DYNAMIC LEAP AND BALANCE TEST (DLBT):
ABILITY TO DISCRIMINATE BALANCE DEFICITS IN INDIVIDUALS WITH CHRONIC ANKLE INSTABILITY

A Thesis in
Kinesiology
by
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Abstract
Clinicians commonly explore functional testing methods that can help them identify individuals with conditions of interest and measure the progress of rehabilitation programs. The Modified Star Excursion Balance Test (mSEBT) is a measure of dynamic balance commonly used in the assessment of lower extremity injuries. It has previously been used to identify dynamic balance deficits in individuals with chronic ankle instability (CAI). The mSEBT measures the dynamic control of body movements over an unchanging base of support (BOS). Most running sports require serial changes in BOS alternating from limb to limb requiring reestablishment of dynamic stability with each change. We created a new dynamic balance test, the Dynamic Leap and Balance Test (DLBT) that requires changes in BOS and recovery of dynamic stability. It is purported to more closely mimic the balance requirements of running sports which can provide clinicians with a more robust measure of dynamic balance for identifying injured populations and physical rehabilitative progression. The secondary purpose of this study was to compare dynamic balance performance between the DLBT and the mSEBT in participants with unilateral CAI. It was hypothesized that the DLBT will show significant differences between the involved and uninvolved limbs between either of the two CAI and control groups. Thirty-six college-aged students were recruited and divided in two groups. Eighteen participants with a unilateral history of CAI were designated as the injured group and eighteen participants without a history of CAI were designated as healthy controls. CAI subjects were identified using the Identification of Functional Ankle Instability (IdFAI) questionnaire. In this case-control study participants were randomly assigned to complete the mSEBT or DLBT on either their CAI (or healthy matched) or uninvolved limb on Day 1 and the same tasks on Day 2 with the other limb. There were no statistically significant differences (P < 0.05) seen between any of the four conditions for
composite or individual reach (anterior, posteromedial, posterolateral) distance measures (% leg lengths) of the mSEBT. Statistically significant differences (P<0.001) in DLBT time were found between limbs. The DLBT time (seconds) for the CAI involved limb (51.85 ± 4.04, 95% CI = 51.18, 53.52) was significantly greater than for the CAI uninvolved limb (44.12 ± 3.60, 95% CI = 42.52, 45.78) and the control matched limb (41.88 ± 3.36, 95% CI = 40.21, 43.55). There were no significant differences in the DLBT time between the limbs in the control participants. These results suggest that the DLBT may be a more robust measure for detecting dynamic balance deficits as compared to the mSEBT in individuals with unilateral CAI. The DLBT is more challenging than the mSEBT as participants have to change the BOS and reestablish dynamic balance. Moreover, the leaping task involved in the DLBT appears to require greater production and attenuation of acceleration and deceleration forces and is more functionally similar to walking, running, cutting and jumping activities. The DLBT is a cost-effective tool that can be used to assess dynamic balance that may be more robust in identifying individuals with CAI than previously proposed measures of dynamic balance such as the modified SEBT.
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INTRODUCTION

Balance is considered to be an important component of motor performance tasks. It is controlled by the central nervous system with input from the visual, tactile, proprioceptive and vestibular systems.\textsuperscript{1,2} There are two main types of balance, static and dynamic. Static balance is defined as maintaining postural equilibrium while holding the body in a stationary position and dynamic balance is maintenance of postural equilibrium while the body’s parts are moving.\textsuperscript{1} Gambetta and Gray\textsuperscript{3} refer to balance as the most important component in athletic ability because balance is required for every movement performed. Balance deficits are generally seen after lower extremity injuries. Individuals with chronic ankle instability (CAI) have often demonstrated balance deficits.\textsuperscript{4,5} CAI is an inclusive term that takes in to account both mechanical and functional instability, as well as associated symptoms in the ankle after lateral ankle sprain.\textsuperscript{6}

There are a number of valid and reliable methods that are used in testing the static balance of a person such as quiet standing on a force plate in a laboratory setting or the Balance Error Scoring System (BESS) in a clinical setting.\textsuperscript{7-10} However, these measures of static balance may not provide relevant information about balance capabilities required to perform dynamic physical tasks.\textsuperscript{11} In laboratory settings, tasks like single-legged jump landing on a force plate are being employed for testing dynamic balance and require a change in base of support (BOS) and controlling the moving body parts unlike static assessment tasks.\textsuperscript{12} Differences in dynamic balance between CAI and uninjured populations have been demonstrated with this testing method.\textsuperscript{12} Subjects with CAI took more time to stabilize themselves than healthy subjects.\textsuperscript{12} Unfortunately, force plates are neither prevalent nor cost-effective in clinical settings. One test that is extensively used in clinical and research settings for dynamic balance assessment,
especially in CAI participants, is the modified Star Excursion Balance Test (mSEBT).\textsuperscript{7,9,13-15} Significantly lower reach distances have been reported in the mSEBT when assessing CAI involved legs compared with healthy legs.\textsuperscript{4,7,16}

However, the mSEBT may not be an accurate representation of the type of dynamic balance that occurs in most functional activities. The mSEBT involves standing on one leg and reaching as far as possible with the opposite leg in multiple directions.\textsuperscript{7} The reaching movements involved in the mSEBT are produced without a change or translation in the BOS. Moreover, the reaching task in the mSEBT is also not a commonly performed movement in sporting or daily living activity.\textsuperscript{17} In addition, some studies have shown no difference in balance between CAI and healthy individuals using the mSEBT.\textsuperscript{18,19} Interestingly, Ramirez et al.\textsuperscript{18} reported a difference in dynamic balance using the wavelet approximation method but could not show differences in dynamic balance using the mSEBT in CAI individuals. The results of this study suggest that the mSEBT may not be the ideal measure for assessing dynamic balance.

Another test that has been used to measure dynamic balance is the Modified Bass Test which requires hoping between marks on the ground, covering them with the head of the metatarsals, and trying to maintain a balanced position for five seconds.\textsuperscript{1,20} Although this test requires change in BOS and limb weight bearing, the leaps require minimal effort and cannot be considered challenging for an active population.\textsuperscript{1,20} Moreover, the test has standard jump distances that are not normalized to the leg length or height of the participant and therefore may not provide an equal challenge to all individuals.

Based on the literature, valid and reliable, cost-effective and efficient clinically-relevant tests that measure dynamic balance abilities during challenging functional tasks that require alternating limb weight bearing and BOS changes are not currently available. Hence, the
Dynamic Leap and Balance Test (DLBT) was created to provide a dynamic balance test that requires a change in BOS along with alternating limb weight bearing that mimics normal activities of daily living and sport activities and requires a level of effort that should be challenging to an active population. The DLBT is a low-cost clinical test based upon the concepts of the SEBT, time-to-stabilization principles and previous dynamic balance tests such as the Modified Bass Test. The primary purpose of this study was to assess the ability of the DLBT to identify dynamic balance deficits in participants with unilateral CAI. The secondary purpose of this study was to compare dynamic balance performance between the DLBT and the mSEBT in participants with unilateral CAI. The primary hypothesis was that the DLBT would show statistically significant differences between the involved and uninvolved limbs in the CAI group. The secondary hypothesis was that the DLBT would be more robust than the mSEBT in detecting balance deficits between involved and uninvolved limbs within the CAI group.
METHODS

Experimental Design and Setting:

This study was completed in the Athletic Training and Sports Medicine Laboratory in the Department of Kinesiology at The Pennsylvania State University. This was a case-control study with one group of 18 healthy participants and one group of 18 participants with CAI. Inclusion criteria for the healthy participants were: 1) age between 18 and 40 years old 2) demonstrated good English speaking skills. Healthy participants were excluded from the study if they had any of the following conditions at the time they participated in the study: 1) currently experiencing pain, numbness or paresthesia in the lower back or lower extremities; 2) history of a significant self-reported orthopedic injury of the lower back or lower extremity within the past 1 year e.g. disc herniation, fracture, ligamentous sprain etc.; 3) history of a significant lower back or lower extremity surgery with in the last 1 year e.g. ACL reconstruction, hip arthroscopy, lumbar laminectomy etc.; 4) currently under the care of a physician or seeking rehabilitation for a lower extremity or lower back injury or pain; 5) history of a head trauma, concussion or other cognitive impairment within the past 6 months; 6) currently experiencing any concussion-like symptoms such as nausea, dizziness, headache etc.; or, 7) currently experiencing balance problems or diagnosed with a neurological condition e.g. stroke, Parkinson’s disease etc.

Inclusion Criteria for Chronic Ankle Instability (CAI) participants:

Based on the recommendations by Gribble et al.\textsuperscript{21} our inclusion criteria for the CAI participants were: 1) a history of at least one significant ankle sprain which occurred more than one year prior to study participation and caused inflammation and resulted in at least one day’s interruption in normal physical activities; 2) at least two episodes of giving away and/or recurrent sprains 6 months before participation in the study; and, 3) self-reported ankle instability
as verified by a score >11 on the Identification of Functional Ankle Instability (IdFAI)
questionnaire. Participants who presented with only unilateral CAI were selected for this study.

**Procedures:**

Potential healthy and CAI participants were given health screening questionnaire (Appendix A) and IdFAI questionnaires (Appendix B) to determine eligibility for the study. If the participants were eligible, they were given the informed consent to read and sign. Once participants signed the informed consent form (Appendix C), they proceeded to day 1 testing. Participants first completed demographic data (age, sex), the injury history sheet (Appendix D), the Tegner Activity Scale (Appendix E) for physical activity level, the Foot and Ankle Ability Measure activity of daily living (FAAM-ADL) subscale and FAAM sport (FAAM-S) subscale questionnaires (Appendix F) and anthropometric testing (height, weight, limb length, and dominant limb). The participants then performed the Knee-to-Wall test. Finally, the mSEBT and the DLBT were assessed.

