Dynamic Postural Stability During Gait Initiation in Individuals with Chronic Ankle Instability: The Influence of Walking Velocity

Elizabeth I. Raycraft
Georgia Southern University

Follow this and additional works at: https://digitalcommons.georgiasouthern.edu/etd

Recommended Citation
https://digitalcommons.georgiasouthern.edu/etd/103

This thesis (open access) is brought to you for free and open access by the Graduate Studies, Jack N. Averitt College of at Digital Commons@Georgia Southern. It has been accepted for inclusion in Electronic Theses and Dissertations by an authorized administrator of Digital Commons@Georgia Southern. For more information, please contact digitalcommons@georgiasouthern.edu.
Chronic ankle instability (CAI) is associated with deficits in strength, balance, and static postural stability, however dynamic postural stability during transitional movements have received limited investigations. The purpose of this study was to assess dynamic postural stability in individuals with CAI during varying speeds of gait initiation (GI). There were twenty-eight voluntary subjects, 14 (M8:F6) subjects with CAI and 14 (M8:F6) control subjects (healthy young athletes, HYA). CAI was assessed using the Foot and Ankle Ability Measure (FAAM) tool. Control subjects had no history of any LAS. Data was collected using two non-conducting forceplates and an electromagnetic tracking system. Subjects performed five trials of each task, first normal speed GI and then fast speed GI. There were no significant differences noted for both A/P and M/L movement and velocity of COP during S1. There were also no significant differences between groups for initial step length or initial step velocity. Lastly, there were no significant differences found between groups for COP-COM at the end of single support phase of gait. The results of this study suggest that GI may not be a challenging enough task to evoke deficits in postural control in individuals with CAI. The GI motor program likely remains unaffected by the development of CAI and these individuals are likely able to compensate for any functional deficits they may experience. Future research should investigate these motor programs using EMG data and also possibly secondary tasks that may challenge these individuals more.

INDEX WORDS: Chronic ankle instability, Dynamic postural stability, Gait initiation
DYNAMIC POSTURAL STABILITY DURING GAIT INITIATION IN INDIVIDUALS WITH CHRONIC ANKLE INSTABILITY: THE INFLUENCE OF WALKING VELOCITY

by

Elizabeth I. Raycraft

B.S., Saginaw Valley State University, 2007

A Thesis Submitted to the Graduate Faculty of Georgia Southern University in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

STATESBORO, GEORGIA

2009
DYNAMIC POSTURAL STABILITY DURING GAIT INITIATION IN INDIVIDUALS WITH CHRONIC ANKLE INSTABILITY: THE INFLUENCE OF WALKING VELOCITY

by

ELIZABETH IRENE RAYCRAFT

Major Professor: Thomas Buckley
Committee: Barry Munkasy
            Barry Joyner

Electronic Version Approved:
May 2009
TABLE OF CONTENTS

LIST OF FIGURES.............................................................................................................. 6

CHAPTER

1 INTRODUCTION............................................................................................................. 7

2 METHODS.................................................................................................................... 13

   Subjects..................................................................................................................... 13

   Equipment................................................................................................................. 13

   Experimental Procedure.......................................................................................... 14

   Data Analysis............................................................................................................. 15

   Statistical Analysis.................................................................................................. 15

3 RESULTS..................................................................................................................... 17

4 DISCUSSION............................................................................................................... 19

REFERENCES............................................................................................................... 22

APPENDICES

   A REVIEW OF LITERATURE....................................................................................... 26

   B HYPOTHESIS, LIMITATIONS, DELIMITATIONS, ASSUMPTIONS, AND DEFINITIONS.................................................................................................................................................. 44

   C SUBJECT PACKET.................................................................................................... 47

   D FIGURES.................................................................................................................... 56
LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure 1</td>
<td>Exemplar COP trace during normal GI for both HYA and CAI</td>
<td>57</td>
</tr>
<tr>
<td>Figure 2</td>
<td>Exemplar COP trace during fast GI for both HYA and CAI</td>
<td>58</td>
</tr>
<tr>
<td>Figure 3</td>
<td>Laboratory set-up for GI trials</td>
<td>59</td>
</tr>
<tr>
<td>Figure 4</td>
<td>A/P movement of COP during S1 during normal and fast GI</td>
<td>60</td>
</tr>
<tr>
<td>Figure 5</td>
<td>A/P velocity of COP during S1 during normal and fast GI</td>
<td>61</td>
</tr>
<tr>
<td>Figure 6</td>
<td>M/L movement of COP during S1 during normal and fast GI</td>
<td>62</td>
</tr>
<tr>
<td>Figure 7</td>
<td>M/L velocity of COP during S1 during normal and fast GI</td>
<td>63</td>
</tr>
<tr>
<td>Figure 8</td>
<td>Initial step length during normal and fast GI</td>
<td>64</td>
</tr>
<tr>
<td>Figure 9</td>
<td>Initial step velocity during normal and fast GI</td>
<td>65</td>
</tr>
<tr>
<td>Figure 10</td>
<td>COP-COM separation at HS(^{-1}) during normal and fast GI</td>
<td>66</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction

The most common athletic injury is the lateral ankle sprain (LAS) with approximately 23,000 to 27,000 occurring daily in the United States.\textsuperscript{1} However, the number may be much higher as it has been estimated that about 55\% of individuals suffering from LAS do not report them or seek medical attention.\textsuperscript{1} The cost to treat these LAS has been estimated to exceed 3.65 billion dollars annually.\textsuperscript{2} Of these individuals sustaining a LAS, up to 75\% may have residual symptoms or develop chronic ankle dysfunction.\textsuperscript{3,4} Up to 40\% of these same individuals might also experience recurring ankle sprains potentially leading to the development of chronic ankle instability (CAI); characterized by impaired proprioception, strength, postural control, and neuromuscular control without ligamentous laxity secondary to multiple lateral ankle sprains.\textsuperscript{1,3-5} An individual who suffers from CAI may experience episodes of “giving way” or sensations of instability within the joint during every day activity and physical activity. Despite the prevalence and complications associated with CAI the pathophysiology remains elusive.

The etiology of CAI has been thought to include a combination of peroneal strength deficits, proprioceptive deficits, and impaired neuromuscular firing-patterns.\textsuperscript{1,6,7} Initially, CAI was thought to result from strength deficits of the peroneals which was also believed to be the most significant contributing factor to the recurrence of lateral ankle sprains.\textsuperscript{8,9} This recurrence was thought to be largely due to the inability to resist sudden inversion of the ankle.\textsuperscript{8,9} Findings over the last decade have suggested that strength may not be the primary factor of CAI as symptoms persist despite bilateral equal strength.\textsuperscript{10,11} Indeed, proprioception is now considered the probable cause of CAI based on noted proprioception deficits in this population.\textsuperscript{1,10,12} These proprioceptive deficits occur secondary to a loss of input from mechanoreceptors causing
improper foot positioning before and during foot contact. However, Riemann suggested that mechanoreceptors alone cannot be the source of the deficits noticed in individuals with CAI, suggesting instead, while acknowledging individual variability, that consideration should be given to other areas within the postural-control system such as, decreased mechanical stability or damaged afferent and efferent neural pathways. A consensus is forming which suggests that strength or proprioceptive deficits alone are not the cause of CAI, but a culmination of the two.

