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Influence of Direction on Stepping Parameters and Postural Stability in Individuals with Chronic: The Influence of Walking Velocity

Jennifer Tolson

Influence of Direction on Stepping Parameters and Postural Stability in Individuals with Chronic Ankle Instability

by

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(Under the Direction of Thomas Buckley)

ABSTRACT

Lateral ankle sprains are a common athletic injury accounting for 25-50% of injuries in sports that include running and jumping. Individuals who suffer from a lateral ankle sprain may develop residual symptoms of chronic ankle instability (CAI). CAI research has examined static and dynamic to static movements and unidirectional tasks; however, static to dynamic transitional movements remains largely unexplored in this population. Therefore, the purpose of this study was to evaluate dynamic postural stability during directional gait initiation in healthy young athletes (HYA) and athletes with CAI. There were no significant differences between the two groups for forward and directional gait initiation for center of pressure-center of mass separation at heel strike minus one, posterior and lateral displacement of the center of pressure during S1, step length, step velocity, and posterior and lateral velocity of the center of pressure during S1, We concluded that gait initiation at a 90° step angle may not be a challenging enough task to alter dynamic postural stability in those with CAI.

INDEX WORDS: Chronic ankle instability, Dynamic postural stability, Gait initiation

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Ankle Instability

by

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DEDICATION

I dedicate this to my parents, my sister, and my grandparents who have shown tremendous love and support throughout the process of completing my thesis. Without them none of this would have been possible.

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Chapter 1

Introduction

Lateral ankle sprains (LAS) are a common athletic injury accounting for 25-50% of injuries in sports that include running and jumping, such as basketball, volleyball, soccer, and football.[1] It is estimated that over 9 million LAS occur annually in the United States.[2] Frequently, LAS result in ligamentous laxity, altered proprioception and muscular function, and sensations of "giving away."[3] The most common predisposition to suffering a LAS is the history of at least one previous ankle sprain, with a noted recurrence rate exceeding 70%.[2-4] Approximately 70% of individuals suffering from a LAS may develop residual symptoms of chronic ankle dysfunction.[2]

Chronic ankle instability (CAI) is defined as, "impaired proprioception, strength, postural control, and neuromuscular control with or without ligamentous laxity."[3] Bonnin proposed two theories that concern the relationship between impaired muscle contraction and CAI.[5] He initially suggested that a strong powerful concentric response on the part of the peroneal muscles was needed to fight the inversion lever and prevent the sprain as the foot and ankle are suddenly forced into inversion.[5] This theory, however, was not fully supported by his initial findings; therefore he revised his theory to involve eccentric control of the ankle evertors in an attempt to counter the lateral displacement of the shank during close-chain stance and movement.[5] Vaes also found during a sudden ankle inversion, the peroneals have a short deceleration time causing a less efficient initial passive control of the high inversion speed; therefore, the peroneals do not have the strength or reaction time to prevent LAS.[6] Willems and Kaminski concluded that a combination of proprioception and the lack strength may be the cause of CAI.[7-9] Participants with CAI were found to have less accurate active position sense at a close to maximal inversion, indicating decreased proprioception. Brown found that individuals with CAI appear to have dynamic balance problems during double-leg stance when using time to stabilization.[10] CAI individuals took longer to stabilize in the anterior-posterior direction after the tibial nerve was stimulated.[10] The current literature suggests CAI is the result of impaired proprioception and strength.

Athletes' postural control systems are constantly challenged as they vary movements due to external stimuli from the environment, teammates, and opponents. These challenges require both dynamic to static (e.g. jump landing) and static to dynamic (e.g. boxing out) transitions. Currently, the predominant research has examined CAI in either static only or dynamic to static transitions. McKeon suggested that static balance testing may lack the sensitivity to detect improvements in postural control.[11] In 2005, Ross assessed time to stabilization after a single leg jump landing in participants with CAI and found that time to stabilization was longer for participants with CAI than for those with stable ankles.[12] This finding suggests individuals with CAI may have poor landing strategies and predispose them to further injury.[12] McKeon agreed with Ross and suggested that perhaps this measure may provide a greater insight into postural control alterations.[11] Wikstrom and Willems investigated CAI using single leg hops and found that CAI includes a combination of decreased proprioception and peroneal weakness, indicating that rehabilitation programs need to emphasize both to help prevent CAI.[3,7,13] Surprisingly, the initiation of movement, or static to dynamic transitions, has received limited attention in the literature.

GI is a functional task representing one of the first voluntary destabilizing behaviors observed in the development of a locomotor pattern as the whole body center of mass (COM) transitions from a large to a small base of support.[14] GI challenges the motor control system because it is a volitional transition from a condition of a static stable support to a continuously dynamic unstable postural control during locomotion.[15] Chang determined that the COP-COM separation at the end of the single support phase of locomotion (also known as heel strike minus one or HS^{-1}) during GI was sensitive enough to differentiate healthy individuals from disabled individuals and suggested that the greater the separation of the COP and COM, the greater the need for postural control.[16](Appendix F, Figure 1) Separation of COP-COM is proportional to the COM horizontal acceleration in an ideal inverted pendulum model of the body pivoting around the ankle.[16] Hass suggested that the greater the COP-COM separation, the greater the moment arm for the ground reaction forces to act for momentum generation; therefore, a greater need for dynamic postural control to counteract the increase moment arm as the separation between COP-COM.[17] Hass also found that since the COP-COM separation has the ability to capture the relationship between momentum generation and dynamic stability arising from dynamic postural control, it may serve as an indicator of disability during GI.[17] Therefore, COP-COM separation at HS^{-1} during activities may indicate the subject's toleration to dynamic unsteadiness.[16] Individuals with balance or proprioceptive deficiencies, such as individuals with CAI, might shorten this distance in order to maintain or enhance their balance control.

