability, and ability to perform a trunk stability pushup off the floor. Our results suggest that these FMS movement tasks are not related to risk factors of CAI. As mentioned previously, the FMS does not focus on a singular injury or injury type. The FMS involves a 4-point scoring scale. To receive a score of “3”, the participant would need to perform the task completely correct with no errors.<sup>47</sup> If the participant completed the movement with modifications, then a score of “2” will be assigned.<sup>47</sup> If the participant could not complete the task with the modifications, a score of “1” is given, and if there is any pain elicited during the task, participants will be assigned a score of “0”.<sup>47</sup> Individuals who score a 14 or less on the FMS should be further movement analysis testing done to identify potential causes of dysfunction and better assist in prevention of injury.<sup>47</sup>

Previous studies have agreed that deficits in ankle range of motion have been associated with CAI.<sup>26-28, 48</sup> According the 2016 International Ankle Consortium,<sup>9</sup> the most common mechanism of an ankle sprain is excessive rearfoot inversion or a combination of plantarflexion and adduction of the foot. We would then expect an increase in ankle inversion to be correlated with a decrease in FMS scores. However, ankle plantarflexion or inversion are not key movements in FMS movement tasks, as most of the tasks involve the ankle in a closed-packed position.

Our study did find a small positive correlation between ankle dorsiflexion and Athlete Single Leg Stability Test level 4 scores ( $r = 0.351$ ,  $p = 0.119$ ,  $r^2 = 0.123$ ). The 88% unexplained variance between these two measures reflects the poor correlation

between the two. These two measurements are correlated might be due to the way the Athlete Single Leg Stability Test is set up and involves the unstable surface. The individual is positioned on the computerized force plate so that their center of balance is directly over the center of the board. Since persons of different heights have different centers of balance than someone else, the Biodex system allows the clinician to change the foot position parameters when confirming the center of balance, so their results are not skewed. The main goal of the Athlete Single Leg Stability Test is to keep the black dot (representing the center of balance) in the center of the bull's eye target on the Biodex screen monitor. The lead researcher (JWL) observed different balancing strategies during subjects' performances of the Athlete Single Leg Stability Test. Some participants used an ankle strategy, while others used more of a hip strategy. Those who balanced more with their body positioning rather than moving their ankle were demonstrating a hip balance strategy. Less available range of motion of the ankle may force the individual to maintain balance using a hip strategy.<sup>31-33</sup>

The use of a binary logistic regression analysis has become common practice in case-control studies because of the statistical model's ability to account for stratification and matching of participants.<sup>56</sup> Despite the potential advantages of using a conditional logistic regression model for analysis of case-control participants, there are situations where this model can produce biased estimates, particularly when the sample size is small.<sup>57</sup> Results from a simulation study has also determined that when participants are matched using only a few demographic variables, such as the case in this study, estimates obtained from conditional logistic regression and binary logistic regression



analysis were similar<sup>58</sup>. Due to the small sample size for this study and the use of loose-matching data, it was determined that a binary logistic regression analysis would be the more appropriate statistical model to investigate the relationship between CAI and the outcome variables in this study.

## **LIMITATIONS**

While we found statistically significant results, our study is not without its limitations. Due to the COVID-19 pandemic, we were required to shut down all in-person data collection at our university after collecting data from only 23 of the 60 participants that we had intended. The decision to close the university to face-to-face classes and research activities and invoke a policy of social distancing was beyond our control. These unique circumstances, coupled with the limited time frame to complete thesis research, resulted in approximately one-third the sample size we had planned. The smaller the sample size, the less statistical power there is to find significant relationships and/or differences that might exist among outcome measures. The cross-sectional nature of this study was another limitation, as with only one data collection point, we cannot know whether we tested our participants on a good, bad or average day for them. Prospective, longitudinal study designs that involve data collection over extended periods of time are more appropriate. Lastly, all data were collected by the same researcher, the primary author of this master's thesis, and he was not blinded to the group identity of the participants. While small, there is a chance of that bias was introduced to this study as a result.