The order of limb testing (left, right) and limb testing procedure (mSEBT, DLBT) to be used on day 1 was randomized using a random number generator. The selected randomized limb was matched with the selected randomized task. Approximately 48 to 72 hours after the first testing session, the contralateral limb to the tested limb on day 1 was tested with the second task (e.g. if the involved leg of the CAI participant was tested on day 1 with DLBT then the uninvolved limb on was tested with mSEBT and vice versa for the uninvolved limb on day 2). A rest of 1 minute was given between each set of three mSEBT trials with a rest of 15 seconds between each directional reach. A rest period of 2 minutes was given between each DLBT trial. There was a rest period of 2 minutes between the mSEBT and the DLBT tasks. There were no warm-up sessions before the testing procedures.
Testing Measures:

Knee-to-Wall Test:

The Knee-to-Wall\textsuperscript{23} test is a weight bearing measure of ankle dorsiflexion range of motion which has been shown to have excellent intrarater reliability (ICC=0.96 to 0.99)\textsuperscript{23} and is better than goniometric measures of range of motion (ICC= 0.85 to 0.96).\textsuperscript{23} Both limbs of each participant were tested. Participants stood facing a wall placing the toes of their test foot on the 10cm mark of a tape measure aligned perpendicular to the wall and lunged forward so that the knee touched the wall. The foot was then moved along the tape measure away from the wall 1 cm at a time and participant repeated the lunge until they were unable to touch the wall with their knee without lifting the heel off the ground (Fig 1). Maximum dorsiflexion was considered to be the maximum distance of the toe from the wall while maintaining the contact between the knee and wall without lifting the heel. Heel contact with the ground was monitored by manual palpation of the heel-to-floor interface to feel for heel rise movement. There was only one trial of Knee-to-Wall test conducted on each leg of the participants on Day1.
Figure 1: Participant demonstrating Knee-to-Wall test
Modified SEBT:

The mSEBT task consisted of performing reaching movements in three specific directions: anterior (ANT), posteromedial (PM) and posterolateral (PL) (Fig 2).24,25 Participants balanced on one limb and had to reach in each of the 3 directions as far as they could, tap their toe without unweighting their limb and then return to the starting position. Participants had to stand in a starting position with hands on hips and reach foot next to medial malleolus of the stance foot. Participants were instructed to keep their hands on their hips and stance foot flat on the ground. For ANT reach, the toe of the stance leg was positioned at the zero mark of the ANT reach line. For PM and PL reach, the heel of the stance leg was positioned at the zero mark of the ANT reach line. The distance from the zero mark to the point of toe touch was measured for each trail. Reach directions for each trial changed and were performed in counterclockwise order. The ANT reach distance was measured first followed by PM and PL reach directions in each set of three trials. Participants repeated a trial if one of the following occurred: 1) stance foot lifted off the ground, 2) hands came off hips, 3) reaching foot did not touch the surface, 4) reaching foot applied unloaded body weight onto the surface, and/or 5) participant lost balance and could not return to the starting position. Participants were given 4 practice trials for each direction with 30 seconds of rest between each trial. Three recorded trials in each of the 3 directions were then performed with approximately 1 minute of rest in between each set of three trials to prevent fatigue. Fifteen seconds of rest was provided between each reach in a three trial set. Testing was performed stocking feet.

Normalization of each reach direction distance was done for data analysis. For each direction, reach distances of all three trials were averaged and divided by leg length to get a normalized percentage value. A composite normalized reach distance was also calculated by summing the average normalized reach score of each direction and then dividing by three.
Figure 2: Reach directions of the Modified SEBT for right stance limb
Figure 3: Participant demonstrating posterolateral reach for left stance limb on the modified SEBT
**DLBT:**

The DLBT utilizes the directional layout of the medial half of a SEBT matrix but requires participants to leap between targets on the matrix lines (Fig 4). All the five directions extend from a center point at $45^\circ$ to each other. There were 11 total targets: one central target and two peripheral targets along each directional line. Target distances were based upon average normalized SEBT reach distances. The average normalized reach distances (% leg length) were multiplied by the leg lengths of the participant to set up the short targets. The far targets were set at 150% of this distance for each direction. The participant began the test by standing on the central target on the limb to be tested. A single limb stance position was maintained on the central target with the unweighted foot slightly behind the stance foot. Once the investigator gave the command to start, the participant started leaping from the central target to the short and long peripheral targets in the pre-determined order from 1-10 (Fig 5) returning to the central target to maintain their initial stance between each peripheral target. Participants were instructed to always alternate limbs with each leap resulting in the initial stance limb to always land on the central target. All peripheral and central targets were circular with a diameter of 15.24 cm.

Participants were only required to touch the peripheral target as quickly as possible with their initial non-stance leg and come back to the central target. Time to complete the leaping pattern was measured using a stopwatch.

Participants were required to stabilize themselves in the starting position for 2 seconds each time they landed on the central target. If the participants were considered stable on the central target for 2 seconds by the investigator they were given the command ‘Go’ and allowed to leap to the next peripheral target. Stability was assessed using components of the Balance Error Scoring System (BESS) criteria: touching down with opposite foot, hip abduction/flexion.
more than 30° and step/stumble or fall. Stability was not assessed at peripheral targets. Missing a target was also considered as an error and participants had to adjust back to the missed target quickly to resume the trial. Each leap required the participant to leap with one leg and land on the other. Participants were instructed to complete this task as quickly as possible. The time taken by the participant to complete the task by leaping to all the peripheral targets and returning to central one was recorded as the dependent measure for this test. Participants were given 3 practice trials with 1 minute of rest between trials before performing 3 recorded trials with 2 minutes of rest between each recording trial. Testing was performed in athletic shoes.
Figure 4: Structural pattern of the DLBT.
Figure 5: Participant demonstrating DLBT starting position
Data Analysis:

Descriptive statistics, such as means and standard deviation were calculated using Minitab 17 (Minitab Inc., State College, PA) for the dependent variables of interest. A one-way analysis of variance (ANOVA) with Tukey post hoc analysis was used to assess the differences between the means of the four conditions of the CAI and control groups: CAI involved, CAI uninvolved, control matched and control unmatched. A two-sample t-test was used to compare demographics, anthropometrics and ankle dorsiflexion range of motion (ROM) differences between the two groups of participants. An a priori alpha level of (P <0.05) was used to denote statistical significance.
RESULTS

Eighteen participants with a history of CAI (8 females and 10 males with a mean age of 20.83 ± 1.29 years) and eighteen healthy controls (8 females and 10 males with a mean age of 20.83 ± 1.38 years) participated in this study. Descriptive statistics for each anthropometric measure were analyzed for all the participants (n=36). A two-sample t-test was used to determine statistically significant differences between the CAI and the healthy control participants (Table 1). There were no statistically significant differences between the groups for any demographic and anthropometric variables.

Table 1: Population demographics and anthropometrics

<table>
<thead>
<tr>
<th></th>
<th>CAI Participants</th>
<th>Healthy Participants</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (M/F)</td>
<td>10/8</td>
<td>10/8</td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>20.83 ± 1.29</td>
<td>20.83 ± 1.38</td>
<td>0.468</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>173.0 ± 8.71</td>
<td>171.0 ± 11.8</td>
<td>0.573</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>72.28 ± 9.92</td>
<td>69.4 ± 13.4</td>
<td>0.465</td>
</tr>
<tr>
<td>Limb Length (cm)</td>
<td>90.81 ± 6.93</td>
<td>88.94 ± 8.94</td>
<td>0.490</td>
</tr>
<tr>
<td>Tegner Activity Level</td>
<td>6.83 ± 1.42</td>
<td>5.89 ± 1.57</td>
<td>0.067</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation
M/F= males/ females
Statistical significance (P< 0.05)
FAAM and IdFAI scores:

CAI participants were selected based on IdFAI score. Participants with CAI had a score of 18.83 ± 5.81 and healthy subjects had a score of 1.50 ± 2.41. IdFAI score for CAI and healthy subjects were significantly different (P < 0.001) as shown by two-sample t-test (Table 2). FAAM-ADL sub-scale scores and FAAM-S subscale scores for CAI subjects were 94.53 ± 1.07 and 86.17 ± 15.67, respectively. However, for healthy subjects FAAM-ADL subscale and FAAM-S subscale scores were 100 ± 0.00 (Table 3).

Table 2: IdFAI scores

<table>
<thead>
<tr>
<th></th>
<th>CAI Participants</th>
<th>Control Participants</th>
<th>difference</th>
<th>P-value (95 % CI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>IdFAI</td>
<td>18.83 ± 5.81</td>
<td>1.50 ± 2.41</td>
<td>17.33</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(14.26,20.41)</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation
Statistical significance (P< 0.05)
IdFAI: Identification of functional ankle instability

Table 3: FAAM score averages

<table>
<thead>
<tr>
<th></th>
<th>CAI Participants</th>
<th>Control Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAAM-ADL</td>
<td>94.53 ± 1.07</td>
<td>100 ± 0</td>
</tr>
<tr>
<td>FAAM-S</td>
<td>86.17 ± 15.67</td>
<td>100 ± 0</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation
FAAM-ADL: Foot and Ankle Ability Measure Activities of Daily Living subscale
FAAM-S: Foot and Ankle Ability Measure Sports subscale.
Knee-to-Wall Test:

There were no statistically significant differences (P > 0.05) seen between the CAI and matched controls or within the CAI group between the involved and the uninvolved limb (Table 4).

Table 4: Knee-to-Wall test scores.

<table>
<thead>
<tr>
<th></th>
<th>CAI Involved (M ±SD) (95% CI)</th>
<th>CAI Uninvolved (M ±SD) (95% CI)</th>
<th>Matched Involved (M ±SD) (95% CI)</th>
<th>Matched Uninvolved (M ±SD) (95% CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knee-to-Wall</td>
<td>10.88 ± 3.07 (9.57,12.204)</td>
<td>10.95 ± 2.65 (9.63,12.265)</td>
<td>11.69 ± 2.90 (10.37,13.010)</td>
<td>11.75 ± 2.50 (10.43,13.065)</td>
<td>0.686</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation (cm)
Statistical significance (P< 0.05)
**Modified SEBT:**

One-way ANOVA with Tukey post hoc analysis was used to analyze the differences between the means of the four conditions: CAI involved limb, CAI uninvolved limb, matched involved and matched uninvolved. There were no statistically significant differences found in mSEBT composite scores for any between or within group comparisons of the CAI and control participants. There were also no statistically significant differences found for individual mSEBT reach directions for any within or between group comparisons of the healthy and the CAI groups.