GI has been utilized to assess postural control in many studies, but they generally have been limited to straight ahead walking.[14-21] In the only investigation of forward GI in individuals with CAI, Wikstrom and Hass found that individuals with CAI appear to alter feed-forward control of GI. However, in addition to forward locomotion, many activities of daily living and sport specific activities require lateral movement; therefore it is surprising that limited research has investigated the effects of direction on GI.[14] Hass suggest that impairments in lateral stability are an important aspect of balance dysfunction as well as falls and older adults are known to have problems turning and moving laterally.[14] Athletes change direction daily while initiating gait in order to block a goal shot in soccer or box out during a basketball free throw. Examining CAI with directional GI may lead to a better understanding of CAI and how to prevent further problems. Recently, Hass found that when initiating gait laterally, transitional frail individuals produced larger and more coordinated movement of the COP in a directionally appropriate manner during laterally directed GI compared to Parkinson's disease individuals; however, young healthy individuals were not tested.[14]

COP is the "weighted average of all the pressures over the surface area in contact with the ground."[18] COM is "the point on the body that moves in the same way that a single particle would move if subjected to the same external force, or the point at which the weight of the body can be considered to act."[19] During GI, the COP and COM each follow a very distant path, or trace. The COP trace has been divided into 3 segments by 2 distinct landmarks.[14] (Appendix F, Figure 2) In order for the COP and COM to begin moving, they first must uncouple.[20] In order to initiate gait, the COP must move posteriorly to generate a forward momentum.[15,17] The first segment (S1) begins with the initiation of movement and ends with COP located at its most posterior and lateral position towards the initiation swing leg.[15,17] This posteriolateral position of the COP is known as Landmark 1.[15,17] As the COP is moving posteriorly and laterally, the COM moves anterolaterally towards the initial stance limb.[20] The second segment (S2) is characterized by a translation of the COP medially towards the initial stance limb ending at Landmark 2, at which point the COP is completely under the initial stance leg.[15,17] During the S2 phase, the COM continues to move anterolaterally towards the initial stance limb. The third segment (S3) extends from Landmark 2 until toe-off of the initial stance leg as COP moves anteriorly.[15,17] The COM continues to move anteriorly during S3, but as the stance leg begins to toe-off, the COM shifts medially slightly towards the initial swing limb to prepare for heel strike of the initial swing leg.[20]

The shift of the COP increases the components of the ground reaction forces anteriorly and towards the initial stance limb, thereby generating forward momentum.[22] The gait initiation motor program, inhibition of the soleus followed by activation of the tibialis anterior, generates the initial momentum necessary for taking a step through the posterior shift of the COP.[20,22] The displacement of the COP influences how fast a person initiates gait and the velocity affects the length of the step the person takes.[22]

The study of GI is a recent approach to assess deficits in postural control impairments in individuals with CAI. Both forward and directional GI studies have revealed alterations in the postural control systems. Directional GI refers to a lateral directed GI, a step at 90° from their initial orientation. Therefore, the purpose of this study is to evaluate dynamic postural stability during directional GI in healthy young athletes (HYA) and athletes with CAI. We hypothesize that individuals with CAI, for both forward and directional GI, will have impaired postural stability demonstrated by an altered COP-COM separation at HS^{-1}, posterior and lateral displacement of COP during S1, step length, step velocity, and posterior and lateral velocity of COP during S1.

Chapter 2

Methods

Participants

A deliberate sample of 28 participants, 14 HYA (8M, 6F) (height = 180.19 ± 7.68 cm, mass = 73.48 ± 14.86 kg, BMI = 22.57 ± 4.08) (Table 1) and 14 with unilateral CAI (8M, 6F) (height = 181.70 ± 9.66 cm, mass = 73.05 ± 14.02 kg, BMI = 21.92 ± 2.49) (Table 2), were recruited from the varsity athletic population at an NCAA Division I university. GI studies have traditionally used sample sizes from 9-59 participants and have found significance.[16,20] The Foot and Ankle Ability Measure (FAAM) was used to categorize a participant's CAI.[23] CAI were determined by 3 or more LAS in the last year or greater than/equal to 5 LAS in a lifetime.[2,3] Control participants were free of any previous medical history of lateral ankle sprains. Exclusion criteria for both groups included: vestibular disorders, inner ear infections within the last 3 months, cerebral concussions within the last year, current delayed onset muscle soreness, presence of metal plates or screws in the body, pacemakers, and history of tibular-fibular fractures or lower extremity dislocations. Participants were matched by gender. Participants provided written informed consent before participating in this study as approved by the university's Institutional Review Board.

Instrumentation

Kinematic data was acquired by an electromagnetic tracking system (Ascension Technologies; Burlington, VT) using the Motion Monitor (Innovative Sports Training, Inc.; Chicago, IL.) commercially available acquisition and analysis software. At the core of the system is a transmitter with three orthogonal coils that are used to create an electromagnetic field.

Sensors in the magnetic field record the magnetic flux and convey the signals to a base computer through cables. The Motion Monitor software calculates sensor position and orientation from data conveyed by the sensors. Kinematic data were collected by the computer at 100 Hz.