## CONCLUSION

Currently, there is no single risk factor that has been identified as the leading risk factor of CAI. The FMS, while not focused on targeting specific injuries, has been shown to predict an overall risk for injury. Our results show that a lower FADI-Sport and a higher Athlete Single Leg Stability Test level 4 score can classify individuals as being more at risk for developing CAI. Using the FMS in conjunction with other screening tools, such as the FADI-Sport subscore and the Biodex Balance System, may provide a better indicator of identifying if an individual is at increased risk for developing chronic ankle instability.

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#### **IV. SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH**

Chronic ankle instability remains a largely overlooked clinical problem that affects more than half a million people worldwide. Individuals with CAI may experience altered gait mechanics during walking and running, which may increase the risk of future injury. There have been no recent studies that have systematically reviewed and identified various biomechanical changes in gait from wearing an ankle support device in CAI individuals. There is no single risk factor that has been identified as the leading risk factor of CAI. The FMS, while not focused on targeting specific injuries, has been shown to predict an overall risk for injury.

Our systematic review concluded that a semi-rigid ankle brace, closed-basketweave, KinesioTape™, and high-dye ankle taping can improve gait kinematics and kinetics in CAI individuals. Our results from our cross-sectional study show that a lower FADI-Sport and a higher Athlete Single Leg Stability Test level 4 score puts an individual at greater risk for developing CAI. Using the FMS in conjunction with other screening tools, such as the FADI-Sport subscore and the Biodex Stability System, may provide a better indicator of identifying if an individual is at high risk of CAI.

Future studies should examine the relationship between these risk factors and CAI in specific populations using a larger sample size and with a longitudinal, prospective experimental study design to determine the cause and effect relationships of ankle injuries and when an individual develops CAI. More randomized controlled trials are also needed to determine biomechanical changes of walking, running, and other functional movement tasks; such as jumping, landing, and other agility movements. More

systematic reviews are also needed in determining the biomechanical effectiveness of an ankle support device during agility and high-velocity movement tasks in a CAI population.

## **APPENDIX SECTION**

### **Review of Literature**

Functional movement has been defined as the ability to produce and maintain a balance between mobility and stability throughout the kinetic chain while performing fundamental patterns with accuracy and efficiency.<sup>1</sup> Understanding the fundamentals of human movement is important because it will help clinicians realize that similar movements occur throughout many athletic activities.<sup>2</sup>

Research in the area of assessing functional movement has focused on issues such as ankle sprains<sup>3</sup>, use of functional assessment tools<sup>4-7</sup>, and neuromuscular deficits<sup>6</sup>; however, testing dynamic postural stability throughout a functional screening assessment is largely unstudied. The Functional Movement Screen™ (FMS), created by Cook et al<sup>2</sup> in 2006, may offer a different approach to injury prevention as it assesses neuromuscular asymmetry of the lower and upper extremities.

For these experiences to be understood, we must understand how ankle ligament injuries can lead to neuromuscular disablement, use of the FMS as a clinical-reported outcome measure from intervention studies, and previous studies that have investigated the reliability of the FMS. The following is an overview of the research of ankle ligament injuries, context of dynamic and static postural stability, description of the FMS and its role in injury prevention programs, a review of the literature regarding inter and intra-reliability of the FMS, static balance tools to assess neuromuscular imbalances, and the use of patient-reported outcome measures for the ankle.

## **Chronic Ankle Instability**

Chronic ankle instability (CAI) is defined as structural changes of the soft tissues around the ankle joint due to repetitive ankle sprains, which causes dysfunction in ankle musculoskeletal stability and neuromuscular control.<sup>3</sup> Among all lower extremity injuries, ankle ligament sprains account for more than 50% of all cases.<sup>3</sup> Chronic ankle instability is triggered through re-injury ankle sprains, which accounts for 55% to 72% of all CAI cases.<sup>3</sup> Intrinsic risk factors associated with CAI include agonist/antagonist muscle ratio (strength/endurance), neuromuscular control deficits, abdominal core muscle weakness, and contralateral muscle imbalances.<sup>4</sup> Ankle sprains occur most often with active movements, such as walking, running, and jumping. Such repetitive injuries lead to functional and chronic ankle joint instability.<sup>3</sup>