Properly assessing both proprioceptive and strength deficits has proven to be difficult. Assessments have ranged from the use of manual muscles tests to isokinetic testing and from static postural testing to more sport-specific dynamic postural testing. McKeon reviewed other research that utilized the Romberg’s test while standing on a forceplate as a measure of altered postural control and found that the Romberg’s test was found not to be an effective enough tool to determine postural control deficits in individuals with CAI and that better tools need to be developed. Wikstrom examined CAI deficits by utilizing measures of time-to-stabilization, which measures stability, and the dynamic postural stability index scoring, which assesses motor control. Wikstrom found that individuals with CAI had increased time-to-stabilization scores in the anterior/posterior (A/P) direction during jump landing and produced higher dynamic postural stability index scores in the A/P and vertical direction during a jump-landing protocol. Wikstrom suggested two potential explanations for the observed impairment. First, those individuals with CAI may take more time to decelerate their center of mass (COM), because they allow their COM to reach the limits of stability, which destabilizes of the body. Second, there are motor changes within the ankle associated with CAI forcing these individuals to be predisposed to recurrent lateral ankle sprains due to using a non-ankle strategy. Some studies have found deficits in individuals with CAI showing that CAI may
affect postural control strategies.\textsuperscript{10,26} Further, evidence suggests that individuals with unilateral CAI tend to land in a dorsiflexed position causing an increased ground reaction force when compared to healthy individuals.\textsuperscript{27} Individuals with unilateral CAI utilize a hip strategy to compensate for deficits in support of the ankle during single leg balancing.\textsuperscript{28} Overall what has been found in these studies is that individuals with CAI have decreased dynamic postural stability during static balancing and jumping. In a preliminary investigation, Hass found that during gait initiation (GI) individuals with CAI shorten their center of pressure (COP) movement towards the unaffected initial stepping leg therefore reducing the COM momentum towards the affected initial stance limb.\textsuperscript{29} It has become increasingly clear that postural instability is a major issue associated with CAI, however, despite having extensive research done the exact mechanics still remain vague.

CAI literature is replete with investigations of dynamic to static studies, such as jump-landing, however surprisingly limited investigations are devoted to examining static to dynamic transitional movements. While dynamic to static movements have yielded important findings, static to dynamic transitional movements also challenge an individual’s postural control systems. For example, a football wide receiver may not begin the play running; he starts statically on the line of scrimmage and then begins the dynamic movement of running when the ball is hiked. During a basketball game a player may be static while waiting under the basket for a free throw shot and then act dynamically to box out and rebound the ball. Given this, valuable insight may be gained by investigating static to dynamic movements in individuals with CAI. GI challenges a person’s dynamic postural control as it represents a transition from a steady static balance to a continuously unstable gait.\textsuperscript{30} GI is potentially more challenging then steady state walking as the
initial separation of the COP and COM requires a higher level of dynamic balance control and neural adaptations.31

COP is the weighted average of all pressures over the surface area of the foot in contact with the ground.32 The COP trace during GI is divided into three segments with two major landmarks (Figure 1 & 2).33 Segment 1 (S1) begins with the initiation of movement and ends when the COP is most posterior and lateral toward the initial swing limb (Landmark 1 (L1)).30 This posterior movement of COP during S1 is what generates the forward momentum that is needed to initiate gait, whereas the lateral movement of the COP initially is what propels the COM towards the initial stance limb.33,34 Segment 2 (S2) is characterized by the translation of the COP towards the initial stance limb ending at Landmark 2 (L2), the position under than stance limb where the COP begins to move forward and the person moves into single stance.30 The final segment, Segment 3 (S3), marks the movement from Landmark 2 until toe-off of the initial stance limb as the COP translates anteriorly.35

COM can be defined as a point in the body that would move in the way a single particle would if subjected to an identical external force.31,36 During quiet stance, the COM is coupled with the COP in the transverse plane.35 As movement is initiated, the COM and COP must uncouple and move in opposite directions to create the forward momentum required for locomotion.35 The COM moves anterior and lateral towards the initial stance limb and continues anterior as the person steps forward.37

COP-COM separation, viewed in the transverse plane, is the separation between the COP and COM at any given time during a movement task.36 This separation, when quantified, can provide insight into postural control and what has been seen is that the greater the separation the greater the need is for postural control.32 Individuals with balance or proprioceptive deficiencies
shorten this distance in order to maintain or enhance their balance control. COP-COM separation during transitional movements have previously been used to assess dynamic postural stability in patients with Parkinson’s disease and the elderly. This measurement is able to capture the relationship between dynamic stability and momentum generation, suggesting it may serve as an indicator of disability during GI. Hass observed the greatest COP-COM separation occurred just prior to the end of single stance, heel strike minus one (HS⁻¹), suggesting the end of single stance may be the most challenging moment in GI.

GI has been well studied during normal self-selected pace; however the role of velocity on GI has received surprisingly limited investigations. Brunt investigated the influence of velocity on GI and found that variables, such as swing toe off and heel strike, remained invariant across varying speeds of gait initiation. He later reported that during fast paced GI the ground reaction force peak increased as compared to self-pace speed and the faster the speed the shorter the stance and swing time. Specifically, stance time decreased 11% and swing time decreased 16% during fast paced GI. Brunt’s investigations examined motor programs by measuring the onset of muscle activity and forceplate data, however COP, COM, and COP-COM were not explored. Since the motor program remains invariant it is likely that the COP movement would remain invariant as well. However, with the increased GRF step length and step velocity may increase.

Postural instabilities have been identified in individuals with CAI during a wide array of athletic and non-athletic maneuvers, however, to our knowledge, there are no studies investigating how transitional movements are affected by CAI in this population. As GI can potentially discriminate postural instabilities in a wide range of pathological populations, it is a potentially effective screening tool. Therefore, the purpose of this study was to investigate
dynamic postural stability during GI in individuals with CAI. Secondarily, we examined the influence of movement initiation velocity in this population.
Chapter 2

Methods

Subjects

Twenty eight subjects volunteered to participate in this study, 14 (M8:F6) control subjects (healthy young athletes, HYA) and 14 (M8:F6) subjects with CAI. Subjects were recruited from the varsity football, men’s and women’s soccer and cheerleading teams at a Division I NCAA institution. CAI, operationally defined as an individual suffering from three or more LAS in the last year and five or more in a lifetime, was assessed using the Foot and Ankle Ability Measure (FAAM) tool.40 Control subjects had no history of any LAS. All subjects were free of any current or previous major orthopedic injuries, neurological impairments, concussions within the last 6 months, vestibular impairments, and lower extremity surgeries requiring surgical pins, screws or plates. All subjects provided written consent prior to participation in this study as approved by the university’s IRB

Equipment

Kinematic data was collected using an electromagnetic tracking system (Ascenson Technologies; Burlington, VA) with Motion Monitor acquisition and analysis software (Innovative Sports Training, Inc.; Chicago, IL). There are 3 orthogonal coils, which create an electromagnetic field, and 9 sensors that record the flux in the electromagnetic field, as the sensors are moved within the field, and then the signal is sent to the computer via cables. Motion Monitor software calculates sensor position and orientation from the electromagnetic signal. The sampling rate for the electromagnetic system was set at 100 Hz.

This study used two non-conducting forceplates (Model OR6-5, Advance Mechanical Technology, Inc.; Watertown, MA) to collect the ground reaction forces and moments which
were used to calculate the COP. All of the forceplate signals were amplified and digitized using an analog to digital card (ComputerBoard DAS 1602-12, ComputerBoard, Inc.; Middleboro, MA). The sampling rate for the forceplate was set at 1000 Hz.