**Table 5: Modified SEBT reach distances**

<table>
<thead>
<tr>
<th></th>
<th>CAI Involved (M ±SD) (95 % CI)</th>
<th>CAI Uninvolved (M ±SD) (95 % CI)</th>
<th>Matched Involved (M ±SD) (95 % CI)</th>
<th>Matched Uninvolved (M ±SD) (95 % CI)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Composite score</td>
<td>76.20 ± 7.21 (73.16,79.25)</td>
<td>77.61 ± 5.79 (74.57,80.66)</td>
<td>75.42 ± 6.43 (72.38,78.47)</td>
<td>75.97 ± 6.38 (72.93,79.02)</td>
<td>0.773</td>
</tr>
<tr>
<td>Anterior Reach</td>
<td>68.70 ± 5.42 (68.77,73.88)</td>
<td>71.33 ± 4.71 (68.77,73.88)</td>
<td>69.46 ± 5.74 (66.91,72.01)</td>
<td>70.12 ± 5.75 (67.57,72.01)</td>
<td>0.523</td>
</tr>
<tr>
<td>Posteromedial reach</td>
<td>83.62 ± 9.47 (80.04,87.20)</td>
<td>84.46 ± 6.82 (80.87,88.04)</td>
<td>82.41 ± 6.90 (78.83,85.99)</td>
<td>82.28 ± 6.93 (78.69,85.86)</td>
<td>0.801</td>
</tr>
<tr>
<td>Posterolateral reach</td>
<td>76.28 ± 7.98 (72.20,80.37)</td>
<td>77.06 ± 8.17 (72.97,81.14)</td>
<td>74.40 ± 9.08 (70.31,78.48)</td>
<td>75.53 ± 9.43 (71.44,79.61)</td>
<td>0.821</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation (% leg length)
Statistical significance (P< 0.05)
CI: Confidence interval
DLBT:

One-way ANOVA analysis reveals statistically significant differences (P<0.001) in DLBT time (seconds) were found between limbs. Tukey post-hoc analysis showed that DLBT time for CAI involved limb demonstrated greater statistical significance than for the CAI uninvolved limb (Table 6). CAI involved limb time also demonstrated greater statistical significance than the matched involved and matched uninvolved limbs. There were no statistically significant differences between the CAI uninvolved and either of the matched limbs or between the matched limbs.

Table 6: Time taken to complete DLBT.

<table>
<thead>
<tr>
<th></th>
<th>CAI Involved (M ±SD)</th>
<th>CAI Uninvolved (M ±SD)</th>
<th>Matched Involved (M ±SD)</th>
<th>Matched Uninvolved (M ±SD)</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>51.85 ± 4.04* (50.188,53.522)</td>
<td>44.12 ± 3.60 (42.45,45.78)</td>
<td>41.88 ± 3.36 (40.21,43.55)</td>
<td>41.63 ± 3.08 (39.96,43.30)</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

Values are mean ± standard deviation (seconds)
Statistical significance (P< 0.05)
CI: Confidence interval
*Denotes statistical significance
DISCUSSION

The primary purpose of this study was to determine if the DLBT is able to reveal differences in dynamic balance performance between CAI involved and uninvolved limbs. Results of our study showed that there were differences demonstrated by the DLBT. Time taken by the participants to complete the DLBT when assessing the CAI involved limb was significantly higher than that of the uninvolved limb as well as the healthy matched and unmatched limbs in the control group. Moreover, the DLBT was more robust in identifying the differences between the CAI involved and uninvolved limbs as compared to the mSEBT which did not demonstrate any significant differences in reach distance between the CAI involved and uninvolved limbs.

In agreement with Ramirez et al.\textsuperscript{18} and Sefton et al.\textsuperscript{19} and contrary to Olmsted et al.\textsuperscript{4}, Gribble et al.\textsuperscript{8}, and Basnett et al.\textsuperscript{16} our findings did not reveal any significant differences in the reach distances of the mSEBT between CAI involved and uninvolved limbs. Ramirez et al.\textsuperscript{18} used the same the inverted Y matrix of the modified SEBT that we used in the current study. They found no significant differences between CAI involved and uninvolved limbs in any of the three directions.\textsuperscript{18} Sefton et al.\textsuperscript{19} on the other hand measured reach distances in the anterior, anteromedial and posteromedial directions. They were unable to detect any differences between CAI involved and uninvolved limbs using this modification of the SEBT.\textsuperscript{19} However, Olmsted et al.\textsuperscript{4} reported the differences between the CAI involved and uninvolved limbs as well as between CAI involved and matched limb in all the 8 directions of the SEBT. Similarly, Gribble et al.\textsuperscript{8} reported differences in reach distance between CAI involved and uninvolved limbs but only in anterior, medial and posterior directions while Basnett et al.\textsuperscript{16} found differences between involved and uninvolved CAI limbs in anterior, posteromedial and posterolateral directions.
In this study, we utilized the common modification of the SEBT consisting of anterior, posterolateral and posteromedial directions to avoid redundancy.\textsuperscript{16,18} However, Hertel\textsuperscript{15} has reported that the anteromedial, medial and posteromedial directions are the most sensitive of the eight. Only the posteromedial direction out of this subset of three sensitive directions was present in the version of SEBT that we used. Unlike Hertel et al\textsuperscript{15} and Olmstead et al.\textsuperscript{4}, we found no difference in posteromedial reach distance between participant groups. However, interestingly, the DLBT contains all the three sensitive directions that Hertel et al.\textsuperscript{15} has reported. If direction is important, this may be one reason that we found differences in the DLBT but not in the mSEBT. This may also be a reason that we found similar results to Raimirez et al\textsuperscript{18} who used the same three directions of the SEBT as we did but different results from Hertel et al.\textsuperscript{15} and Olmsted et al.\textsuperscript{4} who used all 8 directions.

The studies that showed differences in the SEBT reach distances between CAI and healthy participants used less stringent criteria for recruiting CAI participants: 1) participants had a history of at least one acute lateral ankle sprain which resulted in swelling, pain, and temporary loss of function (but none in the previous 3 months) and, 2) multiple episodes of the ankle “giving way” in the past 6 months”.\textsuperscript{4,7,15} In other studies, self-reporting questionnaires like the Ankle Instability Instrument (AII) were used for identifying and recruiting people with CAI that showed differences in the reach distance between healthy and CAI participants.\textsuperscript{28} However, we used the IdFAI questionnaire\textsuperscript{29} in our study for the identification and recruitment of the participants having CAI. Simon et al.\textsuperscript{29} found that IdFAI was more stringent in identifying CAI as compared to other discriminative tools. The IdFAI has not been used as inclusion criteria for CAI participants in previous SEBT studies. This more stringent selection criteria may have been a contributing factor in our inability to find significant differences in the SEBT scores between
the CAI involved and uninvolved limbs and the healthy matched controls but we suspect ROM may have been a greater contributor.

Ankle dorsiflexion ROM may have been a factor in the differentiating ability of the DLBT and the mSEBT to detect differences between our participant groups. It has been shown that decreased ankle dorsiflexion ROM is associated with poor performance on SEBT reach distance. Gribble and Hertel\textsuperscript{26} found that 28\% of the variation in the SEBT anterior reach was associated with the dorsiflexion ROM. Hoch et al.\textsuperscript{30} and Terada et al.\textsuperscript{31} reported that decreased anterior reach distances of SEBT significantly correlated with compromised dorsiflexion ROM measured by the Weight Bearing Lunge Test (WBLT). Basnett et al.\textsuperscript{16} used an inclinometer for measuring dorsiflexion and found that both anterior as well as posterolateral reaches negatively correlated with compromised dorsiflexion ROM of the ankle. In a study in which Ramirez et al.\textsuperscript{18} reported no difference in the SEBT reach distances between involved and uninvolved CAI limbs, they also reported no differences in ankle dorsiflexion ROM. Concurring with the results of Ramirez et al.\textsuperscript{18}, we found no significant differences in dorsiflexion ROM between CAI involved and uninvolved limb as well as between CAI involved and matched and unmatched limbs. The SEBT task may be is more dependent upon ankle dorsiflexion ROM due to the constraints of the task such as keeping the foot flat on the floor. It has also been shown that the SEBT requires greater ROM than hoping tasks. Fullam et al.\textsuperscript{32} have shown that SEBT requires approximately 30.96 ± 7.22\° of ankle dorsiflexion ROM for anterior reach direction of the SEBT. Harst et al.\textsuperscript{33} reported that ankle dorsiflexion ROM for the single legged hop for dominant limb to be 29.5 ± 3.6\° and 28.2 ± 5.2\° for the contralateral limb. Although the DLBT task is similar to the single leg hoping task, it is not a maximal hop and therefore most likely requires less dorsiflexion ROM than a maximal single leg hoping task. Differences in the CAI performance in the SEBT may be
more dependent on the ankle dorsiflexion ROM than in other tests. The DLBT may not have the same task constraints as the SEBT and may inherently require less ankle dorsiflexion ROM for their completion possibly making it more dependent upon the balance mechanism than ankle dorsiflexion ROM limitations.

It has also been reported that patients with CAI may suffer from kinesiophobia and fear re-injury. A task that does not require a change in the BOS may provoke less fear of movement than those requiring leaping and a changing BOS, especially when leaping to the directions that are difficult to visualize as happens with the posterior and posteromedial directions of the DLBT. It is possible that kinesiophobia and fear of re-injury played a role in the performance deficits we found with the DLBT in our CAI group. The mSEBT may not have provoked the same degree of kinesiophobia and fear of re-injury. The DLBT appears to be a more challenging task than the mSEBT and therefore may have provoked greater amounts of kinesiophobia and fear of re-injury which differentially affected our results.