Two non-conducting force-plates mounted flush with the floor (Model OR6-5, Advanced Mechanical Technology, Inc., Watertown, MA) were used to collect ground reaction forces and moments. Force-plate signals were amplified and digitized using an analog to digital card (Computer Board DAS 1602-12, Computer Boards, Inc., Middleboro, MA). Signals from the force-plates were sampled at a frequency of 1000 Hz. Ground reaction forces and moments from the force-plates were used to calculate COP. COM was calculated using the Dempster parameters.[24]

Procedures

The participants were tested in the biomechanics lab at Georgia Southern University. Prior to data collection, the participants completed the informed consent materials, Medical History Questionnaire and FAAM questionnaire (Appendix D and E) and had any questions answered.[23] Participants wore athletic shorts, tee-shirts and sneakers. During set-up, sensors were firmly attached to the participants within the capture area of the electromagnetic tracking system of approximately 1.8 m. Six sensors were attached bilaterally to the lower extremities on the dorsum of foot, the medial surface of the tibia, and the lateral thigh. One sensor was placed on the sacrum and another sensor was placed on C7. The lower extremity and sacrum sensors were attached with double-sided tape. Pre-wrap and athletic tape was used to stabilize the sensors after they were attached to participant. An ace wrap was used to stabilize the sacrum sensor. The C7 sensor was attached with a Velcro shoulder strap. The 9th sensor was used to calculate the centers of the ankle and knee joints with respect to the secured foot, shank, and thigh sensors. The hip joint centers were calculated using the Leardini method.[25]

Participants had the opportunity to practice the tasks until they were comfortable with the set-up. They began by standing on a single force-plate with a self-selected stance width. Once the stance width was chosen, their position was marked to ensure consistency across trials. The participants initiated gait in response to a verbal cue by stepping with the non-CAI foot. Therefore, the CAI limb was considered the initial stance foot. Participants walked across on the lab floor towards a marker place at eye level approximately 3 m away. For the safety and comfort of the participants, a research assistant held the sensor cords and ensured the cords did not contact either force-plate and get in the path of the participant during the trial. The participants walked across the two force-plates for the 0^{o} direction, forward GI, and then walked from the force-plate they were standing on, to a second force-plate for the 90^{o} directional movement, lateral GI (Appendix F, Figure 3 and 4). Five trials for each task were successfully completed. Healthy participants initiated gait with the limb that corresponds with their matched CAI participants.

Data Analysis

The following variables were analyzed to assess for dynamic postural instability during forward and directional GI.

COP-COM separation at HS^{-1}. Separation of COP and COM was calculated from the resultant displacement between the projection of the COM in the transverse plan and the COP.[20] COP-COM Separation at HS^{-1} was measured in centimeters (cm).

Posterior displacement of the COP during S1. The posterior displacement of COP during S1 was measured from movement initiation (first change in medial/lateral ground reaction forces (mean + 2 std)) to the most posteriolateral position of the COP. The posterior displacement was along the z-axis of the force-plates. This was measured in centimeters (cm).

Lateral displacement of the COP during S1. The lateral displacement was measured from movement initiation (first change in medial/lateral ground reaction forces (mean + 2 std)) to the most posteriolateral position of the COP. The lateral displacement was along the x-axis of the force-plates. This was measured in centimeters (cm).

Step Length. Step length was the displacement of the initial step, from initial heel position of the initial stance foot to heel strike of the initial swing foot (the moment when the first vertical ground reaction force on the second force-plate occurs) Step length was measured in meters (m).

Step Velocity. Step velocity was step length divided by the time it takes initial step to heel strike of the initial swing foot and was measured in meters per seconds (m/s).

Posterior velocity of the COP during S1. The posterior velocity was calculated by dividing the posterior displacement of the COP during S1 by the time over which the displacement took place. This was measured in centimeters per seconds (cm/s).

Lateral velocity of the COP during S1. The lateral velocity was calculated by dividing the lateral displacement of the COP during S1 by the time over which the displacement took place. This was measured in centimeters per seconds (cm/s).

Statistical Analysis

Data was collected on seven dependent variables including 1) COP-COM separation at HS^{-1}, 2) posterior displacement of COP during S1, 3) lateral displacement of COP during S1, 4) step length, 5) step velocity, 6) posterior velocity of COP during S1, and 7) lateral velocity of COP during S1. Given that each of these variables was assessed on two tasks, forward GI and directional GI, 14 independent t-tests were conducted to assess mean differences between HYA and CAI groups on each dependent variable. A priori alpha was set at .05 for all tests. Bonferoni correction was not employed given the exploratory nature of the study.

Chapter 3

Results

Between Group Comparisons

All participants were able to complete the experimental trials without any difficulties. There were no significant differences for age (p=.75), height (p=.65), weight (p=.94), ASIS height (p=.68), and BMI (p=.62). (Table 1 and 2)

Forward Gait Initiation

There were no significant differences during forward GI between HYA and CAI for COP-COM separation at HS^{-1} (p=.24), posterior displacement of COP during S1 (p=.12), lateral displacement of COP during S1 (p=.85), step length (p=.36), step velocity (p=.36), posterior velocity of COP during S1 (p=.15), and lateral velocity of COP during S1 (p=.60). (Table 3)

Directional Gait Initiation

There were no significant differences during directional GI between HYA and CAI for COP-COM separation at HS^{-1} (p=.96), posterior displacement of COP during S1 (p=.99), lateral displacement of COP during S1 (p=.57), step length (p=.84), step velocity (p=.27), posterior velocity of COP during S1 (p=.96), and lateral velocity of COP during S1 (p=.29). (Table 3)

Chapter 4

Discussion

The purpose of this study was to assess dynamic postural stability during directional GI in individuals with CAI. The principle finding of this study was no significant differences between groups for the measures in question. We are left to conclude that neither forward GI nor directional GI is a sufficiently challenging task to identify impairments in dynamic postural stability in individuals with CAI.