The sensors were firmly attached to each subject with double sided tape, pre-wrap, stretch tape and white athletic tape while within the electromagnetic capture zone. The positioning for the sensors were as follows: bilaterally on the dorsum of each foot, the medial surface of the both tibias, both of the thighs (approximately on the vastus lateralis midway between the anterior superior iliac spine and the femoral condyles), the sacrum, and the 7th cervical vertebrae. The sacral marker was attached with double sided tape and an ace wrap to prevent any movement. The C7 marker was held in place by a Velcro shoulder strap. The final, 9th, sensor was used to determine joint centers of the ankle and knee. The center of the hip joints were calculated using the Leardini method.41

Experimental Procedure

When subjects arrived at the Biomechanics Laboratory they completed the IRB and FAAM and were given the opportunity to ask any questions (Appendix C). The electromagnetic sensors were than attached to the subject. Next, they were asked to stand on a single forceplate in a self-selected position and the specific task was explained. They were allowed to practice until they were comfortable with task. Their starting position was marked on the forceplate to ensure consistency across trials and conditions. Subjects were instructed to stand quietly prior to the beginning of data collection and initiated movement in response to the verbal command, “go”. The involved ankle was designated the initial stance ankle for the CAI subjects and controls were matched accordingly. Subjects walked about 3 meters in a straight line towards a designated target about 6 meters away at eye level across two forceplates (Figure 3). As they
walked, sensor cords were held by a research assistant to reduce the risk of tripping, to allow the subjects to feel as comfortable as possible, and to prevent the cords from hitting the forceplate. Subjects performed five trials of each task, first normal speed GI and then fast speed GI. Normal GI was a self-selected everyday walking pace for the individual whereas the fast speed GI was as fast as they could possibly walk without it being a jog.

Data Analysis

Movement initiation (MI) was identified by the first change in the medial/lateral (M/L) COP (± 2 SD from the mean of the first 0.5 seconds of the trial). Variables of interest included the A/P movement of COP during the S1 phase and the velocity of the A/P movement of COP during this phase. Also of interest were the M/L movement of COP during the S1 phase and the velocity of the M/L movement of COP during this phase. Initial step length was calculated by using the difference between MI of the initial stance leg and heel strike (HS) of the initial step leg. Initial step velocity was calculated by dividing initial step length by the time required to get from MI to HS. The resultant COP-COM separation, in the transverse plane, was measured at the end of single stance phase. All dependent variables were measured during both normal and fast speed GI.

Statistical Analysis

All data analysis was done using SPSS statistical software (version 15.0; SPSS Inc, Chicago, IL) and Microsoft Excel (Microsoft 2007; Microsoft Corporation, Redmond, WA). The dependent variables for each subject’s trials were averaged for each task producing one mean with a standard deviation for each dependent variable. Descriptive statistics, including height, ASIS-medial malleolus measurement, weight, age, and BMI were collected for each subject. Independent t-tests compared descriptive statistics between groups. All data was
analyzed by a 2x2 MANOVA with repeated measures for each of the dependent variables followed up with independent t-tests. The dependent variables are A/P movement and velocity of COP during S1 phase, M/L movement and velocity of COP during S1 phase, initial step length, initial step velocity, and resultant COP-COM separation at the end of single stance phase. The P-value was set at .05.
Chapter 3

Results

All subjects were able to complete the experimental trials without incident. Independent t-tests showed no significant differences between groups for age (HYA: 20.0 ± 1.1 years, CAI: 19.8 ± 1.1 years; p=.74), height (HYA: 180.1 ± 7.6 cm, CAI: 181.6 ± 9.7 cm; p=.66), weight (HYA: 73.4 kg, CAI: 73.1 kg; p=0.93), ASIS-medial malleolus distance (HYA: 91.4 ± 5.6 cm, CAI: 92.3 ± 5.7 cm; p=.67), or body mass index (HYA: 22.5 ± 4.0, CAI: 21.9 ± 2.5; p=.62).

There were no significant differences noted for COP measures. There were no significant differences between groups for the A/P movement of COP during S1 during normal GI (HYA= 5.0 ± 1.4 cm and CAI= 4.1 ± 1.5 cm, p=.13) (Figure 4). There were no significant differences between groups for A/P velocity of COP during S1 during normal GI (HYA= 13.0 ± 4.8 cm/s and CAI= 10.6 ± 5.5 cm/s, p=.19) (Figure 5). There were no significant differences between groups for M/L movement of COP during S1 during normal GI (HYA= 4.0 ± 1.5 cm and CAI= 3.9 ± 1.3 cm, p=.80) (Figure 6). There were no significant differences between groups for M/L velocity of COP during S1 during normal GI (HYA= 10.9 ± 5.8 cm/s and CAI= 9.9 ± 5.1 cm/s, p=.51) (Figure 7). There were no significant differences between groups for initial step length during normal GI (HYA= 63.4 ± 7.2 cm and CAI= 63.0 ± 5.2 cm, p=.85) (Figure 8). There were no significant differences between groups for initial step velocity during normal GI (HYA=0.56 ± 0.08 m/s and CAI= 0.52 ± 0.1 m/s, p=.37) (Figure 9). There were no significant differences found between groups for COP-COM at HS^{-1} during normal GI (HYA= 23.2 ± 4.4 cm and CAI= 21.8 ± 3.4 cm, p=.43) (Figure 10).

There were no significant differences between groups for the A/P movement of COP during S1 during fast GI (HYA= 8.7 ± 1.3 cm and CAI= 8.5 ± 1.8 cm, p=.81) (Figure 4). There
were no significant differences between groups for A/P velocity of COP during S1 during fast GI (HYA = 23.3 ± 5.5 cm/s and CAI = 24.6 ± 10.9 cm/s, p = .70) (Figure 5). There were no significant differences between groups for M/L movement of COP during S1 during fast GI (HYA = 4.8 ± 1.9 cm and CAI = 4.4 ± 1.4 cm, p = .55) (Figure 6). There were no significant differences between groups for M/L velocity of COP during S1 during fast GI (HYA = 12.3 ± 5.0 cm/s and CAI = 12.7 ± 6.8 cm/s, p = .55) (Figure 7). There were no significant differences between groups for initial step length during fast GI (HYA = 75.8 ± 9.7 cm and CAI = 77.5 ± 7.6 cm, p = .60) (Figure 8). There were no significant differences between groups for initial step velocity during fast GI (HYA = 0.76 ± 0.9 m/s and CAI = 0.77 ± 0.13 m/s, p = .94) (Figure 9). There were no significant differences found between groups for COP-COM at HS\(^1\) during fast GI (HYA = 36.6 ± 4.7 cm and CAI = 37.4 ± 4.6 cm, p = .36) (Figure 10).
Chapter 4

Discussion

The purpose of this study was to investigate impairments in dynamic postural stability during GI in individuals with CAI. Specifically, we evaluated spatiotemporal variables of locomotion as well as COP excursions and COP-COM interactions in subjects at both a self-selected pace and fast paced GI. Individuals with CAI did not present with any significant differences when compared to the healthy matched controls.