Lateral ankle sprains (LAS) comprise 25% to 30% of all sport-related injuries<sup>5</sup>. Common symptoms after suffering LAS include pain, instability or “giving way”, loss of function and repetitive ankle injuries that can lead to CAI.<sup>6,7</sup> Evidence suggests that CAI is associated with poor postural control due to an impairment in proprioception and neuromuscular control (NMC).<sup>6,7</sup> Patients with CAI may also display a delayed onset of muscle activation around the ankle, knee and hip during the transition from bilateral to unilateral movements, which might indicate deficits in proprioception and NMC.<sup>6</sup>

Without properly assessing functional mobility and stability in CAI patients, it is inappropriate to assume one has CAI.<sup>5</sup> Previous injury has been identified as the most prominent risk factor in numerous injury risk studies.<sup>5,6</sup> It is possible that there is a

fundamental change in motor control, such as strength and range of motion (ROM), as well as neuromuscular deficiencies.<sup>5</sup>

### **Postural Control**

Clinicians use postural control assessment to evaluate injury risk, functional deficits from injury, and level of improvement after an intervention.<sup>8</sup> Postural control can be grouped into static and dynamic categories. Static postural control requires the individual to establish a base of support and maintain the position while minimizing body movement.<sup>8</sup> Dynamic postural control involves a level of expected movement around a base of support.<sup>8</sup> Certain tasks that involve dynamic postural control might involve jumping or hopping to a new location with immediate attempt to remain as motionless as possible.<sup>8</sup> Postural control assessments can be conducted with reliable and valid instrument equipment, such as the Neurocom Balance Master, Balance Error Scoring System (BESS), a force platform, or the Biodex Balance System (BBS).<sup>8-10</sup>

The ankle plays a vital role in posture and locomotion.<sup>9, 10</sup> Any changes in center of gravity (COG) are corrected by the ankle by shifting the COG position in the base plane.<sup>9, 10</sup> In addition, center of pressure (COP) displacement is an outcome measure that has helped identify postural instability.<sup>9</sup> Weakness of ankle-stabilizing muscles is a major cause of postural instability.<sup>9</sup> Deficits in postural control in individuals with CAI have been proposed to come from diminished equilibrium.<sup>11</sup> Due to diminished equilibrium, there is a greater dependence and reliance on hip strategy to maintain balance.<sup>10,11</sup> Previous studies have suggested that individuals who sustain severe ankle injuries have demonstrated deficits in hip muscle function.<sup>10,11</sup>

## **Role of Functional Movement Screen™ in Injury Prevention**

Currently, there is no gold standard test that exists for evaluation of movement capacity. The Functional Movement Screen (FMS), however, has been recommended as a screening tool for movement-pattern limitations and side-to-side movement asymmetries.<sup>6</sup> The FMS may offer a different approach to injury prevention and performance predictability.<sup>2</sup> The FMS is a physical examination used to measure movement patterns in a practical and dynamic way.

Purposes of a screening tool are to identify body asymmetries, assess mobility/stability within the kinetic chain of whole-body movements, and detect poor-quality movement patterns.<sup>7,12,13</sup> Difficulty in preventing injuries seems to be directly related to the inability to consistently determine those athletes who are predisposed to injuries.<sup>12</sup> The FMS is comprised of seven fundamental movement tests that require balance of mobility/stability, as well as neuromuscular and motor control.<sup>2, 14</sup> Regional interdependence is a term used to describe the relationship between one-body region that may contribute to dysfunction of another region.<sup>2</sup>

The seven movement patterns of the FMS are the deep squat, hurdle step, inline lunge, shoulder mobility, active straight leg raise, trunk stability pushup and rotary stability. All seven screening tests evaluate flexibility, stability, and strength qualitatively.<sup>15</sup> Of the seven tests; the deep squat, hurdle step, and the in-line lunge are correlated with lower extremity function.<sup>15</sup> Each FMS test is scored based on the degree of compensatory movements required to complete the movement, and summed to

determine the overall FMS composite score (FMS-CS).<sup>14</sup> Previous studies determined that an FMS-CS of  $\leq 14$  out of 21 points is classified as having a high risk of injury.<sup>4, 16, 17</sup>

Motor learning is not about a specific body part, joint, or use of isolated muscles; rather, it is about synergy, balance, symmetry, and skill during the whole movement pattern.<sup>17</sup> The ability to predict injuries is equally as important as the ability to evaluate and treat injuries.