Research on GI and dynamic postural control has suggested that the combined analysis of the COP and COM movements during quiet stance and dynamic activity would provide insight into the assessment of balance as compared to analyzing either variable alone.[17] The COP-COM separation at HS^{-1} has been proposed as a variable sensitive to changes or impairments in postural stability.[17] In our study, we found no significant differences for the COP-COM separation at HS^{-1} for HYA and CAI during forward (23.4 cm and 21.7 cm) and directional GI (33.6 cm and 33.5 cm). (Appendix F, Figure 5) Previous investigators have found the COP-COM separation at HS^{-1} during forward GI for healthy young adults is approximately 23 cm, for young elderly is 21 cm, and for elderly with disability is about 16 cm.[26-28] There is a higher demand placed on the postural control system when the COP-COM separation at HS^{-1} is greater.

Posterior displacement of the COP during S1 period generates the forward momentum needed to initiate gait.[14] As people age or become disabled, there is a reduction in the magnitude of the posterior COP displacement during S1 within GI.[14] Despite not reaching statistical significance, we noted a 21% reduction in the posterior translation of the COP (4.8 cm and 3.9 cm, p=.12) between HYA and CAI groups. (Appendix F, Figure 6) These findings are consistent with a previous investigation which found a posterior translation of 4.7 cm in HYA.[21] In elderly and disabled populations, this posterior displacement has ranged from as little as 2.7 cm in Parkinson's disease patients to 3.5 cm in a healthy elderly population suggesting that there is an alteration in the control mechanism responsible for shifting the COP posteriorly which progressively deteriorates with disability and aging.[12,21] The posterior displacement of the COP is the result of the GI motor program whereby the tibialis anterior (TA) fires immediately following the relaxation of the soleus (SOL).[29] Therefore, a diminished TA activation pattern will likely reduce the posterior displacement of the COP. Despite what the literature has found between PD and transitionally frail individuals for posterior displacement of COP, our results suggest it is likely that CAI do not have the same impairment in the motor program.

The lateral displacement of COP, which is controlled by the muscle activation of the gluteus medius, propels the COM towards the initial stance limb.[29] In this study there were no differences between HYA and CAI groups for lateral displacement of the COP during S1 (4.0 cm vs. 3.9 cm). (Figure 6) These findings for both groups fell within the previously established range of 2.9 to 4.5 cm seen in HYA and were substantially greater than previously reported in elderly, transitionally frail, and PD patients (1.8-2.5 cm).[14] We likely did not find significance because the lateral COP displacement is largely based on gluteus medius activity and it is unlikely that CAI injury impairs the activation of the gluteus medius.

Surprisingly, there is limited research available that describes laterally directed GI.[14] Hass found that during directional GI the COP moves posterior and towards the initial swing foot like in forward, but the magnitude of the posterior displacement is reduced.[14] This was not surprising since forward momentum is not as relevant in the lateral directed initiation, whereas the momentum generation in the intended direction of movement (lateral) should be amplified.[14]

In our study, we found no differences in the posterior displacement of the COP between CAI and HYA (0.37 cm and 0.38 cm, p=.99) or lateral displacement of COP (0.55 cm and 0.66 cm, p=.57). (Appendix F, Figure 7) Hass found that PD individuals reduce the magnitude of the posterior displacement of COP (2.1 cm) during a lateral step less than transitionally frail (1.5 cm).[14] To explain this observation, it's suggested that PD individuals may produce minimal postural adjustments as a result of deficits in the ability to generate propulsive forces or as an attempt to simplify the motor act.[14] During forward GI the literature indicates that the older or more disabled you become the greater you restrict your posterior COP movement, however the limited research on directional GI this suggests this movement may be counterproductive. The PD and transitionally frail individuals inappropriately scale the motor program during directional GI, whereby the HYA and CAI individuals perform the task in a more efficient manner by not generating unneeded forward momentum, which is counterproductive to the goal of the task.

Since we found no differences in the posterior and lateral displacements of the COP, we not surprised about not finding differences with step length for forward (0.6 ± 0.1 m and 0.6 ± 0.2 m) or directional (0.4 ± 0.1 m and 0.4 ± 0.1) GI. (Appendix F, Figure 8) The GI motor program generates the initial momentum necessary for taking a step through the posterior shift of the COP.[22] The displacement of the COP influences how fast a person initiates gait and the velocity affects the length of the step the person takes.[22]

Before the COM begins to move, the COP must shift posterior and towards the initiation swing limb. This shift of the COP increases the components of the ground reaction forces anteriorly and towards the initial stance limb, thereby generating momentum forward.[22] The GI motor program generates the initial momentum necessary for taking a step through the posterior shift of the COP.[22] Polcyn found that posterior velocity of the COP was highly correlated with walking speed.[22] She found that a decrease in posterior COP shift in the elderly (0.78 ± 0.12 cm) as compared to a young population (0.88 ± 0.07 cm), caused a decrease in the step velocity.[22] She suggested this could be attributed by an imbalance in the motor programming. In this study, we found no significant differences between HYA (0.5 ± 0.1 m/s and 0.4 ± 0.1 m/s) and CAI (0.5 ± 0.1 m/s and 0.3 ± 0.1 m/s). (Appendix F, Figure 9)