Finding no significant differences in our data leads us to conclude that GI, at our chosen speeds, may not be a challenging enough task to identify postural instability in individuals with CAI. We are left to speculate this is due to the motor programs responsible for GI remaining intact in individuals with CAI. The motor program of primary interest involves the interaction of the tibialis anterior and the soleus. During quiet stance, the soleus is tonically active and the tibialis anterior is inhibited. However, in order to initiate gait, the COP and COM must uncouple with the COP being driven posteriorly to allow generation of forward momentum needed to move the COM anteriorly. This posterior movement of the COP is created by the inhibition of the soleus and activation of the tibialis anterior. Brunt demonstrated that the interval between the inhibition of the soleus and the onset of the tibialis anterior remained the same regardless of the speed of GI. Additionally, Brunt demonstrated that the relative timing for stance and swing tibialis anterior onsets, fore-aft (A/P) force onset, swing toe-off, and swing heel-strike remained unchanged across varying speeds of GI. He suggested this is due to the capabilities of the motor program to compensate for changes in speed. What this means for our study is that the COP movement created by this motor program remains unchanged, at both normal and fast speeds, between the groups because the motor program itself is likely not
impaired by CAI. Our results for A/P movement of COP during S1 during normal GI in HYA was similar with Halliday’s (5.0 cm and 4.7 cm respectively).\textsuperscript{42}

Another interesting aspect of the GI motor program is the activity of the gluteus medius which influences lateral movement of the COP towards the initial swing limb.\textsuperscript{18} This muscular activity at the hip propels the COM towards the initial stance limb.\textsuperscript{34} However, it is unlikely that the musculature of the hip, specifically the gluteus medius, is impaired by CAI. Therefore, it is likely that the lack of differences noted in the lateral excursion of the COP during the S1 phase of GI is due to the unimpaired motor programs. The results for M/L movement of COP during S1 for HYA was also similar with Halliday’s findings (4.0 cm and 3.6 cm respectively).\textsuperscript{42}

An individual’s step length and velocity is primarily determined by the momentum that is generated by the posterior translation of the COP which occurs during the S1 phase of GI.\textsuperscript{34} Our results demonstrated no differences in the posterior or lateral movement of the COP; therefore we would not expect differences in step length, step velocity, or separation of the COP-COM. The separation of the COP and COM is a function of both the momentum generated during the S1 phase, which drives the COM forward and away from the COP, as well as the initial step length.\textsuperscript{31} As neither of these measures varied between groups, it is not surprising that no differences were noted in COP-COM separation.

Even though we found no significance differences in our dependent variables, it must be noted that postural instabilities have previously been identified within this population. This has been shown in numerous studies looking at both static and dynamic to static movements. Wikstrom and Ross have both independently shown longer time-to-stabilization during jump-landing protocols in those with CAI.\textsuperscript{4,25,43} Brown found that individuals with CAI took longer to stabilize in the A/P direction during static balancing with perturbations.\textsuperscript{12} Also, the star
excursion balance test detected reach deficits in individuals with CAI.\textsuperscript{17} So even though the research clearly shows that individuals with CAI do in fact have postural stability deficits it we are unable to determine why this did not translate to our research. We believe it to be strongly related to motor programs and their ability to endure through CAI.

As with all research there are limitations to this study. A research assistant maintained control of the cords and allowed appropriate slack at all times, however it is possible the subjects may still have restricted their movement. Making sure the subject is giving constant feedback as to the amount of slack is a good way to avoid this. In addition to a non-randomized sample, our decision not to differentiate specifically between functional and mechanical instability may have limited our findings. This is a place where further research needs to develop.

Future studies investigating postural stability during transitional movements in individuals with CAI should consider collecting EMG data of the tibialis anterior and soleus to gain more information on the motor programs involved with the movements. Studies should also consider looking at differentiating between functional ankle instability and mechanical ankle instability. Future studies may also consider adding a secondary task to increase the challenge to the ankle.

In conclusion, the results of this study suggest that GI may not be a challenging enough task to evoke deficits in postural control in individuals with CAI. The GI motor program likely remains unaffected by the development of CAI and these individuals are able to compensate for any functional deficits they may experience. Further research needs to be done to explore what tasks may be challenging enough to elicit changes in COP movement and COP-COM separation in individuals with CAI.
References


Appendix A

Review of Literature
Anatomy and Physiology

The ankle is complex in its entirety. There are numerous ligaments, tendons, muscles, and nerves that function together to produce movement at the ankle joint. Disruption to any part of this joint may lead to dysfunction of the ankle during movements. One possible problem that might arise would be chronic ankle instability (CAI).

The ankle is comprised of three articulations: the talocrural joint, the subtalar joint, and the distal tibiofibular syndesmotic joint, which work together to allow motion in the rearfoot.\(^1\) Inversion and eversion occurs in the frontal plane, internal and external rotation occur in the transverse plane, and dorsiflexion and plantarflexion occur in the sagittal plane.\(^1\) The talocrural joint is formed by the tibia, fibula, and the dome of the talus.\(^1\) At this joint the movements we can see are plantarflexion and dorsiflexion.\(^2\) In a healthy ankle there should be approximately 20 degrees of dorsiflexion and 50 degrees of plantarflexion.\(^2\)

The subtalar joint is formed by the calcaneus and the talus.\(^1\) This particular articulation acts like a ball and socket joint.\(^1\) The talar head acts as the ball and the anterior calcaneal and proximal navicular surfaces for the socket.\(^1\) Inversion and eversion are the movements taking place here in the subtalar joint.\(^2\) Approximately 20 degrees of inversion and 5 degrees of eversion are considered to be normal.\(^2\)

The tibia and the fibula articulate to form the distal tibiofibular syndesmosis.\(^1\) This joint allows limited movement between the tibia and fibula, however some accessory gliding is necessary for normal mechanics.\(^1\) Other bones in the ankle are the navicular, cuboid, first through third cuneiform and fifth metatarsal.\(^1,2\)

There are several ligaments that are found in the ankle. On the medial side there is the tibiocalcaneal ligament, anterior and posterior tibiotalar ligaments, and tibionavicular ligament.
Collectively, the four medial ligaments are frequently referred to as the deltoid ligament. The tibiocalcaneal ligament attaches on the calcaneus and arises from the apex of the fibula.\textsuperscript{2} Attaching the posterior portion of the talus to the medial malleolus is the posterior tibiotalar ligament.\textsuperscript{2} The anterior tibiotalar ligament originates on the anteromedial portion of the medial malleolus and inserts on the medial talus.\textsuperscript{2} The tibionavicular ligament originates on the tibia and runs beneath the anterior tibiotalar ligament and then inserts on the medial surface of the navicular.\textsuperscript{2} On the lateral side of the ankle there is the calcaneofibular ligament which runs from the lateral malleolus to its insertion on the lateral aspect of the calcaneus.\textsuperscript{1,2} The anterior talofibular ligament, which is the most commonly sprained, originates on the lateral malleolus and inserts on the talus near the sinus tarsi while the posterior talofibular courses from the lateral malleolus to its attachment on the talus and calcaneus.\textsuperscript{1,2} The posterior talofibular ligament is the strongest of the three lateral ligaments.\textsuperscript{1,2} The anterior and posterior tibiofibular ligaments can be found at the distal ends of the tibia and fibula.\textsuperscript{2} The crural interosseous ligament, an extension of the interosseous membrane, can also be found connecting the distal ends of the fibula and tibia.\textsuperscript{2}

The lower leg is divided into four separate compartments: anterior compartment, lateral compartment, superficial posterior compartment, and the deep posterior compartment. The dorsiflexors of the ankle can be found in the anterior compartment.\textsuperscript{2} These muscles are the tibialis anterior, extensor hallucis longus, extensor digitorum longus, and the peroneus tertius.\textsuperscript{2} The tibialis anterior and extensor hallucis longus also assist in subtalar inversion.\textsuperscript{2} Both the extensor digitorum longus and peroneus tertius contribute to eversion.\textsuperscript{2} Securing these anterior compartment muscles to the dorsum of the foot is the extensor retinaculum, which prevents a bowstring effect from occurring during toe extension and dorsiflexion.\textsuperscript{2} Also found in the
The anterior compartment is the deep peroneal nerve, a branch from the common peroneal nerve, which innervates most all of the anterior muscles of the lower leg and ankle. Blood is supplied to the anterior compartment by the anterior tibial artery which branches off to become the dorsalis pedis artery. The dorsalis pedis artery supplies blood to the dorsum of the foot.