### **Influence of Intervention Programs on FMS Scoring**

Functional rehabilitation exercise through proprioceptive sense training has been known to decrease re-injury rate of the ankle joint. Ju et al.<sup>3</sup> conducted an 8-week functional rehabilitation program which included proprioceptive exercises with CAI patients. Their results showed an improvement in stabilization, postural sway and isokinetic muscular function of the unstable ankle joint.

The use of an off-season functional rehabilitation intervention program can improve a patient's FMS score above the injury threshold ( $\leq 14$ ).<sup>5, 16, 20, 21</sup> Chimera et al.<sup>13</sup> discovered that lower extremity ROM along with core function deficits will lead to a diminished FMS movement patterns and have a low FMS composite score (FMS-CS). Kiesel et al.<sup>5</sup> conducted a study on American professional football players, using the FMS as a pre- and post-test measurement for an off-season intervention program. Results showed a 52% increase in the FMS-CS that was over the established threshold score after completing the intervention.

Muscle imbalances can result in compensatory movement patterns, resulting in poor biomechanics and eventually results in injury.<sup>18</sup> Previous studies have reported



that functional rehabilitation exercise through proprioceptive sense training will decrease the ankle re-injury rate in CAI patients.<sup>3, 14,17, 20</sup> Stanek et al<sup>20</sup> performed a study on 56 healthy fireman and an 8-week corrective exercise program in correlation to a rise in FMS-CS. Their results showed 65% of all participants had an increase in FMS-CS, while 55% and 58% had improved mobility and stability scores, respectively.

Jaber et al.<sup>6</sup> studied activity of the hip and ankle muscles during the Star Excursion Balance Test (SEBT), a reliable clinical test that distinguishes dynamic postural control. The SEBT and FMS have similarities in which both are functional movement assessment tools of the lower extremity. The result of their study show diminished postural control of the gluteus maximus in the posterior direction of the SEBT. Jaber et al concluded that future research should target hip muscles in a conditioning and rehabilitation program in CAI patients and to use the SEBT as an outcome measure. The FMS serves to pinpoint functional deficits that are related to proprioceptive and mobility/stability weakness.<sup>8</sup> The FMS may be included as a pre participation examination (PPE) assessment to determine functional deficits.<sup>14</sup>

Because the injury threshold score for the FMS-CS is inconsistent, it is recommended that the examiner pay more attention to individual performance in each of the FMS tests rather than the sum of scores.<sup>7, 16</sup> Minthorn et al.<sup>7</sup> proposed a clinical question of whether an individualized training program will improve movement patterns in adults who are involved in high-intensity training. These authors published a critically appraised topic that included an analysis of 3 different studies that have tested if a training program will increase movement patterns. They identified that the FMS is

accurately correct with identifying the true-positives, which are participants with an FMS-CS score of  $\leq 14$  and also sustained an injury, was a high 63%.

### **Reliability of the FMS**

Previous studies have identified a high interrater reliability in the FMS when scored by a trained individual.<sup>5, 6, 21</sup> Interrater reliability is defined as the measurement of the extent to data collectors assigning the same score to the same variable. On the other hand, test-retest is another form of reliability, which assesses biological variability, instrumentation error by the participant, and error by the rater.<sup>21</sup>

The FMS has been previously identified as a reliable test, due to a good reliability score found for the test-retest analysis (ICC=0.60).<sup>21</sup> Shultz et al<sup>21</sup> used intraclass correlation coefficients (ICC) to assess the test-retest reliability of the FMS. According to Shultz et al, an ICC of 1 is considered “perfectly reliable”, an ICC greater than 0.75 is “excellent”, and ICC values between 0.40 and 0.75 are “fair” to “good”.<sup>21</sup>

Marques et al.<sup>16</sup> identified athletes who scored  $\leq 16.5$  on the FMS-CS as having a 4.7 greater chance of suffering a lower limb injury during the regular season. Parenteau et al.<sup>22</sup> aimed to determine interrater and intrarater reliability of the FMS among young elite ice hockey players. Data collection for interrater reliability was collected through rating the FMS in person, and intrarater reliability was done through video rating of the FMS. Results show high intrarater reliability for FMS-CS, with an ICC of 0.96 (95% CI; 0.92-0.98), as well as high inter-rater reliability with an ICC of 0.96 (95% IC; 0.92-0.98). Current data indicate that the FMS is more sensitive than specific, meaning it can

correctly identify patients with a disease more than correctly identify those who do not.<sup>6</sup>