After a systematic review of postural control and lateral ankle instability, McKeon concluded that there are postural control deficits in those with CAI as compared to HYA, using tests like single leg stance, time-to-stabilization, and Star Excursion Balance Test.[30] Brown found that individuals with CAI took longer to return to a stable state as compared to healthy, providing evidence for the effects of CAI on sensorimotor system.[10] Olmsted found deficits in the proprioception between CAI and controls using the Star Excursion Balance Test and concluded that it’s an effective test for detecting deficits in individuals with CAI.[31] Wikstrom found that the dynamic postural stability index can be used in conjunction with a functional single-leg hop stabilization test to detect dynamic postural stability in CAI.[32] While impairments in postural stability have been well documented in the CAI literature, there seems to be agreement that tasks that are static and dynamic to static can detect deficits, but static to dynamic tasks may not be challenging enough.

Like all research, there are limitations to this study. Our decision not to differentiate specifically between functional and mechanical instability may have limited our findings. This may have limited our results because it is possible that only one of these instabilities may affect dynamic postural stability. It is possible the participants may have restricted their movement, even though a research assistant held the cords and allowed appropriate amount of slack constantly. By restricting their movements, the participants may have used a different motor programming which could affect the dynamic postural stability. Our measurements were also dependent upon the electromagnetic system and its limitations. The electromagnetic system only has a 1.8 m capture range and COM calculations could vary based upon the accuracy of the joint measurements. As a participant comes close the edge of the capture zone that the data may be bad which can affect the results. Data collection can also be affected by vibrations of the electromagnetic sensors during participant's movement. The vibrations of the sensors can add unwanted noise to the data collected which can affect results. The results of our study could have also been limited by the power results found an average observed power of 0.146 which is well below an appropriate power value of 0.8. To achieve a strong power, we would have needed to have 134 participants in each group.

Future research should continue to study postural instability during various directions in both HYA and CAI subjects in order to address some of the limitations of our study. Future studies may also consider looking at the difference between mechanical and functional CAI and directional GI to see if there are any affects on dynamic postural stability. Various speeds during 90° step angle with GI may also be investigated, as it could be a more challenging task on the dynamic postural stability. EMG testing of the lower extremity muscles should also be studied to assess the motor programming that controls the COP displacement. Another future research idea may be add a second task (e.g. dual task) to the testing procedures and see if dynamic postural stability. Dual task trails could be interesting to study along with CAI because athletes have to think about other things that are occurring on the field while playing and it may affect dynamic postural stability.

According to the results of our study, there appears to be no changes in dynamic postural stability during directional GI for those with CAI compared to HYA. This suggests that directional GI may not be a challenging enough task to affect dynamic postural stability in those with CAI. Despite noted postural instabilities associated with CAI during forward GI, surprisingly we found no deficits in postural instabilities with CAI during directional GI.

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APPENDIX A

Research Hypothesis

1) Healthy young individuals will have a difference in COP-COM separation at HS^{-1} during a) forward and b) directional GI than those with chronic ankle instability.
2) Healthy young individuals will have a difference in posterior displacement of the COP during S1of a) forward and b) directional GI than those with chronic ankle instability.
3) Healthy young individuals will have a difference in lateral displacement of the COP during S1 of a) forward and b) directional GI than those with chronic ankle instability.
4) Healthy young individuals will have a difference in posterior velocity of the COP during S1of a) forward and b) directional GI than those with chronic ankle instability.
5) Healthy young individuals will have a difference in lateral velocity of the COP during S1 of a) forward and b) directional GI than those with chronic ankle instability.
6) Healthy young individuals will have a difference in step length during a) forward and b) directional GI than those with chronic ankle instability.
7) Healthy young individuals will have a difference in step velocity during a) forward and b) directional GI than those with chronic ankle instability.

Limitations

1) The participants were selected from a convenience sample of both female and male participants, recruited within a single university in the southeastern United States.
2) The electromagnetic tracking system requires the use of cords to transmit the information from the sensors to the computer so it may cause movement restrictions.
3) The system requires manual location of joint lines to calculate joint centers which may affect the accuracy of measurements due to multiple raters.
4) Vibration of the electromagnetic sensors during participant's movement.

5) An average observed power value of 0.146.

Delimitations

1) Participants were within the ages of 18 and 26 years old.
2) Participants were all physically active individuals
3) The electromagnetic tracking system only has a 1.8 m capture zone to collect reliable data in.
4) While all tasks simulated GI activity, tests were carried out in a controlled lab setting, where the participants had prior knowledge to the GI being performed.
5) Any participant with a previous history of ankle sprains, surgery or, fracture to either lower extremity were unable to participant.

Assumptions

1) Participants were truthful when reporting their medical history and activity level.
2) Participants gave maximum effort on every trial during every task.
3) There were no gender differences among the variables.
4) Data collection instruments maintained calibration throughout the experiment.
5) All post assessment calculations were accurate for every trial for every task.

Definitions

1) Chronic Ankle Instability (CAI): impaired proprioception, strength, and postural and neuromuscular control with or without ligament laxity.
2) Center of Pressure (COP): the point of application where the resultant of all the ground reaction forces act.
3) 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.

4) Heel Strike minus one (HS^{-1}): the last moment in swing phase before heel strike.

5) Healthy: an athlete without a previous history of ankle sprains, significant lower extremity injuries, neurological-vestibular pathology to be used as control participants in the study.