The extent to which the task involved in the SEBT is dynamic has also challenged. Kinzey and Armstrong described the reaching tasks used in the SEBT as novel tasks not resembling many common functional activities like running, cutting and walking that we perform in our daily lives. The DLBT was designed based upon several principles and observations: 1) previous research on TTS and the BESS with regard to judging postural stability; 2) normalization of the short and long distances in the DLBT task to the leg length of each individual; and 3) the movement tasks in the DLBT mimic the dynamic balance stability requirements of functional activities such as walking, running and cutting. Dynamic balance requirements for an assessment depend on the task/activity on which it is based upon. We organized tasks in to three categories to help us with understanding dynamic balance:
1) Tasks involving movement of body segments over unchanging base of support e.g. dipping you toe in the water. The SEBT can be a test that can be used for testing balance in these types of activities.

2) Tasks involving movement of body segments and serial changes in the base of support while maintaining same limb support e.g. figure skating, gymnastics, ballet and freestyle skiing. Various single leg hopping functional performance tests can be used for testing balance in these types of activities.

3) Tasks involving movement of body segments and serial changes in the base of support requiring alternating limb support and gaining a new state of equilibrium with each change in BOS e.g. all sports involving running, jumping and cutting.

We believe the task and balance requirements involved in the DLBT most closely mimic the tasks in the third category. Based upon task and balance requirements, we believe the DLBT is a new and unique method of assessing dynamic balance.

**CONCLUSION**

The DLBT has been shown to be reliable (in a previous unpublished study) and able to detect differences in dynamic balance between the CAI involved and uninvolved limbs. In our study the mSEBT was unable to detect differences in balance between CAI uninvolved and uninvolved limbs. The DLBT appeared to be more robust in detecting the balance deficits in participants with CAI as compared to the SEBT. Moreover, the DLBT is a cost effective and easy to use tool. It can be a good tool for assessing the progress of an athlete with a lateral ankle sprain during the rehabilitation process. Finally, since the task involved in the DLBT closely mimics functional activities that are required in most sports the DLBT can be used as an assessment tool to determine return to play readiness.
Limitations:

There were several limitations to our study. BESS criteria were used for judging the quality of stability of the participants. BESS has shown a varying degree of reliability with an intertester reliability ranging from an ICC of 0.57\textsuperscript{27} to 0.85.\textsuperscript{32} Although, BESS has shown to be reliable, there is still subjectivity involved in making movement judgements. Moreover, subjective calculation of 2 seconds time by the examiner for assessing stability of the participants when they were balancing on the central target may also have added error to our measurements. The subjective nature of our postural stability assessments is a limitation to this study.

Another possible limitation can be the threshold scoring criteria of the IdFAI. It has been reported that IdFAI is more refined and strict criteria for identifying people who have CAI.\textsuperscript{29} However, it still cannot gauge the degree of the instability in participants with CAI as it only requires the participants to subjectively rate their own ankle function. There is no direct measure of joint laxity, which can provide us the degree of instability. Varying degrees of laxity or restricted mobility at the ankle joint may be part of a CAI clinical picture and may affect the results of balance testing.

Future Investigation:

Future studies may focus on assessing the dynamic balance of the participants using more objective measures like motion analysis systems, pressure mats and force plates. Further exploration of the effect of dorsiflexion ROM on the performance on the DLBT should also be explored. Interrater reliability of the DLBT is not yet established. Interrater reliability studies will help in further establishing the reliability of the DLBT and help establish its usefulness in clinical situations. Finally, use of the DLBT with other injured populations such as knee or hip patients should be pursued.
Literature Review

Balance is a widely used term in clinical settings with no universally accepted definition. Balance or equilibrium in physics is described as the net effect of forces acting on the object to be zero.\(^\text{36}\) This happens in humans when center of mass (COM) falls inside the base of support (BOS). A person would become unbalanced when the COM would fall outside the BOS.\(^\text{37}\) This happens in humans when center of mass (COM) falls inside the base of support (BOS). A person would become unbalanced when the COM would fall outside the BOS.\(^\text{37}\) Postural control, hence, can be defined as ability to maintain the COM within the base of support.\(^\text{37}\)

Moreover, balance depends upon the ability to simultaneously react to visual, vestibular and proprioceptive inputs for maintaining postural stability while moving. Postural stability is the maintenance of postural alignment by the help of muscular tone generated in response to the gravity, supporting surface and sensory information like visual feedback and balancing strategies to stabilize COM during perturbations.\(^\text{38}\) Any of the impairments that can result in the deficits in the mechanism that are necessary for postural control can result in balance disorders. There are two types of balance, static and dynamic.

Static balance is the maintenance of the center of mass over the stationary base of support while the base of support is moving or when an external perturbation is applied to the body.\(^\text{39}\) Bass\(^\text{40}\) also defined the terms static and dynamic balance. According to her, static balance is defined as “balance in which the equilibrium is maintained for one position of the body” and dynamic balance is defined as “balance that is concerned in keeping one’s equilibrium while in motion or while changing from balanced position to another”. Dynamic balance is also considered as an equilibrium that is maintained while series of positions are changed.
consecutively.\textsuperscript{40} Static and dynamic balancing mechanisms are distinct because they rely on different types of mechanoreceptors. Static quiet stance balance tend to stimulate slow adapting mechanoreceptors, while dynamic balance tasks tend to activate fast adapting mechanoreceptors.\textsuperscript{11}

**Balance Strategies:**

An inverted pendulum model with closed loop feedback is used for describing balance control in humans. Postural stability is the ability to maintain the COM over the BOS, as with an inverted pendulum.\textsuperscript{41–43} In this closed loop feedback system, the mechanoreceptors present in the muscular system send signals to the CNS, which then initiates or maintains the necessary muscular reaction. External forces are sensed by skeletal muscle sensory organs, the muscle spindles and the golgi tendon organs. The afferent sensory information from the muscle is processed by the neural system that produces efferent motor signals to react to these forces by either contraction or relaxation and facilitate maintenance of postural stability. For example, the gastrocnemius contracts when anterior motion of the tibia is sensed to produce posterior motion.\textsuperscript{44} This system helps in subconsciously maintaining balance against perturbations and gravitational force.\textsuperscript{45}

Hip and ankle muscles play an important role in maintaining the postural equilibrium through ankle, hip and stepping strategies controlled by the central nervous system.\textsuperscript{46} There is a synergistic activation of trunk and lower limb musculature in automatic postural responses. Hip abductors and lateral rotators and ankle invertors and evertors control movements in the frontal plane, however, movements that take place in the sagittal plane are controlled by hip flexors and extensors and ankle flexors and extensors.\textsuperscript{46} Ankle musculature is engaged first in maintaining balance against the external forces through ankle strategy. When the external forces surpass the
forces that are produced by muscles of ankle to maintain balance then hip musculature becomes activated and balance is maintained through a hip strategy which augments the ability of ankle musculature to maintain the control of head, arm and trunk (HAT) and keep the COM within the BOS. Athletes who can control more forces with their ankle musculature have less stress on hip musculature. Likewise, athletes with strong hip musculature put less strain on ankles for controlling HAT movements. Ankles strategies are generally believed to control small perturbations, while hip strategies are believed to control large and quick perturbations.

In sagittal plane, the flexors and extensors of ankle such as gastrocnemius, tibialis anterior and soleus are assisted by the flexors and extensors of hip such as iliopsoas, rectus femoris and gluteus maximus in the control of perturbing forces. Trunk leans because of the contraction of these muscles helps in controlling the COM over the BOS. Similarly, in frontal plane, the abductors and adductors of hip help maintain stability in the medial and lateral directions and are assisted by the peroneal and tibialis muscles of the ankle. However, if the force is large enough that muscles of hip and ankle are unable to maintain the COM within the BOS then there is a need to change the BOS to reposition it under the COM by taking a step. This change in BOS is called the stepping strategy. It was found that women with weak hip muscles relied more on the ankle muscles for maintaining stability to compensate for lower proximal muscle strength and stability. This resulted in more strain on the distal muscles and joints. This imbalance results in a larger displacement of center of pressure (COP) which may increase the likelihood of injury. Previous researchers have found that ankle sprain risk increases with the increase in displacement of COP. Weakness of abductors of hip will impair control of movements in the medial and lateral directions, the directions in which most ankle sprains occur. The COM of the body is located around the L2 vertebral level and is near to the gluteus medius, the major
abductor of the hip. Therefore, the gluteus medius is of prime importance in controlling head and trunk movements over the lower extremity, thus reducing strain on the ankle musculature for maintenance of the postural stability. If the hip abductors are weak then ankle musculature has to apply more force to control movements of the COM. If ankle muscles are also weak then postural stability may be compromised and lower extremity injury may result. 49

Together these strategies help in maintaining balance in our normal daily living and sporting activities. Improvement in performance in these balancing strategies can result in having better postural control. However, the role of any particular type of strategy may depend on the types of movement or the particular sporting activity.

**Balance assessment:**

There are different measures of assessment used for static and dynamic balance. In laboratory settings, balance is assessed by quantifying postural sway (displacement of COM over the BOS) and time-to-boundary (time taken to bring COM with in the BOS). Static balance measurement is usually done by measuring the amount of postural sway in quiet standing. 50 Larger sways in the quiet standing may be an indication of some potential static balance deficits. 50 Moreover, it was found that older people had more postural sway than that of younger people which implied weakness in the muscles that are important in maintaining balance. 50 Static balance deficits can be associated with increased risk of ankle injuries. 51 In one study, high school athletes who demonstrated greater postural sway in single leg stance on a force plate had more injuries in their lower extremity. It was concluded that static balance deficits could result in higher risk of injuries. Thus, this study provided evidence to clinicians that static balance deficits can be indicative of predicting injuries. 52 However, the problem with such type of studies are that they are difficult to replicate due to the expensive instrumentation used like force plates.
Unfortunately, the use of expensive instrumentation such as force plates in a clinical setting is not always feasible. Moreover, static balance measures are not necessarily reflective of dynamic balance capabilities. Differences in balance mechanisms, task difficulty and sensory organs stimulated make static balance measuring techniques inappropriate for assessment of dynamic balance.\textsuperscript{11,53} Therefore, in laboratory settings, alternate measures have been employed to assess dynamic balance. One common dynamic balance task is single-legged jump landing onto a force plate. Time-to-Stabilization (TTS) after landing is used as a measure of a dynamic balance in this task. In the single-legged jump landing task, participants have to jump up to 50 to 55\% of their maximum vertical jump and then land on a force plate on a single leg while trying to stabilize themselves as quickly as they can upon landing.\textsuperscript{12} It has been shown that participants with stable ankles took less time in stabilizing themselves as compared to the participants who had functional ankle instability.\textsuperscript{12} The problem with this type of measure is the need for expensive equipment like force plates and expertise for operating them which are difficult to find in clinical settings. Hence, these laboratory measures of testing static and dynamic balance are not commonly used in clinical settings.