In the lateral compartment there is the peroneus longus, peroneus brevis and peroneus tertius. All three of these muscles collectively are evertors of the foot. Peroneus longus and brevis also assist in plantarflexion of the foot while peroneus tertius assists in dorsiflexion. The peroneus brevis runs deep to the peroneus longus and together they pass posterior to the lateral malleolus. Holding both of these muscles’ tendons down behind the lateral malleolus are the superior and inferior peroneal retinacula. The peroneus longus and brevis split away from each other at the peroneal tubercle before they insert in their respective places. The peroneus longus runs on the plantar aspect of the foot and inserts on the distal base of the first metatarsal and the first cuneiform. The peroneus brevis inserts on the styloid process of the fifth metatarsal. The peroneus tertius originates on the distal portion of the fibula and runs superior to the lateral malleolus before inserting on the dorsal aspect of the base of the fifth metatarsal. In the lateral compartment the superficial peroneal nerve can be found, which innervates the peroneus brevis and tertius. Supplying blood to the lateral ankle is the peroneal artery, a branch of the posterior tibial artery.

The triceps surae, comprised of the gastrocnemius, soleus, and plantaris, can be found in the superficial posterior compartment. The gastrocnemius and plantaris originate on the posterior aspects of the femoral condyles while the soleus originates off the posterior tibia. Both the gastrocnemius and soleus insert on the calcaneus via the achilles tendon allowing it to contribute to plantarflexion of the ankle. Running deep between the soleus and the tibialis
posterior is the tibial nerve, the longest branch of the sciatic nerve. The tibial nerve supplies innervation for all muscles in the superficial and deep posterior compartments. Following the same path as the tibial nerve is the posterior tibial artery.

Found in the deep posterior compartment is the tibialis posterior, flexor digitorum longus, and the flexor hallucis longus. The tibialis posterior acts exclusively on the ankle and foot making it a primary adductor of the forefoot. It also assists in plantarflexion and inversion. The flexor digitorum longus and flexor hallucis longus act primarily to perform flexion of the toes. Both muscles also aid in plantarflexion and inversion of the ankle.

There are four nerve roots of significance in the ankle: L4 (deep peroneal), L5 (deep peroneal), S1 (tibial), and S2 (lateral plantar). The dermatome for L4 is the medial lower leg, foot and the great toe. The L5 dermatome runs from the lateral aspect of the proximal lower leg to the anterior portion of the lower leg down the dorsum of the foot and includes the second through fourth phalanges of the foot. The dermatome for S1 is the lateral aspect of the foot and distal lower leg, the fifth phalange and the Achilles tendon. The dermatome for S2 is essentially the belly of the gastrocnemius. The myotome for L4 is the anterior tibialis function. The L5 myotome is the function of the extensor hallucis longus muscle. The S1 myotome is the peroneal muscle function while S2 has no myotome associated with it. To test the deep tendon reflex for L4 and L5 you would do a patellar tendon reflex where as S1 and S2 is the Achilles tendon reflex.

Chronic Ankle Instability and Current Research

On a daily basis there are approximately 23,000 lateral ankle sprains (LAS) making it the most common injury occurring in sports. LAS account for up to 25% of injuries in running and jumping sports such as basketball, soccer, football and volleyball. It is estimated that this
may be a low number given that it has been reported that 55% of individuals do not seek medical attention following a lateral ankle sprain.\textsuperscript{4} The cost to treat these moderate to severe lateral ankle sprains has been expected to exceed about 3.65 billion dollars annually.\textsuperscript{6,7} These sprains to the lateral ankle lead to more time lost from sport participation than any other sport-related injury.\textsuperscript{8} Once an individual experiences a lateral ankle sprain they are more likely to experience additional ankle sprains and up to 75% will have residual symptoms or develop chronic ankle dysfunction.\textsuperscript{3,4,8} Recurring lateral ankle sprains can lead to chronic ankle instability. Chronic ankle instability is defined, “as impaired proprioception, strength, postural control, and neuromuscular control without ligamentous laxity”.\textsuperscript{4,5} This dysfunction is often characterized by feelings of the ankle giving way, edema, pain during activity and even recurrent injury.\textsuperscript{4} Not only will those who experience recurrent lateral ankle sprains be likely to develop CAI, but 30-78% will also have incidences of degenerative arthritis.\textsuperscript{3}

During an injury to the lateral ankle there are many physiological changes that occur. Immediately, one might experience edema, ecchymosis, pain and may also encounter problems with decreased range of motion, strength, proprioception and overall function. The anterior talofibular ligament and calcaneofibular ligament either stretch or rupture completely during injury.\textsuperscript{3} Injury to these ligaments is due to excessive supination of the rearfoot with an externally rotated lower leg during heel strike of gait or the landing of a jump.\textsuperscript{1} The actual damage to the ligament occurs when the tensile strength of the tissue is exceeded by the strain on the ligament.\textsuperscript{1} If the ankle is in a plantarflexed position at time of initial contact the likelihood of suffering a LAS is increased. This is due to the fact that plantarflexion is one of the component movements of supination.\textsuperscript{1} When the ankles, diagnosed with CAI, were looked at arthroscopically, cartilage
lesions were noted on the talus and tibia. These lesions can lead to chronic pain, arthritis, and instability within the ankle.

Initially, researchers believed that CAI was a result of strength deficits within the ankle musculature. Some of the terms used to describe the cause of CAI were pronator (peroneal) weakness, evertor weakness, and calf dysfunction. One theory behind CAI, proposed by Bonnin, suggests that the invertors must be strong enough to resist the inversion mechanism associated with lateral ankle sprain. Bosein et al reported that peroneal weakness, due to overstretched muscles and atrophy, is the most significant contributing factor to the recurrence of lateral ankle sprains. As researchers tested the evertor muscles for strength they were particularly looking at the peroneal muscles. Many of these studies used manual muscle testing as a means of determining strength deficits, which was very subjective. This means that the testing depended upon the person performing the manual muscle tests which would provide inconsistent results. Due to this limitation, researchers had to develop other methods of testing strength. Tropp, in 1985, was the first researcher to study isokinetic strength and CAI and his finding was that muscle impairment was due to insufficient rehabilitation and muscle atrophy not CAI. Researchers also turned to examining isokinetic strength by measuring peak torque with a Cybex isokinetic dynamometer at 30°s⁻¹ and 120°s⁻¹. Wilkerson et al found that there were significant differences in the inversion strength of the involved limb between those individuals with CAI and those without. Lentell, however, failed to find evertor weakness to be associated with CAI when testing isokinetic strength at 0°s⁻¹ and 30°s⁻¹. There were other researchers, Schrader, Ryan, and Bernier, that followed that found similar results to Lentell’s study. Schrader, found that a lack of concentric muscle strength was not a contributing factor to CAI after assessing eversion and dorsiflexion strength with a Kin Com
dynanmometer. More recent studies have found that strength alone is not the cause of CAI.\textsuperscript{8,9} Willems stated, “a deficit in muscle strength is one cause of instability; however, it is difficult to say whether these findings are the cause or the effect of the instability”.\textsuperscript{9} He also stated that a possible cause of recurrent sprains is the combined action of diminished proprioception and evertor muscle weakness.\textsuperscript{9} So strength is part of the issue at hand, but not the main or only cause of CAI.