APPENDEX B

Literature Review

Anatomy and Physiology

The stability of the ankle joint is proved by 3 major contributors: the congruity of the articular surfaces when the joints are loaded, the static ligamentous restraints, and the dynamic stabilization from the musculotendinous units.[1]

The lower leg, which lies between the knee and the ankle, contains two bones: the tibia and the fibula. The distal portions of the tibia and the fibula form the ankle joint along with the talus.[2] The calcaneus does not help form the ankle joint, which is created by the talocrural and subtalar joints, but it plays a critical role in the function of the joint.[2]

The tibia is the second longest bone in the body and is the principle weight-bearing bone on the lower leg.[2] The tibia is a triangularly shaped bone in the upper two-thirds but is rounded in the lower third.[2] In the lower third of the tibial shift is where the most pronounced change occurs. This change produces an anatomical weakness.[2] The shaft of the tibia has 3 surfaces: posterior, medial and lateral. The lateral and posterior surfaces are covered by muscles that help move and support the ankle joint; the medial surface is subcutaneous.

The long and slender fibula is located on the lateral aspect of the lower leg. The main function of the fibula is to provide an attachment site for muscles of the lower leg.[2] The distal ends of both the tibia and the fibula are referred to as the medial malleolus and the lateral malleolus, respectively. The lateral aspect of the ankle joint has greater stability than on the medial aspect due to the bony arrangement of the tibia and the fibula.[2] The lateral malleolus of the fibula extends further distally than the medial malleolus creating the greater stability.[2]

The talus is the link between the lower leg and the foot and it is the main weight-bearing bone of the ankle joint. It is located superficial to the calcaneus and it receives the articular surfaces of the tibia and the fibula.[2] The calcaneus does not form the ankle joint, but it is important because it provides attachment sites for major ligaments that support the ankle and the Achilles tendon.

The ankle joint is comprised of 3 articulations: the talocrural joint, the subtalar joint and the distal tibiofibular joint. These 3 articulation work together to coordinate rearfoot movement, which occurs in all 3 cardinal planes: sagittal-plane motion (plantarflexion-dorsiflexion), frontal-plane motion (inversion-eversion), and transverse-plane motion (internal and external rotation).[1] The coordinated movement of the 3 joints allows the rearfoot to move about an axis of rotation oblique to the long axis of the lower leg instead of an isolated motion within the individual planes.[1] Due to the oblique axes of the subtalar and talocrural joints, rearfoot motion does not occur strictly in the cardinal planes which cause a coupling of the rearfoot motion that best can be described as pronation and supination.[1]

The talocrural joint is a synovial joint[3], created by the articulation of the distal end of the tibia, the distal end of the fibula, and the dome of the talus. The talocrural joint is also classified as a hinge joint.[2] In the hinge joint, the articular surfaces are moulded to each other in such a manner as to permit motion only in one plane, forward and backward, the extent of motion at the same time being considerable.[2] The axis of rotation of the talocrural joint passes through the medial and lateral malleoli.[77] The axis is slightly anterior to the frontal plane as it passes through the tibia but slightly posterior to the frontal plane as it passes through the fibia.[77] The bony arrangement is often referred to as the ankle mortise.[2] The ankle mortise is the tibiofibular socket formed by the plafond (vault), the tibial malleolus and the fibular malleolus. The ligaments that support the talocrural joint are the anterior talofibular ligament (ATF), posterior talofibular ligament (PTF), calcaneofibular ligament (CF) and the deltoid ligaments. The ATF originates off the anterolateral surface of the lateral malleolus and inserts on the talus.[4] The ATF resists the motion of inversion of the talocalcaneal unit in the plantarflexed position and it also limits the anterior translation of the talus on the tibia.[4] The PTF originates from the posterior aspect of the lateral malleolus and runs inferior and posterior to attach to the talus and calcaneus.[4] The PTF limits the posterior translation of the talus on the tibia.[2, 4] The third lateral ligament, the CF, originates from the outermost portion of the lateral malleolus and inserts on the calcaneus.[4] The CF is the primary resistant of talar inversion within the midrange of talocrural motion.[4]

The deltoid ligament is a strong, flat, triangular band that originates from the medial malleolus and inserts to the talus, the calcaneus, and the navicular.[4] The deltoid ligament is comprised of four ligaments: the anterior tibiotalar (ATT), the tibiocalcaneal (CT), the posterior tibiotalar (PTT), and the tibionavicular (TN).[4] These ligaments provide the medial static ligamentous support of the ankle joint.

The subtalar joint is formed by the articulations between the talus and the calcaneus. Due to the shapes of the talus and calcaneus, the subtalar joint has 2 separate articulating surfaces that function together.[3] In the anterior portion of the subtalar joint, the articular surface of the calcaneus is concave and the surface of the talus is convex.[3] In the posterior portion of the subtalar joint, the articular surface of the calcaneus is convex and the articular surface of the talus is concave.[3] The subtalar joint has two separate cavities that share a common axis of rotation.[77] The axis is an oblique axis of rotation, which averages a 42° upward tilt and 23° medial angulation from the perpendicular axes of the foot.[77] The subtalar joint is supported by a complex ligamentous support structure which is separated into 3 groups: deep ligaments, peripheral ligaments and the retinacla.[1] The deep ligaments, the cervical and interosseous ligaments, stabilize the subtalar joint and form a barrier between the anterior and posterior joint capsule.[1] The cervical ligament runs anterior and lateral to the interosseous ligament and runs from the cervical tubercle of the calcaneus anteriomedially to the talar neck and resists supination.[1] The interosseous ligament originates on the calcaneus just anterior to the posterior subtalar joint capsule and runs superiomedially to its insertion on the talar neck and resists supination and pronation.[1] The peripheral ligaments include the calcaneofibular ligament (CFL), the lateral talocalcaneal ligament (LTCL) and the fibulotalocalcaneal ligament (FTCL).[1] The LTCL runs parallel and anterior to the CFL and only crosses the posterior subtalar joint.[1] It helps prevent excessive supination of the subtalar joint.[1] The FTCL is also known as the ligament of Rouviere.[1] The FTCL runs from the posterior surface of the lateral malleolus to the posteriolateral surface of the talus and then to the posteriolateral calcaneus and assists in resisting excessive supination.[1]