Balance Error Scoring System (BESS)

In a clinical setting, for static balance assessment, Balance Error Scoring System (BESS)\textsuperscript{54} is often used. In the BESS, participants have to perform three standing tasks while standing on two different surfaces, first they stand on a flat stable surface and then on an unstable foam surface. Participants must first stand on both legs (double leg stance), then on the dominant leg only (single leg stance) and finally with the non-dominant limb behind the dominant limb (tandem stance). Participants have to stand with their eyes closed with their hands on hips and maintain their balance for 20 seconds in each position, on both surfaces. Opening eyes, removing
hands from the hips, falling out of position, lifting the heel or forefoot, taking a step, failing to gain the initial position within 5 seconds, abducting hip for more than 30° are counted as an error. The BESS has shown a excellent intratester reliability (ICC = 0.90) and intertester reliability (ICC = 0.85).

To make static balance tasks more challenging investigators frequently utilize foam pads during assessment. Other things that can be used to put more demand on body’s balance mechanisms during balance assessment include the Both Sides Up (BOSU) (Ashland, Ohio), an air filled bladder or half form roller. In a study, in which participants were asked to balance on three different surfaces, it was found that BOSU was more challenging than air filled bladder or half form roller. In addition to that, it was also more challenging for participants to stand on air-filled bladder than half form roller.

Star Excursion Balance Test (SEBT)

There are number of clinical balance assessment tools that are used for assessing dynamic balance. One of the most common tests of dynamic balance that is used in clinical settings is the Star Excursion Balance Test (SEBT). The SEBT consists of a star like grid pattern with 8 designated lines in 8 directions, oriented at 45° angles to each other. Individuals are required to stand in the center of the grid on their limb that is tested and try to reach to their maximum distance with the other non-weight bearing limb. Individuals have to tap down lightly with their non-weight bearing limb at the maximum distance they can reach from the center of the grid. This reach distance is taken as the dependent measure for quantifying balance. The SEBT is a reliable test for dynamic balance with excellent intertester reliability (ICC= 0.86-0.92). The SEBT is an assessment tool commonly used to measure balance deficits after injury in patients who have CAI or are recovering from anterior cruciate ligament (ACL) reconstruction surgery.
Hence, the SEBT has been used to assess the progress of rehabilitation programs in patients with lower extremity injury.\textsuperscript{59} The SEBT has also used to predict the risk of lower extremity injury.\textsuperscript{59} Plisky et al.\textsuperscript{59} tested 235 basketball athletes on the SEBT before the start of season and then kept track of injuries as the season progressed. It was found that injury risk was 2.5 times higher with a deficit of 4 cm in the anterior reach distance of the SEBT than those without any deficits.\textsuperscript{59} The authors recommended that balance tests like the SEBT should be incorporated into physicals before the start of season to screen for individuals with higher potential injury risk.\textsuperscript{59}

To reduce the redundancy and to make the SEBT more easy to administer only three directions of anterior, posteralateral and posteromedial were used.\textsuperscript{15} As a result, a modification of SEBT was made and called the Y-balance test. The Y-balance test consists of only the three above mentioned directions. It made more efficient and helped in eliminating the redundancy in testing all 8 directions. The Y-balance test has also shown excellent intertester reliability (ICC= 0.85-0.93).\textsuperscript{60} However, Kinzey and Armstrong\textsuperscript{17} have challenged the dynamicity of SEBT, suggesting that there is no translation in base of support during SEBT performance which is a requirement of dynamic balance tasks. The base of support during SEBT performance remains static and therefore the stance in the SEBT was seen as a position of “quasi-static equilibrium”. Moreover, the authors suggested that the task performed in SEBT for assessing balance is a novel, non-functional task as this type of reaching movement does not form the part of natural movements in our daily lives whether in sports or normal daily living activities.\textsuperscript{17}

Bass Test

Bass Test is another clinical dynamic balance assessment tool.\textsuperscript{40,61} In bass test, participants are required to step over the pattern of 11 marks (2\times 2.5 cm marking of tape) that are laid out on the floor. Participants follow the laid pattern by stepping and holding over each mark on their big
toe for 5 seconds. Point system is used to assess the balance of each participant. Participants are
given 1 point for reaching every target and 1 additional point is given for holding over the target
for each second. A total score of 100 points is used. Missing target, touching the ground with the
heel when landing (5 points each), only partially covering the target (3 points each), and 1 point
each for balancing errors (touching down with heel of the standing foot or moving the standing
foot during the 5-seconds hold) were counted as errors. The higher the score is the better is
the balance. The bass test demonstrated a moderate reliability (ICC = 0.75).

Multiple Single-Leg Hop-Stabilization Test

The Multiple Single-Leg Hop-Stabilization Test is derived from Bass Test. It consists
of the same pattern of 11-tape marking (2*2.5 cm) on the ground. However, participants are
required to complete this task on one leg rather than on two alternating limbs. Moreover, inter
tape mark distances are changed according to the height of the person and are not standardized as
in the Bass test. Participants have to keep their hands on iliac crest always while performing the
task. The scoring criteria is also simplified. Investigators count 3 points for landing errors and 10
points for balancing error and a lower score indicates balance. Landing errors counted are not
covering the tape mark completely, stumbling on landing, and everting or inverting the foot more
than 10°. Balancing errors consist of touching the ground with non-dominant limb, touching the
non-dominant limb to the dominant limb, or dominant limb movement in to excessive flexion,
extension or abduction and hands off hips.

Functional Reach Test

The Functional Reach Test is another dynamic balance assessment tool that can be utilized
in clinics. It is administered with the participant standing. The participant is required to stand
next to, but not touch, a wall. If the participant touches the wall or takes a step, then a trial has to
be repeated. The shoulder of the arm that is closer to the wall is positioned at 90° of flexion with closed fist. The investigator records the position of the third metacarpal that is marked as the starting position. The participant is instructed to reach as far as possible without taking the step. After the participant has performed the maximum reach then the position of third metacarpal is again recorded. Scores are determined by taking the difference between the final and initial positions of the third metacarpal. Reach distances are taken as the dependent measure for quantifying balance.\textsuperscript{62} One problem with this type of task for testing balance is that it is only assessing stability in sagittal plane.\textsuperscript{62} In addition to that, the BOS also remains static, like in the SEBT, during the reaching task however translational movement of BOS is necessary in dynamic tasks or movements.\textsuperscript{17} This task is similar to the SEBT but utilizes upper body reaching movements rather than lower body reaching movements. Hence, the degree to which this test can be considered dynamic is questionable.

There are also number of functional performance tests that by nature rely on components that require dynamic balance but they aren`t necessarily designed as an assessment tool for balance. They can be sensitive for assessing balance deficits but they are not specific for determining balance problems. The most commonly used functional tests are the hop tests. There is a battery of 5 hopping tasks (single leg hop, crossover hop, triple hop, 6-m timed hop, and single leg hop height) that are utilized in assessing the functional status of patient recovering from different lower extremity impairments, most commonly after anterior cruciate ligament (ACL) reconstruction.\textsuperscript{25} Moreover, in addition to the single leg hoping tests there are other functional performance tests like the stairs hopple test\textsuperscript{63}, figure-of-eight test\textsuperscript{63}, stairs running test\textsuperscript{63}, and shuttle run test\textsuperscript{64} that may also provide clinicians with information regarding a patient`s balance abilities.
The SEBT is the commonly used measure dynamic balance in clinical settings especially in CAI population.\textsuperscript{4,15,16} However, the reaching task involved in the SEBT is a novel task and does not mimics the functional activities like walking, running, cutting etc. performed in the daily life or during common sports.\textsuperscript{17} Similarly, functional reach test\textsuperscript{62} also has a novel reaching task involved upper body and is not mimicking the functional activities that are commonly performed. In both, SEBT and functional reach test there is no serial changes in the BOS and alternating limb support that form an integral component of most of the dynamic activities that are being performed. Bass test\textsuperscript{40} is another measure of dynamic balance used that involved the alternating limb support and changing the base of support. However, in Bass test\textsuperscript{40} the distances between the two strips of tape laid on flour are not normalized to the leg length rather the distance is standardized for every individual. This raises questions on the functionality of Bass test. Moreover, the frontal directions are not included in the Bass test\textsuperscript{40} and it is testing balance in the anterior direction for the most part. Posterior and posteromedial directions apparently put a greater challenge on body’s balancing abilities as there is a compromise in the vision while going to these directions. The Multiple Single-Leg Hop-Stabilization test\textsuperscript{53} is a modification of the Bass test\textsuperscript{40}. However, instead of hoping from one leg to another it involves hoping on the same leg to the tape marks laid on the flour. Hoping on one leg is also a novel task not close to the daily living activities like walking, running and cutting which involve alternating limb support.