Proprioception can be defined as a person’s ability to sense the position of one or more joints in space.\textsuperscript{2} Most studies that assessed proprioception, as a potential cause of CAI, determined that there were impairments in those individuals with CAI.\textsuperscript{1,9,18} Some authors suggest that people who incur lateral ankle sprains have a loss of proprioceptive input from mechanoreceptors causing improper foot positioning before and during foot contact.\textsuperscript{9} Mechanoreceptors are specialized sensory organs that respond to mechanical stimuli such as tension, pressure, or displacement.\textsuperscript{19} Those individuals with CAI are more likely to have an overly inverted foot position, due to diminished proprioception, which will likely result in re-injury to the lateral ankle due to a varus thrust as the foot touches the ground.\textsuperscript{9}

As research has evolved so has our ability to understand CAI. We have come to understand that CAI is a complex problem and that more continuous research must be done to fully comprehend it. CAI is associated with strength deficits and proprioceptive deficits. Properly assessing both of these deficits has proven to be an issue with researchers. We have moved from the use of manual muscles\textsuperscript{8} tests to isokinetic testing\textsuperscript{20,21} and from static postural testing\textsuperscript{18,19,22,23} to more sport-specific dynamic postural testing\textsuperscript{25,26}. As more research is done it is our aim to be able to better identify the exact cause of CAI and how to better assess it.
Docherty\textsuperscript{25} used unilateral hopping tests to test the relationship between functional performance and CAI. No significant differences were found for the single hop for distance and the up-down hop.\textsuperscript{25} Significant differences, performance deficits, were found, however, for the side hop and the figure-of-8 hop.\textsuperscript{25} What this information brings to the body of knowledge is that these functional tasks potentially place a greater stress, due to the mechanics of how they are performed on the lateral structures of the ankle putting them at greater risk of injury.\textsuperscript{25}

In order to detect reach deficits researchers used the star excursion balance test (SEBT), which is “a functional test that incorporates a single-leg stance on one leg with maximum reach of the opposite leg”.\textsuperscript{23} Athletes with CAI were found to have decreased reach deficits during the star excursion balance test as compared to their own uninjured limb and those individuals without CAI.\textsuperscript{23} What this implies is that those individuals with CAI have decreased dynamic postural control.\textsuperscript{23} Dynamic postural stability is an incorporation of sensory and motor pathways of the central nervous system that allow the body to synchronize together purposeful movements and postural control during locomotion.\textsuperscript{27} Any alteration to these pathways can create a balance dysfunction.\textsuperscript{27} Olmstead states, “dynamic assessment, such as time-to-stabilization measures or the SEBTs, may be better than static postural-control assessment to determine functional deficits in those with CAI”.\textsuperscript{23} This is believed to be true because studies that had looked at static postural control found nothing of significance as far as performance deficits, implying that static postural tests are not challenging to the ankle.\textsuperscript{23}

Brown looked at both a static postural test, stable double leg stance, and a dynamic postural test, double leg stance with perturbation.\textsuperscript{18} What was found was that individuals with CAI did have longer anterior/posterior time-to-stabilization (TTS) in the double leg stance following a perturbation.\textsuperscript{18} TTS is defined as “the time required to minimize resultant ground
reaction forces (GRF) within a range of the baseline GRF while moving from a dynamic to static state”.

Ground reaction forces are the forces that the ground exerts on the body during movement. Ross looked at single-leg jump-landing tests and TTS and identified longer stabilization time in those with CAI. Ross suggests that being able to identify deficits in TTS before returning an athlete to physical activity could prevent recurrent lateral ankle sprains.

Wikstrom looked at the step down and the vertical jump protocols while measuring TTS to determine which is a more effective tool in determining deficits in those individuals with CAI. His results suggest that the jump protocol will better be able to identify dynamic stability deficits in individuals with CAI. There are however, according to Wikstrom, several flaws with using TTS as a means of measuring dynamic postural stability, which is an individual’s ability to maintain balance while moving from a dynamic to static state. One flaw is that when measuring TTS the result is 3 separate measures, anterior-posterior, medial-lateral, and vertical. As beneficial as it may seem to have multiple-force directions, it does not provide a common thread for the 3 directions. As a solution to this problem the Dynamic Postural Stability Index (DPSI) was developed. When tested it was found that the DPSI was at least as accurate as TTS but it can provide a comprehensive measurement of the dynamic postural stability. Wikstrom concluded that, “the DPSI is a more reliable and precise measure of dynamic postural stability than TTS while still incorporating the functional single-leg hop stabilization test and maintaining directional components.” Wikstrom found in one article that individuals with CAI had increased TTS scores during jump landing. There was no significance found between groups for TTS in the medial/lateral direction, however, TTS was longer in the anterior/posterior direction in those individuals with CAI. Furthermore, he finds that individuals with CAI have worse DPSI scores than those without. Individuals with CAI produced higher DPSI scores in the
anterior/posterior direction and also in the vertical direction. Generally, overall those individuals with CAI had higher DPSI scores during a jump-landing protocol. Wikstrom suggested two potential explanations for the observed impairment. It is theorized that those individuals with CAI may take more time to decelerate their center of mass (COM) which in turns causes destabilization of the body. Another theory is that there are motor changes within the ankle associated with CAI forcing those individuals with CAI to be predisposed to recurrent lateral ankle sprains due to using a nonankle strategy. Hass found with his research that during gait initiation (GI) individuals with CAI will shorten their center of pressure (COP) movement towards the initial stepping leg therefore reducing the center of mass (COM) momentum towards the initial stance limb.

Frequently studies look at the dynamic to static movements while the static to dynamic movements are being neglected. As important as the dynamic to static movements are going the other way is just as important during any athletic event. For example, a football wide receiver does not begin the play running; he starts statically on the line and then begins the dynamic movement of running when the ball is hiked. During a basketball game a player may be statically waiting under the basket while a free throw is shot and then has to dynamically move to box out and rebound the ball. Given this more research needs to be done looking at this aspect of athletics, especially with those individuals with CAI. GI challenges a person’s dynamic postural control as it represents a transition from a steady static balance to a continuously unstable gait. Given that initiating gait requires more movement of the center of pressure (COP) and center of mass (COM) than steady state walking, GI is more challenging because it requires a higher level of dynamic balance control and neural adaptations.
Center of Pressure and Center of Mass

COP, the weighted average of all pressures over the surface area in contact with the ground\textsuperscript{35}, is influenced by net ankle movements and hip control, anterior/posterior and medial/lateral, respectively.\textsuperscript{24,34} More specifically, the plantarflexor muscles control the anterior and posterior movements while the hip abductors and adductors control medial and lateral movements.\textsuperscript{24} The COP trace during GI is divided into three segments with two major landmarks.\textsuperscript{36} Segment 1 (S1) begins with the initiation of movement and ends when the COP is most posterior and lateral toward the initial swing limb (landmark 1 (L1)).\textsuperscript{32,36,37} This posterior movement of COP during S1 is what generates the necessary momentum that is needed to initiate gait, whereas the lateral movement of the COP initially is what propels the COM towards the initial stance limb.\textsuperscript{36} Segment 2 (S2) is characterized by the translation of the COP towards the stance limb ending at landmark 2 (L2), the position under than stance limb where COP begins to move forward.\textsuperscript{32,36,37} The final segment, segment 3 (S3), marks the movement from landmark 2 until toe-off of the initial stance limb as the COP translates anteriorl.\textsuperscript{32,36,37}

COM can be defined as “the point in the body that moves in the same way that a single particle would move if subjected to the same external force”, in other words it reflects body position.\textsuperscript{27,34} As gait is initiated the COM will begin to move lateral towards the initial stance leg.\textsuperscript{36,37,38} Then the COM will begin to move anterior at about the same time that L1 is observed.\textsuperscript{36,37,38} COM is measured along with the COP to eliminate measuring the secondary consequences of swaying movements instead of the movement itself.\textsuperscript{37}