The distal tibiofibular joint, which is a syndesmosis joint, is the articulation between the tibia and fibula, which is stabilized by the anterior and posterior inferior tibiofibular ligaments and the thick interosseous membrane. The distal tibiofibular joint allows only limited movement between the two bones, but accessory gliding at this joint is crucial to normal mechanics throughout the entire ankle complex.[1] The involuntary motions of anterioposterior glide and slight spreading of the mortise occur at the distal tibiofibular joint.[77] The fibula glides superiorly during dorsiflexion and inferiorly during plantarflexion.[77] The structural integrity of the distal tibiofibular joint is necessary to form the stable roof for the talocrural joint.[1]

The musculature that provides dynamic stability and movement for the ankle joint are external to the joint itself. The muscles originate in the lower leg, across the ankle joint and insert on the bones of the foot. The lower leg is divided into 4 compartments that contain muscle and neurovascular structures that are bound by fascia.[2, 4]

The anterior compartment consists of the tibialis anterior, the extensor hallucis longus, the extensor digitorum longus, the peroneus, the deep peroneal nerve and the anterior tibial artery. The anterior tibialis is the primary mover for ankle dorsiflexion and subtalar joint inversion. The other anterior muscles assistant with ankle dorsiflexion, but are primarily responsible for toe extension.

The lateral compartment contains the three peroneal muscles: the peroneus longus, the peroneus brevis, and the peroneal tertius. The superficial peroneal nerve and the peroneal artery form the neurovascular bundle within the lateral compartment.[2, 4] The peroneals are strong evertors of the foot and contribute to plantarflexion of the ankle.

The superficial posterior compartment houses the gastrocnemius, the soleus, the plantaris, the tibial nerve and the posterior tibial artery. The gastrocnemius and the soleus have a common insertion on the calcaneus via the Achilles tendon.[2] These muscles are the prime movers during plantarflexion, but since the gastrocnemius is a 2-joint muscle it is mostly involved with knee extension.

The posterior tibialis, the flexor digitorum, and the flexor hallucis longus are within the deep posterior compartment. According to Starkey, the deep posterior compartment does not contain a neurovascular bundle, whereas others say that the posterior tibial artery lies within the deep posterior compartment.[2,4] The posterior tibialis muscle is the only muscle that acts primarily on the ankle. It is the primary adductor of the forefoot and assists in plantarflexion and inversion. The other muscles provide secondary assistance for plantarflexion and inversion of the ankle.

The ankle is formed by the tibia, fibula, and talus. The articulations of the 3 bones create 3 joints: the talocrural, the subtalar and the distal tibiofibular joints. The ankle joint is stabilized by static and dynamic structures.

Pathophysiology

Frequency/cost

Lateral Ankle Sprains (LAS) are among the most common injuries in athletics.[1, 5-15] It has been estimated that between 23,000 and 27,000 ankle sprains occur daily in the United States, which is an estimated number of 8 to 10 million sprains a year.[5, 8, 16] Due to the frequent nature of LAS and the medical care needed to treat them, in 2003 it was estimated to cost the United States $3.65 billion to treat LAS annually.[17, 18] LAS often occur in sports that include running, jumping and landing, such as basketball, volleyball and soccer.[7, 10] Of those who suffer LAS, it is estimated that 55-56.8% of them will not seek medical care.[8, 16] The recurrence rate for LAS is between70-80%.[1, 8-9, 16, 19-20, 77] Between 40-75% of those who sprain their ankle will report having residual symptoms that include pain, repeated sprains and episodes of "giving way" 6-18 months after initial injury.[8-9, 19, 21] Approximately 40% of those who suffer LAS will be affected by CAI.[10, 22]

LAS commonly occur during the initial contact of the rearfoot during gait or landing from a jump.[16] Jump landings are responsible for about 45% of all ankle injuries.[16] Of those 45%, half occurred as a result of landing half of the foot on the playing surface and the other half on another player's foot.[16] The most common mechanism of injury is excessive supination of the rearfoot about an external rotated lower leg.[1, 3] The lateral ankle ligaments are most commonly the ones affected with this mechanism of injury due to the increase in torque caused by the excessive inversion coupled with external rotation.[1] The ATF is the most common ligament injured with LAS, followed by the CF and PTF.[1] When the ATF ligament is sprained it allows for increase internal rotation of the rearfoot and leads to further stress on the remaining intact ligaments, which is commonly referred to as "rotational instability."[1] Rotational instability is commonly overlooked with LAS.[1] The PTF is most commonly injured with more severe LAS and is often has an associated fracture or dislocation or both.[1]

What is CAI?