**Effects of Ankle Injury on Balance**

Excessive inversion or eversion of the ankle can put stress on the ligaments controlling movements in the frontal plane and hence can result in an injury. The most commonly injured ligaments are the lateral ankle ligaments as a result of excessive inversion.\textsuperscript{65} Ankle sprains are reported as the most common lower extremity injuries in physically active or athletic
populations. The NCAA reported that the lower extremity injuries account for 50% of all the injuries from the data that was taken over 16 years for 15 different types of sports. Ankle injuries accounted for 15% of all the lower extremity injuries in this study.\textsuperscript{66} Ankle sprains can result in the loss of time from participation in sports. In one study, it was reported that soccer players who suffered from ankle sprain had a loss of 6.5 days on an average as compared to healthy players.\textsuperscript{67} There is also a greater possibility that a person who suffered one ankle sprain will have another. Individuals who suffered an ankle sprain once have a 40% chance of having recurrent sprains with some residual symptoms of pain, swelling, instability, functional impairment and ‘giving away’.\textsuperscript{68} These residual symptoms after an ankle sprain have been termed chronic ankle instability (CAI).\textsuperscript{6} CAI is divided into two sub-groups: mechanical and functional instability. When the lateral ligament is injured because of excessive movement, it results in overstretching and can cause the laxity in the joint along with arthrokinematic impairment and degenerative and synovial changes within the joint resulting in mechanical instability.\textsuperscript{69} It becomes difficult to attain a closed pack position in dorsiflexion during dynamic activities because of mechanical instability, which can put ankle at further risk of ankle sprains.\textsuperscript{69} Functional insufficiencies are described as the impairment of strength, sensorimotor, neuromuscular and overall postural control.\textsuperscript{69,70} Ankle proprioception provides awareness of the position of the joint relative to other body parts and indications of when it is moving. Proprioception is required to inform the CNS about position and movement of all joints. Mechanoreceptors are present inside ligaments and are sensory organs that help the CNS in detecting the position and movement of the joint. When the ligament is damaged, these receptors also are affected and hence there is a defect in sensing the position of the ankle joint.\textsuperscript{69,71} If there is impairment in proprioception, it can impair neuromuscular control allowing the ankle to be put into vulnerable positions that can lead to
injury.\textsuperscript{71} Glencross et al.\textsuperscript{72} assessed plantar flexion joint position sense in individuals with CAI. It was shown that the subjects could not replicate the exact plantar flexion position in their CAI ankle as compared to the uninjured ankle. Chronic ankle instability leads to deficits in sensorimotor control which can lead to altered postural control.\textsuperscript{73} McKeon reported that ankle sprains can result in impaired postural control which can increases the risk of recurrent ankle sprain.\textsuperscript{74} Deficits in postural control have been found between CAI and healthy individuals using the time-to-boundary (TTB) measure. The CAI group showed lower TTB as compared to healthy participant that is indicative of deficits in controlling their body weight on one limb. Moreover, deficits in static balance were also observed in CAI participants.\textsuperscript{75} It was reported that CAI participants had more anterior and lateral sway in COP when they stood with their eyes opened.\textsuperscript{76} When eyes closed, more anterior-posterior changes in the COP were observed.\textsuperscript{76} These results showed that CAI individuals have more movement in COP during static balance conditions.

Alterations in the COP were also detected in dynamic activities. COP during walking was studied between the CAI group and a group of healthy participants. It was observed that CAI group had more laterally placed COP than the healthy participants.\textsuperscript{77} The SEBT is a common clinical measure that is used in detecting dynamic balance deficits in people with CAI. It has been reported that participants with CAI show lesser reach distances when compared with the normal healthy participants.\textsuperscript{4,7} In addition to that, within participant differences were also reported with the injured limb showing decreased reach distances as compared to uninjured limb.\textsuperscript{4} It has been suggested on the basis of clinical testing with the SEBT that participants with CAI show dynamic balance deficits.\textsuperscript{4,16} Olmsted et al.\textsuperscript{4} reported the differences between the CAI involved and unininvolved limbs as well as between CAI involved and matched limb in all the 8 directions of the SEBT. Akbari et al.\textsuperscript{78} reported worst performance on the injured side as
compared to uninjured side in unilateral CAI participants. Similarly, Gribble et al.\(^8\) reported differences but only in anterior, medial and posterior directions and Basnett et al.\(^6\) supporting the previous findings reported differences between involved and uninvolved CAI limbs in anterior, posteromedial and posterolateral directions. Hertel et al.\(^{15}\) found differences with the SEBT in CAI participants in anterior, anteromedial and posteromedial directions and suggested these three directions to be most sensitive. Nagakawa and Hoffman\(^{79}\) also confirmed the previous findings by reporting poor performance in CAI participants on the SEBT when compared with healthy. In contrary to the mentioned findings, Ramirez et al.\(^{18}\) and Sefton et al.\(^{19}\) reported no differences in the SEBT performance between involved and uninvolved limbs within the CAI participants as well as between the CAI and healthy individuals. Sefton et al.\(^{19}\) reported no differences in the balance in anterior, anteromedial and posteromedial SEBT reach directions. Ramirez et al.\(^{18}\) found no differences in the anterior, posteromedial and posterolateral reach directions in involved versus uninvolved CAI limbs. Although, Ramirez et al.\(^{18}\) found differences in the involved CAI limbs using motion analysis wavelet approximation method. These studies show that although SEBT is most commonly used to measure dynamic balance deficits in CAI involved participants however, it may not be an ideal measure for testing dynamic balance.

**Conclusion:**

In conclusion, several studies have shown balance deficits are common in individuals with CAI. Studies conducted in a laboratory on force plates have shown that there are balance deficits in both static and dynamic balance. Moreover, clinical measures like BESS have shown impairment in the ability to balance during quiet standing as well. However, due to the difference in the balancing mechanism during static and dynamic activities, the static balance measures used in clinics cannot be used for testing dynamic balance. In previous literature, many clinically
friendly dynamic balance assessment tools have been utilized. The majority of the studies that emphasized clinical testing of participants with the history of CAI used the SEBT as a tool for assessing their dynamic balance abilities. However, it has been argued that the reaching task used in the SEBT may not be an accurate representation of the dynamic activities we perform in our daily and sporting activities such as walking, running, and cutting. Moreover, the task used in SEBT can be questioned that if it is dynamic or not because in almost every dynamic activity there is a translation in the BOS but in the reaching task of SEBT, the BOS always stays static. Additionally, the simple reaching task that is used in SEBT may not be demanding enough to challenge the balancing mechanisms of athletic populations. Consequently, SEBT may not be an appropriate measure for testing dynamic balance in all types of athletic populations. There is a need for new clinical dynamic balance measuring tools that involve tasks that are more challenging, functional and dynamic than the reaching task used in the SEBT. Developing a new reliable and valid dynamic balance test that is cost-effective and clinically oriented can help in filling this gap present in literature. It can provide us with the better insight regarding the dynamic balance capabilities of healthy and injured populations such as those people with CAI.
APPENDICES:

Appendix A: Health Screening Questionnaire

**Orthopedic**

*Regarding your lower extremity (feet, ankles, lower legs, knees, thighs, hips, low back and head please answer the following questions:*

### Foot & Ankle

<table>
<thead>
<tr>
<th>Question</th>
<th>Circle one:</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you have a history of any broken bones?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so where/when:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you have a history of any torn or sprained ligament(s)?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so where/when:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are you currently having &quot;giving-way&quot;/instability at your ankle?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so when/how often:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you ever had surgery on your foot or ankle?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so when/body part:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Lower Leg & Knee

<table>
<thead>
<tr>
<th>Question</th>
<th>Circle one:</th>
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<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you have a history of any broken bones?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so where/when:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you have a history of any torn or sprained ligament(s)?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so where/when:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are you currently having &quot;giving-way&quot;/instability at your knee?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so when/how often:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you ever had surgery on your lower leg or knee?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so when/body part:</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Question</th>
<th>Circle one:</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you have a history of any muscle/tendon strains or tears?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so where/when:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you have a history of any dislocation(s)?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so where/when:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you/are you currently seeking aid or treatment for an injury?</td>
<td></td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>If so when/body part:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currently having lower leg or knee pain, numbness &amp; paresthesia?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate your pain: 0 1 2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Investigator: ______________________  Signature: ______________________  Date: ______________________
### Thigh & Hip

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you have a history of any broken bones?</td>
<td></td>
<td></td>
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<tr>
<td>Circle one:</td>
<td></td>
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<tr>
<td>If so where/when:</td>
<td></td>
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</tr>
<tr>
<td>Do you have a history of any torn or sprained ligament(s)?</td>
<td></td>
<td></td>
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<tr>
<td>Circle one:</td>
<td></td>
<td></td>
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<tr>
<td>If so where/when:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Are you currently having &quot;giving-way&quot;/instability at your hip?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circle one:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If so when/how often:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you ever had surgery on your thigh or hip?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circle one:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If so when/body part:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currently having thigh or hip pain, numbness &amp; paresthesia?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circle one:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate your pain: 0 1 2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Low Back

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do you have a history of any broken bones?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circle one:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If so where/when:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you have a history of any torn or sprained ligament(s)?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circle one:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If so where/when:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do you have any degenerative disc issues?</td>
<td></td>
<td></td>
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<tr>
<td>Circle one:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If so when/how often:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Have you ever had surgery on your low back?</td>
<td></td>
<td></td>
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<tr>
<td>Circle one:</td>
<td></td>
<td></td>
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<tr>
<td>If so when/body part:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currently having low back pain, numbness &amp; paresthesia?</td>
<td></td>
<td></td>
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<tr>
<td>Circle one:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate your pain: 0 1 2 3 4 5 6 7 8 9 10</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Head Trauma & Concussion

<table>
<thead>
<tr>
<th>Question</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Have you ever had a head injury or concussion?</td>
<td></td>
<td></td>
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<tr>
<td>Circle one:</td>
<td></td>
<td></td>
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<tr>
<td>If so when:</td>
<td></td>
<td></td>
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<tr>
<td>Do you currently have any neurological conditions?</td>
<td></td>
<td></td>
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<tr>
<td>Circle one:</td>
<td></td>
<td></td>
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<tr>
<td>If so what:</td>
<td></td>
<td></td>
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<tr>
<td>Are you currently experiencing any of those symptoms due to a head injury?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Circle one:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>If yes select:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Headache</td>
<td></td>
<td></td>
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<tr>
<td>- Dizziness</td>
<td></td>
<td></td>
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<tr>
<td>- Trouble falling asleep</td>
<td></td>
<td></td>
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<tr>
<td>- Pressure</td>
<td></td>
<td></td>
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<tr>
<td>- Confusion</td>
<td></td>
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<tr>
<td>- More emotional</td>
<td></td>
<td></td>
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<tr>
<td>- Neck pain</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Fatigue</td>
<td></td>
<td></td>
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<tr>
<td>- Difficulty concentrating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Nausea</td>
<td></td>
<td></td>
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<tr>
<td>- Nervous</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Difficulty remembering</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Balance problems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Sensitivity to light</td>
<td></td>
<td></td>
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<tr>
<td>- Sensitivity to noise</td>
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</tbody>
</table>

Investigator: __________________ Signature: __________________ Date: __________
Appendix B: Identification of Functional Ankle Instability (IdFAI)

IDENTIFICATION OF FUNCTIONAL ANKLE INSTABILITY (IdFAI)

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

Please carefully read the following statement:
"Giving way" IS DESCRIBED AS A TEMPORARY UNCONTROLLABLE SENSATION OF INSTABILITY OR ROLLING OVER OF ONE'S ANKLE.