### **Instrumented Balance Assessment Tools**

Currently, there is no gold standard for assessment of dynamic postural control. A need exists for a clinically accessible test of postural control that produces objective information about postural control variables that can identify prolonged impairments to functional movement.<sup>23</sup> The Neurocom Balance Master (NeuroCom International Inc., Clackamas, OR) is a reliable and validated (ICC = 0.92, 95% CI = 0.85-0.96) tool used to assess variables of static and dynamic stability.<sup>23</sup> The Neurocom is typically used for assessment of sport-related concussions (SRC) in regard to rehabilitation progression and return-to-play decisions. The Neurocom device allows for several balance assessment tests, such as the Sensory Organization Test (SOT), Motor Control Test, modified Clinical Test of Sensory Integration and Balance (mCTSIB), Adaptation Test, Weight/Bearing Squat, and Unilateral Stance.<sup>24</sup> The use of the Neurocom to evaluate postural stability in individuals with CAI is largely unstudied.

The Balance Error Scoring System (BESS) provides a quantitative static measure of balance using an error scoring system.<sup>25</sup> The BESS is performed in 3 stances (double legged, single legged, and tandem stance) on both a hard surface and a foam surface. Linens et al.<sup>25</sup> performed a study regarding CAI participants exhibiting impaired postural stability using the BESS. Their results indicated that CAI participants had more postural stability deficits doing the BESS (total errors; CAI =  $13.59 \pm 4.00$ , Control =  $11.06 \pm 3.01$ ;

$p < 0.01$ ). Clinicians can benefit from these results to identify CAI individuals who may benefit from rehabilitation that reestablishes postural stability.<sup>25</sup>

The BBS provides valid, reliable and repeatable objective measures of an individual's ability to balance on stable and unstable surfaces.<sup>13</sup> The BBS is used to assess dynamic postural control and calculates 3 separate measures, Medio-Lateral Stability Index (MLSI), Antero-Posterior Stability Index (APSI), and Overall Stability Index (OSI).<sup>12, 13, 26</sup> A high score from these measurements indicate substantial movement away from the COG, which results in poor balance.<sup>13, 26</sup> The BBS consists of a mobile balance platform, giving up to 20 degrees of surface tilt in 360 degrees range.<sup>12, 13, 26</sup> The stability level refers a predetermined stability of the balance platform. The degree to which the platform tilts during the BBS assessment is indicated by the individual's ability to balance.<sup>13, 26</sup>

Whole-body-vibration (WBV) training is a form of neuromuscular training that has been used as a preventative and rehabilitation tool.<sup>26</sup> There is an absence of research of WBV training in patients with CAI. Training on an unstable surface has been suggested as a valuable aid in sensory-motor rehabilitation of the ankle.<sup>26</sup> Guzman et al.<sup>26</sup> performed a study to evaluate fifty CAI patients through WBV training, using the BBS as an outcome measuring tool. Participants were randomly assigned to either the vibration group, non-vibration, or control group. After taking baseline data, participants followed a 6-week balance-training protocol. At the conclusion of the 6 weeks, all fifty participants were put through a BBS post-test. Results showed improvement of OSI ( $p =$

0.01) and APSI ( $p = 0.03$ ) scores in the vibration group. The main finding of this study was that a 6-week WBV training program improved balance in CAI participants.

The SEBT has been deemed a reliable and valid clinical test in distinguishing dynamic postural control differences between individuals with and without unstable ankles.<sup>6</sup> In the SEBT, postural control is reflected by reach distance in 8 different directions, with a greater postural control is usually indicated by an increase in reach distance in order to maintain a stable unilateral base of support.<sup>6</sup> There is minimal research regarding muscle activation necessary to complete the SEBT in individuals with CAI. Jaber et al.<sup>6</sup> studied dynamic postural control and electromyography (EMG) activity of the tibialis anterior (TA), peroneus longus (PL), gluteus medius (Gmed) and gluteus maximus (Gmax) muscles during the performance of the SEBT in individuals with and without CAI. For EMG analysis, a 6-channel MyoMuscle 1200 EMG System (Noraxon INC, Scottsdale, AZ) was used to record muscle activity during the SEBT. The Gmax and TA contributed to sagittal plane stability, and Gmed and PL contributed to frontal plane stability.