COP-COM separation, viewed in the transverse plane, is the separation between the COP and COM at any given time during a movement task.\textsuperscript{34} This distance when measured will give us some insight into postural control.\textsuperscript{37} What is seen is that the greater the separation, the greater
the need for postural control.\textsuperscript{37} Individuals with a balance or proprioceptive deficiencies, such as individuals with CAI, have been shown to shorten this distance in order to maintain or enhance their balance control.\textsuperscript{37} COP-COM separation has already been used as a measuring tool for dynamic postural stability in patients with Parkinson’s disease and the elderly with good results.\textsuperscript{27,34,35,37} This measurement is able to capture the relationship between dynamic stability and momentum generation, suggesting it may serve as an indicator of disability during GI.\textsuperscript{37} The COM is coupled with COP in the transverse plane during quiet stance.\textsuperscript{37} As movement is initiated the COM and COP will uncouple and move in opposite directions to create forward momentum.\textsuperscript{37} Hass\textsuperscript{37} observed the greatest separation just prior to the end of single stance, heel strike minus one (HS\textsuperscript{-1}), of GI making this the portion when COP-COM should be measured. HS\textsuperscript{-1} has been shown to be the most challenging point of GI due to COP and COM being at their most separated point.\textsuperscript{27} Another positive aspect to using COP-COM, as seen through studies done by Corriveau, is that this measurement has good test-retest, interrater reliability, and intrasession reliability.\textsuperscript{35,39}

During GI, there will be ground reaction forces during toe off of the initial swing foot, heel off of the initial stance foot and heel strike of the initial swing foot.\textsuperscript{40} The faster the initiation of gait is the quicker the peak ground reaction force will be reached.\textsuperscript{40} Along with that, the peak ground reaction force itself will increase with a faster GI.\textsuperscript{40}

In order for an individual to perform any desired movement task there needs to be a motor program of the muscles involved to allow the movement to happen. A motor program is “a structured set of central commands that define a temporal relationship of muscle activation”.\textsuperscript{40} GI begins with an inhibition of the soleus in the initial stance limb which is shortly followed by the onset of the tibialis anterior of that same leg.\textsuperscript{40} This action allows the COP and COM to
Researchers believe that these actions are governed by the same central command as they remained invariant across GI velocities. During quiet stance the soleus, along with the hamstrings and gastrocnemius, is tonically active until GI begins when the soleus in the initial swing leg begins to fire frequently. Nearly simultaneously the tibialis anterior of both legs fires to create dorsiflexion. These muscles fired when the gastrocnemius and soleus of the initial stance leg became silent. This series of events causes the COP to move posteriorly. Next, the soleus of the swing leg fires which causes the COP to then move lateral towards the swing foot.

Over many years the research about CAI has progressed in a beneficial manner. We now know that the cause of CAI is not strength or proprioception alone but a combination. Our ability to test individuals with CAI has also improved. We are now better able to more accurately and efficiently test for performance deficits in individuals suffering from CAI. With a strong effort we can continue to better understand the principles behind CAI and better be able to prevent the high recurrence rate of lateral ankle sprains and the unsightly cost to treat them.
References


Appendix B

Hypothesis, Limitations, Delimitations, Assumptions, and Definitions
Research Hypothesis

1. Healthy individuals will have a greater posterior movement of COP during S1 during normal and fast gait initiation than those with chronic ankle instability.

2. Healthy individuals will have a greater posterior velocity of COP during S1 during normal and fast gait initiation than those with chronic ankle instability.

3. Healthy individuals will have a greater M/L movement of COP during S1 during normal and fast GI than those with chronic ankle instability.

4. Healthy individuals will have a greater M/L velocity of COP during S1 during normal and fast GI than those with chronic ankle instability.

5. Healthy individuals will have a greater initial step length during normal and fast gait initiation than those with chronic ankle instability.

6. Healthy individuals will have a greater initial step velocity during normal and fast gait initiation than those with chronic ankle instability.

7. Healthy individuals will have a greater COP-COM separation at HS$^{-1}$ during normal and fast gait initiation than those with chronic ankle instability.

8. These differences between healthy individuals and those with chronic ankle instability will be even greater during fast gait initiation than normal gait initiation.

Limitations

1. Movement restriction due to cords

2. Non-randomized sample

3. Vibrations of sensors because of participants movement

4. Dominant limb and its affects

5. Limited subject selection
Delimitations

1. Hawthorne Effect – lab based setting and movement tasks.

Assumptions

1. Accurate and up-to-date medical records
2. Participant exhibits maximal effort
3. Post assessment calculations are accurate

Definitions

1. Chronic Ankle Instability (CAI) – impaired proprioception, strength, postural control, and neuromuscular control without ligamentous laxity secondary to multiple lateral ankle sprains. 3 or more LAS in a year or 5 or more LAS in a lifetime.
2. Center of Mass (COM) – the point on the body that moves in the same way that a simple particle would move if subjected to the same external force.
3. Center of Pressure (COP) – the point of application where the resultant of all the ground reaction forces act.
4. Heel Strike minus 1 (HS−1) – the last moment in swing phase before the heel strikes the ground.
5. Healthy – an athlete without a previous history of ankle sprains, significant lower extremity injuries, and neurological-vestibular pathology to be used as control subjects in the study.
7. Fast speed gait initiation – as fast as the individual can walk without it being a jog.
Appendix C

Subject Packet
COLLEGE OF HEALTH AND HUMAN SCIENCES

DEPARTMENT OF HEALTH AND KINESIOLOGY

CONSENT TO ACT AS A SUBJECT IN AN EXPERIMENTAL STUDY

1. Title of Project: Dynamic Postural Stability during Gait Initiation in Individuals with Chronic Ankle Instability

   Investigator’s Name: Thomas Buckley, Ed.D., ATC  Phone: (912) 478 - 5268

   Participant’s Name __________________________ Date: __________________________

   Data Collection Location: Biomechanics Laboratory, Georgia Southern University Campus

2. The purpose of this study is to compare the balance, coordination and bodily control of individuals with chronic ankle instability. There will be thirty subjects who participate in this study. The results of this study will help athletic trainers in the evaluation and treatment of chronic ankle instability.

3. You are being asked to participate in this study because you are an adult without a current history of major leg or trunk injury or you have been identified as having multiple ankle sprains. Additionally, you have no history of any nerve, inner ear or balance disorders. Lastly you have no history of head injury in the past six months.

   If you agree to participate in this study you will be asked to attend one testing session that will last about 90 minutes. During the session you will be asked to walk in various directions at both normal and fast pace.

   During the session you will be wearing sensors that will analyze your body position while walking and you will walk across forceplates which will measure the forces under your foot. Additionally, surface electrodes will be on your skin measuring the activity in your muscles. None of these instruments will cause any pain or discomfort nor will any item penetrate the skin. Following the application of the sensors, you will be asked to perform the walking tasks.

   During each of the test trials, we will make several types of measurements concerning your walking and balance abilities. The position of your foot, shank, thigh, and trunk will be made using a special computer system that uses magnetic based sensors to track your body’s motion. Nine sensors will be attached using double sided or elastic tape. Cables will be attached from each of these sensors to a personal computer.
4. The risk assumed during the testing is no greater than you experience during your normal daily activities. I understand that medical care is available in the event of injury resulting from research, but that neither financial compensation nor free medical treatment is provided. I also understand that I am not waiving any rights that I may have against the University for injuries resulting from negligence of the University or investigators. Should medical care be required, you may contact Health Services at (912) 681 – 5641.