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

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

☐ Never ☐ > 2 years ☐ 1-2 years ☐ 6-12 months ☐ 1-6 months ☐ < 1 month

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

☐ Have NOT seen someone ☐ Mild (Grade I) ☐ Moderate (Grade II) ☐ Severe (Grade III)

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

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

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

☐ Never ☐ > 2 years ☐ 1-2 years ☐ 6-12 months ☐ 1-6 months ☐ < 1 month

6.) How often does the "giving way" sensation occur in your ankle?

☐ Never ☐ Once a year ☐ Once a month ☐ Once a week ☐ Once a day

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

☐ Never rolled over ☐ Immediately ☐ Sometimes ☐ Unable to stop it

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

☐ Never rolled over ☐ Immediately ☐ < 1 day ☐ 1-2 days ☐ > 2 days

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

☐ Never ☐ Once a year ☐ Once a month ☐ Once a week ☐ Once a day

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

☐ Never ☐ Once a year ☐ Once a month ☐ Once a week ☐ Once a day
Appendix C: Informed Consent

CONSENT FOR RESEARCH
The Pennsylvania State University

Title of Project: Identifying balance deficits in chronic ankle instability subjects versus healthy controls using the Dynamic Leap and Balance Test and the modified Star Excursion Balance Test

Principal Investigator: Abbis Haider Jaffri
Address: 146 Recreation Building
          University Park, PA 16802
Telephone Number: 717-319-7480

Advisor: Sayers John Miller, III
Advisor Telephone Number: 814-865-6782

Subject’s Printed Name: _____________________________

We are asking you to be in a research study. This form gives you information about the research. Whether or not you take part is up to you. You can choose not to take part. You can agree to take part and later change your mind. Your decision will not be held against you. Please ask questions about anything that is unclear to you and take your time to make your choice.

1. Why is this research study being done?

We are asking you to be in this research because we are developing a new dynamic stability test that would be used in screening for the dynamic stability of people with Chronic Ankle Instability (CAI). The research is going to find out the differences in balance between subjects with CAI and normal healthy adults.

2. What will happen in this research study?

If you are a healthy subject then you have to fill health history questionnaire and if you are CAI subject then you have to fill IdFAI and FAAM questionnaire. You will then complete two balance testing sessions. Testing will occur over two testing sessions, lasting approximately one (1) hour on Day1. Session two (2) will occur approximately two (2) days to seven (7) days following session one (1), lasting approximately thirty (30) minutes.

Session 1, Day1: Physical Measures, Modified Star Excursion Balance Testing(Y-SEBT) and Dynamic Leap and Balance Test (DLBT)

You will provide age and sex and physical measurements (height, weight, limb length, and foot length) will be taken. Also, an activity questionnaire will be administered to determine your current level of activity. Dominant limb will be identified with the question “what leg would you kick a ball with?” Following this collection of data, you will begin the Y-Star Excursion Balance Test(Y-SEBT) portion of the protocol. You will then be asked to stand on your either of the limb depending upon the
randomization and reach as far as you can in each of the three (3) directions while maintaining your balance. You will complete two (2) practice trials and three (3) recorded trials. You have approximately one (1) minute to rest between each trial. After the Y-SEBT, the DLBT would be conducted. The test will incorporate the directional layout of the SEBT while using a more dynamic leaping task. Starting the central target (C) you will leap to each of the numbered targets in a predetermined pattern (Figure 1). You will then leap back to the central target (C) and maintain stability for at least two seconds unless the command of ‘GO’ is given before you leap to the next target. Each trial will include 20 leaps. You will have three (3) practice trials and three (3) recorded trials with a one (1) minute of rest between each practice trial and two (2) minute of rest between each recorded trial. This session will take almost 1 hour.

**Session 2: Dynamic Leap and Balance Test (DLBT) and Modified Star Excursion Balance Test (Y-SEBT)**

You will repeat the Y-SEBT and DLBT in exactly the same way as performed in the session 1 but with the limb other than the one tested on Day 1 on both the tests. In session 2, you will not have to complete any questionnaires and no physical measurements would be taken. It would take almost 30 minutes.

---

**Figure 1. Dynamic Leap and Balance Test - Right & Left Foot**

![Figure 1](image1.png)

**Figure 2.**

![Figure 2](image2.png)

3 directions: Anterior, Posteromedial and Posterolateral.
3. **What are the risks and possible discomforts from being in this research study?**
   There are risks associated with performing any type of exercise. You may become sore after doing some of the tests for this study. There is also a very small chance that you could fall or hurt yourself while participating in these tasks.

4. **What are the possible benefits from being in this research study?**
   4a. **what are the possible benefits to you?**
   There are no direct benefits for being part of this research study. The study may help us understand how Chronic Ankle Injury (CAI) subjects differ from healthy subjects in terms of their balance. And, are there any balance deficits in CAI subjects. This study would also help in establishing the validity of DLBT.

   4b. **what are the possible benefits to others?**
   This study would result in the development of validity of cost effective and clinically relevant DLBT. If it showed any differences in balance between CAI and healthy subjects then it can be used in clinics and field settings to test individuals with different disorders to diagnose any balance deficits.

5. **What other options are available instead of being in this research study?**
   There are no other options available for this study. You do not have to participate in this study.

6. **How long will you take part in this research study?**
   If you agree to take part, it will take you about 2 weeks to complete this research study. You will be asked to return to the research site two times. The first testing day should take approximately 1 hour and second testing session will take approximately 30 minutes.

7. **How will your privacy and confidentiality be protected if you decide to take part in this research study?**
   Efforts will be made to limit the use and sharing of your personal research information to people who have a need to review this information.
   - A list that matches your name with your code number will be kept in a locked file or password protected file in the office or within a protected computer of the research team.
   - Your research records will be labeled with code number and will be kept within a locked or password protected file within the office of the primary investigator or within a protected computer of the research team.

   In the event of any publication or presentation resulting from the research, no personally identifiable information will be shared.

   We will do our best to keep your participation in this research study confidential to the extent permitted by law. However, it is possible that other people may find out about your participation in this research study. For example, the following people/groups may check and copy records about this research.
   - The Office for Human Research Protections in the U. S. Department of Health and Human Services
   - The Institutional Review Board (a committee that reviews and approves research studies) and
   - The Office for Research Protections.

   Some of these records could contain information that personally identifies you. Reasonable efforts will be made to keep the personal information in your research record private. However, absolute confidentiality cannot be guaranteed.
8. What are the costs of taking part in this research study?

8a. What will you have to pay for if you take part in this research study?
There are no costs to participate in this study.

8b. What happens if you are injured as a result of taking part in this research study?
In the unlikely event you become injured as a result of your participation in this study, medical care is available. It is the policy of this institution to provide neither financial compensation nor free medical treatment for research-related injury. By signing this document, you are not waiving any rights that you have against The Pennsylvania State University for injury resulting from negligence of the University or its investigators.

9. Will you be paid or receive credit to take part in this research study?
You will not be paid or receive credit for participating in this study.

10. Who is paying for this research study?
There is no funding for this study.

11. What are your rights if you take part in this research study?
Taking part in this research study is voluntary.

- You do not have to be in this research.
- If you choose to be in this research, you have the right to stop at any time.
- If you decide not to be in this research or if you decide to stop at a later date, there will be no penalty or loss of benefits to which you are entitled.

During the course of the research you will be provided with any new information that may affect your health, welfare or your decision to continue participating in this research.

12. If you have questions or concerns about this research study, whom should you call?
Please call the head of the research study Abbis Jaffri, at 717-319-7480 or at auj175@psu.edu if you:

- Have questions, complaints or concerns about the research.
- Believe you may have been harmed by being in the research study.

You may also contact the Office for Research Protections at (814) 865-1775, ORProtections@psu.edu if you:

- Have questions regarding your rights as a person in a research study.
- Have concerns or general questions about the research.
- You may also call this number if you cannot reach the research team or wish to talk to someone else about any concerns related to the research.

INFORMED CONSENT TO TAKE PART IN RESEARCH

Signature of Person Obtaining Informed Consent

Your signature below means that you have explained the research to the subject or subject representative and have answered any questions he/she has about the research.

____________________________  _______________  __________________
Signature of person who explained this research Date Printed Name

Signature of Person Giving Informed Consent
Before making the decision about being in this research you should have:

- Discussed this research study with an investigator,
- Read the information in this form, and
- Had the opportunity to ask any questions you may have.

Your signature below means that you have received this information, have asked the questions you currently have about the research and those questions have been answered. You will receive a copy of the signed and dated form to keep for future reference.

**Signature of Subject**

By signing this consent form, you indicate that you voluntarily choose to be in this research and agree to allow your information to be used and shared as described above.