EMG records the highest maximal voluntary contraction (MVIC) of the muscles being tested and used for normalization.<sup>6</sup> To establish MVIC%, peak amplitude value must be calculated for each muscle during the period from toe-off to toe-touch and return to starting position of each SEBT trial.<sup>6</sup> Results show the CAI group having significantly less reach distance during the anterior direction ( $p = 0.021$ ,  $n^2 = 0.30$  and  $p = 0.009$ ,  $n^2 = 0.35$ ). For EMG activation amplitude, a significant difference in mean EMG activity was seen from the TA in AD ( $p < 0.01$ ,  $n^2 = 0.70$ ) and the PL and Gmax in

posterior-lateral direction ( $p = 0.049$ ,  $n^2 = 0.32$  and  $p = 0.011$ ,  $n^2 = 0.50$ , respectively). CAI participants had delayed gluteal muscle activation onset times during the AD and PLD of the SEBT, which is considered as a potential factor for continual instability.<sup>6</sup>

The review of literature of different balance assessment tools allows clinicians to examine the results and interpret them to use for clinical practice. Most of the tools explained here are geared more toward SRC injuries, but previous studies have shown how they can also be used in injury assessment and prevention of the lower extremity.

### **Patient Reported Outcome Measures for the Ankle**

Many outcome measures have been developed to evaluate various clinical interventions, many are patient-reported outcome measures (PROMs).<sup>27</sup> A PROM should be reliable, valid, and responsive,<sup>27</sup> and provide measures of patient's degree of pain, impairment, disability, and quality of life.<sup>27, 28</sup> The use of PROM's is critical in evaluating the efficacy of orthopedic procedures and are highly used in clinical settings to assess outcomes of health care.<sup>28</sup> Specifically for the ankle joint, there are multiple PROM used to measure functional limitations, such as the Foot and Ankle Ability Measure (FAAM), Ankle Joint Functional Assessment Tool (AJFAT), Cumberland Ankle Instability Tool (CAIT), Foot and Ankle Disability Index (FADI), and Chronic Ankle Instability Scale.<sup>28</sup>

All of these PROMs evaluate functional disability activities of daily living (ADL) in individuals with CAI.<sup>28-31</sup> The clinical relevance of using PROMs should be valued because investigating patient perceptions may reveal certain characteristics distinct to the individual's impairments and help guide them through a rehabilitation program.<sup>28</sup>

Recent evidence suggests that CAI is likely associated with decreased PROM scores.<sup>28</sup>

Before putting CAI patients through rehabilitation, however, the clinician must first rule out other ankle injuries, as misclassification of an individual with an ankle injury other than CAI might result in an effective rehabilitation program.<sup>29, 30</sup>

## **Summary**

The definition of functional movement is the ability to produce and maintain a balance between mobility and stability throughout the kinetic chain while performing functional movement patterns. Ankle ligament sprains are amongst the most common athletic injury, accounting for more than 50% of all injury cases. Re-injury of ankle sprains can lead to CAI and structural changes of soft tissue surrounding the ankle joint. CAI can lead to dysfunction in proprioception and NMC of the ankle joint, as well as difficulty in maintaining mobility/stability throughout functional movements. CAI patients can have deficits in dynamic-postural control, which can lead to diminished functional movement.

The FMS is a reliable screening tool that assesses body asymmetries, mobility/stability of whole-body movements, as well as neuromuscular and motor control deficits. The purpose of the FMS is to test for potential risk of injury through the completion of seven functional movement tests. Using the FMS as an outcome measure in intervention studies can show improvement in FMS-CS, which means having a lower risk of injury. Previous studies show that the FMS can be used as an outcome measure in prevention programs to determine if individuals are at less risk of suffering injury. Using static balance tools can be helpful for clinicians in assessing deficits in stability and

functionality in CAI patients. There is also a need for more research using the Biodex Stability System to assess dynamic-postural control in individuals with lower extremity dysfunction/disabilities and determine the extent that ASLST scores and FMS-CS are correlated. Existing evidence suggests that PROMs are a helpful quantitative assessment tool to investigate the patients' perception of their disability that will help guide them through an appropriate rehabilitation program.

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