5. You will likely receive no direct benefit for participating in this study, however you will be provided your results, once calculated, if you so request. The results of this study may be used to better understand and treat individuals with chronic ankle instability.

6. You will attend one testing session which will last approximately 90 minutes.

7. I understand that all data concerning myself will be kept confidential and available only upon my written request to Thomas Buckley, Ed.D.. I understand that any information about my records will be handled in a confidential (private) manner consistent with medical records. My identity on all records will be indicated by a case number. I will not be specifically mentioned in any publication of research results. However, in unusual cases my research records may be inspected by appropriate government agencies or released to an order from a court of law. All information and research records will be kept for a period of five years after the termination of this investigation.

8. If I have any questions about this research project, I may call Thomas Buckley at (912) 478-5268. If I have any questions about my rights as a research participant in this study it should be directed to the IRB Coordinator at the Office of Research Services and Sponsored Programs at (912) 681-0843 or by email at: oversight@georgiasouthern.edu

9. You will not receive compensation for your participation in this project. You will be responsible for no additional costs for your participation in this project.

10. I understand that I do not have to participate in this project and my decision to participate is purely voluntary. At any time I can choose to end my participation by telling the primary investigator.

11. I understand that I may terminate participation in this study at anytime without prejudice to future care or any possible reimbursement of expenses, compensation, employment status, or course grade except provided herein, and that owing to the scientific nature of the study, the investigator may in his/her absolute discretion terminate the procedures and/or investigators at any time.

13. I understand there is no deception involved in this project.

14. I certify I am 18 years of age or older and I have read the preceding information, or it has been read to me, and understand its contents. Any questions I have pertaining to the research have been, and will continue to be answered by the investigators listed at the beginning of this consent form at the phone numbers given (912-478-5268).
15. I have been provided a copy of this form

Title of Project: Dynamic Postural Stability during Gait Initiation in individuals with Chronic Ankle Instability

Principal Investigator: Thomas Buckley, Ed.D., ATC
2121-C Hollis Building
Georgia Southern University
(912) 478 – 5268
TBuckley@GeorgiaSouthern.edu

Other Investigator: Barry Munkasy, Ph.D.
2105-B Hollis Building
Georgia Southern University
(912) 478 – 0985
BMunkasy@georgiasouthern.edu

Participant Signature Date

I, the undersigned, verify that the above informed consent procedure has been followed.

Investigator Signature Date
Dynamic Postural Stability During Gait Initiation in Individuals with Chronic Ankle Instability

Subject Initials: ___________________________  Subject ID #: ____________

(First  M  Last)

Date of Testing: _____ / _____ / _____

A. Demographic Data
   (1) Subject Date of Birth: _____ / _____ / _____
   (2) Age: _____________
   (3) Gender: _____________
   (4) Year in School:  Freshman  Sophomore  Junior  Senior  Grad Student

B. Injury History
   (1) Have you completed the “Ankle Instability Instrument”?  YES  NO
   (2) Have you ever suffered an injury to either foot, ankle, leg or knee?  YES  NO
      If YES, please describe: ________________________________
   (3) Have you ever had surgery on either foot, ankle, leg, or knee?  YES  NO
      If YES, please describe: ________________________________
   (4) Do you have balance disorders?  YES  NO
      If YES, please describe: ________________________________
   (5) Do you have diagnosed with a metabolic disorder?  YES  NO
      If YES, please describe: ________________________________
   (6) Do you have been diagnosed with a neurological disorder?  YES  NO
      If YES, please describe: ________________________________
   (7) Do you have been diagnosed with a vestibular disorder?  YES  NO
      If YES, please describe: ________________________________
   (8) Are you currently taking any medications?  YES  NO
      If YES, please describe: ________________________________
Ankle Instability Instrument

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

1. Have you ever sprained an ankle? □ Yes □ No
   If yes,
   1a. How many times have you sprained your ankle?
      □ ≤2 times □ 3 – 4 times □ 5 – 6 times □ ≥ 6 times

2. Have you ever seen a doctor for an ankle sprain? □ Yes □ No
   If yes,
   2a. How did the doctor categorize your most serious ankle sprain
      □ Mild (Grade 1) □ Moderate (Grade 2) □ Severe (Grade 3)

3. Did you ever use a device (such as crutches) because you could not bear weight due to an ankle sprain? □ Yes □ No
   If yes,
   3a. In the most serious case, how long did you need to use the device?
      □ 1 – 3 days □ 4 – 7 days □ 1 – 2 weeks □ 2 – 3 weeks □ >3 weeks

4. Have you ever experienced a sensation of your ankle “giving way”? □ Yes □ No
   If yes,
   4a. When was the last time your ankle “gave way”?
      □ < 1 month □ 1-6 months ago □ 6-12 months ago □ 1-2 years ago □ >2 years ago

5. Does your ankle ever feel unstable while walking on a flat surface? □ Yes □ No
6. Does your ankle ever feel unstable while walking on uneven ground? □ Yes □ No
7. Does your ankle ever feel unstable during sports activities? □ Yes □ No
8. Does your ankle ever feel unstable while going up stairs? □ Yes □ No
9. Does your ankle ever feel unstable while going down stairs? □ Yes □ No

Foot and Ankle Ability Measure (FAAM)
Activities of Daily Living Subscale

Please answer every question with one response that most closely describes your condition within the past week. If the activity in question is limited by something other than your foot or ankle, mark not applicable (N/A).

<table>
<thead>
<tr>
<th>Activity</th>
<th>No Difficulty</th>
<th>Slight Difficulty</th>
<th>Moderate Difficulty</th>
<th>Extreme Difficulty</th>
<th>Unable To Do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking on even ground</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking on even ground w/o shoes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking up hills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking down hills</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Going up stairs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Going down stairs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking on uneven ground</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stepping up and down curbs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Squatting</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coming up on your toes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking initially</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking 5 min. or less</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking approx. 10 min.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walking 15 min. or more</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Because of your **foot and ankle** how much difficulty do you have with:

<table>
<thead>
<tr>
<th></th>
<th>No Difficulty</th>
<th>Slight Difficulty</th>
<th>Moderate Difficulty</th>
<th>Extreme Difficulty</th>
<th>Unable To Do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Home Responsibilities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Activities of daily living</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light to moderate work (standing, walking)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy work (push/pulling, climbing, carrying)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recreational activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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%
Foot and Ankle Ability Measure (FAAM)

Sports Subscale

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

<table>
<thead>
<tr>
<th>Activity</th>
<th>No Difficulty</th>
<th>Slight Difficulty</th>
<th>Moderate Difficulty</th>
<th>Extreme Difficulty</th>
<th>Unable To Do</th>
<th>N/A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Running</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Jumping</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Landing</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Starting and stopping quickly</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cutting/lateral movements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low impact activities</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to perform activity with your normal technique</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ability to participate in your sport for as long as you would like</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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 D

Figures
Figure 1 – Exemplar COP trace during normal GI for both HYA and CAI.
Figure 2 – Exemplar COP trace during fast GI for both HYA and CAI.
Figure 3 – Laboratory set-up for GI trials.
Figure 4 – A/P movement of COP during S1 during normal and fast GI.
Figure 5 – A/P velocity of COP during S1 during normal and fast GI.
Figure 6 – M/L movement of COP during S1 during normal and fast GI.
Figure 7 – M/L velocity of COP during S1 during normal and fast GI.
Figure 8 - Initial step length during normal and fast GI.
Figure 9 – Initial step velocity during normal and fast GI.
Figure 10 – COP-COM separation at HS$^{-1}$ during normal and fast GI.