___________________________  ___________  ___________________
Signature of Subject             Date             Printed Name
Appendix D: Data Scoring Sheets

Dynamic Leap and Balance Test (DLBT) Data

Demographics & Star Excursion Balance Test (SEBT) Data

<table>
<thead>
<tr>
<th>Birthdate</th>
<th>Height</th>
<th>Weight</th>
<th>Sex</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>Month</td>
<td>Year</td>
<td>Feet Inches</td>
</tr>
</tbody>
</table>

Shoe Size

<table>
<thead>
<tr>
<th>Dominant Limb</th>
<th>Limb Length</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which leg do you kick a ball with?</td>
<td>True</td>
</tr>
<tr>
<td>Left</td>
<td>Right</td>
</tr>
</tbody>
</table>

Normalized Limb Lengths - 100% and 150%

<table>
<thead>
<tr>
<th></th>
<th>Male</th>
<th>Female</th>
<th>100%</th>
<th>150%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anterior</td>
<td>79.2</td>
<td>76.9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Anterior Medial</td>
<td>85.2</td>
<td>83.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Medial</td>
<td>97.7</td>
<td>90.7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior Medial</td>
<td>95.6</td>
<td>89.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Posterior</td>
<td>93.9</td>
<td>85.3</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Investigator: __________________ Signature: __________________ Date: ________________
Dynamic Leap and Balance Test (DLBT)

DLBT Scoring Sheet

Day ______ Errors: ✓ Box error missing the box
X Hip error > 30°
0 Step, Stumble or Fall error

Subject # ______

Trial 1         Trial 2         Trial 3

Time ______

Modified Star Excursion Balance Test (Y-Balance Test)

Trial 1         Trial 2         Trial 3

Mean Reach Distances
Anterior: _______
Posteromedial: _______
Posterolateral: _______
Appendix E: Tegner Activity Scale

Tegner Activity Level Scale

Please indicate in the space below the HIGHEST LEVEL of activity that you participate in CURRENTLY.

Current: Level

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level 10</td>
<td>Competitive sports - soccer, football, rugby (national, elite)</td>
</tr>
<tr>
<td>Level 9</td>
<td>Competitive sports - soccer, football, rugby (lower divisions), ice hockey, wrestling, gymnastics, basketball</td>
</tr>
<tr>
<td>Level 8</td>
<td>Competitive sports - raquetball or bandy, squash or badminton, track and field athletics (jumping, etc.), down-hill skiing</td>
</tr>
<tr>
<td>Level 7</td>
<td>Competitive sports - tennis, running, motorcross, speedway, handball</td>
</tr>
<tr>
<td>Level 6</td>
<td>Recreational sports - soccer, football, rugby, bandy, ice hockey, basketball, squash raquetball, running</td>
</tr>
<tr>
<td></td>
<td>Recreational sports - tennis and badminton, handball, raquetball, down-hill skiing, jogging at least 5 times per week</td>
</tr>
<tr>
<td>Level 5</td>
<td>Work - heavy labor (construction, etc.)</td>
</tr>
<tr>
<td>Level 4</td>
<td>Competitive sports - cycling, cross-country skiing</td>
</tr>
<tr>
<td>Level 3</td>
<td>Recreational sports - jogging on uneven ground at least twice weekly</td>
</tr>
<tr>
<td>Level 2</td>
<td>Work - moderately heavy labor (e.g. truck driving, etc.)</td>
</tr>
<tr>
<td>Level 1</td>
<td>Work - light labor (nursing, etc.)</td>
</tr>
<tr>
<td>Level 0</td>
<td>Work - light labor</td>
</tr>
<tr>
<td></td>
<td>Walking on uneven ground possible, but impossible to back pack or hike</td>
</tr>
<tr>
<td></td>
<td>Work - sedentary (secretarial, etc.)</td>
</tr>
<tr>
<td></td>
<td>Sick leave or disability pension because of injury</td>
</tr>
</tbody>
</table>

Investigator: ___________________ Signature: ___________________ Date: ___________________
Appendix F: Foot and Ankle Ability Measure (FAAM)

Foot and Ankle Ability Measure (FAAM)

Please answer every question with one response that most closely describes to your condition within the past week.

If the activity in question is limited by something other than your foot or ankle mark not applicable (N/A).

| No difficulty | Slight difficulty | Moderate difficulty | Extreme difficulty | Unable to do | N/A |

Standing

Walking on even ground

Walking on even ground without shoes

Walking up hills
Walking down hills
Going up stairs
Going down stairs
Walking on uneven ground
Stepping up and down curbs
Squatting
Coming up on your toes

Walking initially

Walking 5 minutes or less

Walking approximately 10 minutes

Walking 15 minutes or greater
Because of your **foot and ankle** how much difficulty do you have with:

<table>
<thead>
<tr>
<th>No difficulty at all</th>
<th>Slight difficulty</th>
<th>Moderate difficulty</th>
<th>Extreme difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
</tr>
</thead>
</table>

**Home Responsibilities**

**Activities of daily living**

**Personal care**

Light to moderate work (standing, walking)

Heavy work (push/pulling, climbing, carrying)

**Recreational activities**

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

0 %
FAAM Sports Scale

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

<table>
<thead>
<tr>
<th>No difficulty at all</th>
<th>Slight difficulty</th>
<th>Moderate difficulty</th>
<th>Extreme difficulty</th>
<th>Unable to do</th>
<th>N/A</th>
</tr>
</thead>
</table>

Running

Jumping

Landing

Starting and stopping quickly

Cutting/lateral movements

Low impact activities

Ability to perform activity with your normal technique

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

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

0%

Overall, how would you rate your current level of function?

Normal    Nearly normal    Abnormal    Severely abnormal
Appendix G: Recruitment flyer

**Research Volunteers Needed**

*Study of balance deficits in subjects with Chronic Ankle Injury (sprain) (CAI)*

**Measurements:** Dynamic Leap and Balance Test (DLBT) and Modified Star Excursion Balance Test (Y-SEBT)

**Purpose:** to identify any balance deficits in subjects with chronic ankle injury (CAI) in comparison to healthy subjects.

Testing requires two (2) sessions, 1st session of 1 hour and 2nd of 30 minutes, within the Athletic Training & Sports Medicine Laboratory over approximately two weeks.

In order to qualify for the research study, you must meet the following criteria:

- English speaking
- Ages 18-40 years old
- Both healthy and CAI individuals are needed for this study. Healthy individuals would be matched with CAI individuals.
- Healthy individual
  - No current lower extremity pain or injuries
  - No current low back pain or injuries
  - No major history of lower extremity or low back surgeries
  - No recent head trauma or concussions
  - No issues with balance
- Chronic Ankle Injury (CAI individuals)
  - History of at least one ankle sprains
  - Not currently experiencing signs and symptoms of recent ankle sprain
  - No history of surgery or fractures that needed realignment in lower extremity.

Departments of Kinesiology
Athletic Training & Sports Medicine

For more information, contact Abbis Jaffri by Email: **auj175@psu.edu** or Phone: **717-319-7480**
References:


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ACADEMIC VITAE
ABBIS HAIDER JAFFRI

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219 Johnson Terrace, State College, PA, 16803
abbis.haider@gmail.com

FORMAL EDUCATION

M.S.  PENNSYLVANIA STATE UNIVERSITY
      (MASTERS OF SCIENCE IN KINESIOLOGY)  2014-2016

B.S.PT KING EDWARD MEDICAL UNIVERSITY
      (BACHELORS OF SCIENCE IN PHYSIOTHERAPY)  2008-2012

HONORS AND AWARDS

1) Laptop as an award of merit
2) Distinction in medical physics
3) Distinction in psychiatry n psychology
4) Distinction in sociology n special education
5) Topped in kinesiology
6) 2nd position in final professional examination
7) 2nd best graduate in Physiotherapy session (2008-2011)
8) 1st in metric in secondary school

INTERNATIONAL AWARDS

Selected as a Principal Candidate for Pursuing Master’s Degree in the USA on a Fulbright Scholarship in the Fall 2014 by the State Department of the United States of America.

RESEARCH EXPERIENCE

1) Presented Poster in a Kines Graduate Research Showcase, fall 15, in Penn State University.
2) Did my undergard thesis : "Determination of most affected side of face in Bell’s Palsy patients"

TEACHING EXPERIENCE

1) Teaching Assistant (TA) for KINES 202, musculoskeletal Anatomy for spring 16 in Department of Kinesiology, Penn State University.
2) Teaching Assistant (TA) for KINES 434, musculoskeletal rehabilitation of lower limb for fall 15 in Department of Kinesiology, Penn State University.
PUBLICATIONS


PROFESSIONAL EXPERIENCE

• UNDERGRAD. EXPERIENCE: (2010-2012)
  1. Worked as a clinical intern in orthopedic ward Mayo hospital Lahore
  2. Worked as a clinical intern in medicine ward Mayo hospital Lahore
  3. Worked as a clinical intern in general surgery ward Mayo hospital Lahore
  4. Worked as a clinical intern in pediatrics medicine ward Mayo hospital Lahore
  5. Worked as a clinical intern in pediatrics surgery ward Mayo hospital Lahore
  6. Worked as a clinical intern in general physiotherapy ward Mayo hospital Lahore
  7. Worked as a clinical intern in physiotherapy ward Ganga ram hospital Lahore
  8. Worked as a clinical intern in pulmonary ward Mayo hospital Lahore
  9. Worked as a clinical intern in cardiology unit Mayo hospital Lahore
  10. Worked as a clinical intern in neurology unit Mayo hospital Lahore
  11. Worked as a research assistant for 1 year in School of Physiotherapy, Mayo hospital king Edward Medical University Lahore Pakistan.

• POST PROFESSIONAL EXPERIENCE:
  1. Worked as a full time Physiotherapist in ICU/CCU, orthopedic unit, neurology ward, pediatrics, general surgery, urology unit, general ward and outpatient Physiotherapy Department of National Hospital DHA, Lahore Pakistan from 09/2012 to 07/14.
  2. Did 24 hours of observation/shadowing in Spaulding Rehabilitation Hospital Boston, MA in different rehabilitation sections.

LANGUAGES

Urdu: native language
English: advanced speaking, reading, writing and listening skills
Punjabi: moderate language skill