Chronic ankle instability (CAI) has been defined as, "altered mechanical joint stability due to repeated disruptions to ankle with resultant perceived and observed deficits in neuromuscular control."[20] CAI has been linked to two probable causes: mechanical instability (MI) and functional ankle instability (FAI).[1] Mechanical instability and FAI have been found not to be mutually exclusive, but likely have some overlap.[1, 8] A review of literature found that only 42% of FAI was associated with mechanical instability and only 36% of mechanical instability was associated with FAI.[1, 8]

Mechanical instability is referred to as anatomical changes, most notably joint laxity of the lateral ligaments and capsule.[1, 8- 9] There are several changes that lead to mechanical instability, including pathological laxity or hypermobility, impaired arthokinematics or hypomobility, the development of degenerative joint disease and synovial changes.[1] These anatomical changes may happen in combination or isolation.[1]

Pathological laxity is often the result of ligamentous damage.[1] The severity of pathological laxity depends on the amount of ligamentous damage to the lateral ligaments.[1] It can be assessed with a physical examination, stress radiographs, and instrumented arthrometry.[1]

Pathologic laxity is often present in individuals with CAI, 11% of healthy individuals also have asymmetric ankle laxity as assessed by the anterior drawer and talar tilt tests.[1] The result of pathological laxity is hypermobility and an increase in the accessory motion available at a joint.[77] Decrease accessory motion of a joint indicates an enlargement of the neutral zone. The neutral zone is the area of the joint that accessory motion is possible without ligamentous tensioning.[77] Further strain is placed on the injured ligaments due to the increase motion and it may lead to the axis of rotation to become more anterior or posterior in the frontal plane.[77]

Impaired arthokinematics can be caused by both a positional fault at the inferior tibiofibular joint and Hypomobility.[1] The positional fault, in individuals with CAI, is when the distal fibula, the lateral malleolus, is displaced inferiorly and anteriorly from it is original position.[1] If the lateral malleolus is fixed in this position then the ATF may be more relaxed in this position.[1] As a result of the increased slack, the talus is allowed to move through a greater range of motion when the rearfoot starts to supinate before the ATF becomes taut.[1] This may result in repeated bouts of LAS due to episodes of recurrent instability.[1]

Hypomobility is defined as, “the diminished range of motion” of a joint.[1] Hypomobility is thought to be a predisposition to lateral ankle sprains because if the talocrural joint is not able to fully dorsiflex, it will not reach its closed-packed position during the stance phase of walking.[1] If the closed-packed position is not reached the ankle joint will be able to invert and internally rotate more easily.[1] Although the decrease in dorsiflexion ROM can be attributed to a tight gastrocnemius-soleus complex, more often the decrease is likely due to limitations in the accessory joint movement.[77] The abnormal restrictive barrier to accessory movement changes the pattern of movement of the axis of joint rotation. Abnormal stress is placed on the ligaments due to the axis becoming slightly anterior to the lateral malleolus as it passes through the tibia and fibula.[77]

Mechanical instability may be also caused by synovial impingements and degenerative changes of the ankle joint. Synovial impingements are caused by hypertrophic synovial tissue and inflammation in the talocrural and posterior subtalar joint capsules.[1] Hertel found that of those who required surgery for lateral ankle instability, 67% had anterolateral impingement syndrome of the talocrural joint and 49% had talocrural synovitis.[1] Additionally, individuals undergoing surgery for ankle-ligament repair were greater than 3 times more likely to have osteophytes than those with asymptomatic ankles. Osteophytes are the overgrowth of bone tissue or small round lumps of extra bone that grows around joints. It is unclear whether degenerative changes are in response to structural predispositions or to repeat bouts of ankle instability that lead to recurrent LAS.[1]

FAI is defined as, "impaired proprioception, strength, and postural and neuromuscular control without ligamentous laxity."[8-9, 16, 23] FAI has also been defined based on the athlete's subjective complaint of the ankle "giving way."[6-7, 21, 24-26] FAI has been established by quantifying deficits in ankle proprioception, nerve-conduction velocity, postural control, cutaneous sensation, neuromuscular response times, and strength.[1] FAI has been studied in both clinical and laboratory settings to detect and explain deficits in athletes. These deficits have been examined through proprioception, muscle strength and postural control; however most of these studies were done from a static state or a dynamic to static state. [1, 5-10, 16-17, 19-35]

Studies have found that those prone to repetitive ankle sprains have impaired proprioception at the ankle on measures of kinesthesia and active replication of joint angles.[1] The clinical relevance of these deficits is still not understood at this time according to Hertel.[1] Hertel found that impaired neuromuscular-recruitment patterns have been found in individuals with a history of repetitive LAS.[1] Due to mixed methodologies, there are conflicting results on the reflexive response times of the peroneal muscles. They found that the peroneal response may be impaired in CAI due to impaired proprioception, slowed nerve-conduction velocity or central impairments in neuromuscular-recruitment strategies.

Strength

Strength was originally thought to be the cause of CAI, but current research has found that strength does not have an affect. The peroneals have been the most studied muscles because they were thought to help control LAS.[26, 28, 31- 32] However, studies have shown that the peroneals fire too late during a LAS that they do not help prevent or control it.[26, 28, 31- 32] Strength is an important consideration during rehabilitation, but it should not be the main focus. During Kaminski's review, he found 2 theories that concern the relationship between muscle weakness and CAI.[28] The first theory was proposed in 1950 by Bonnin suggested that a strong powerful concentric response on the part of the peroneal muscles was needed to fight the inversion lever and prevent the sprain as the foot and ankle are suddenly forced into inversion.[28] Bonnin mentioned that in untrained individuals, a false step may catch the weak muscles "off guard", meaning the forces have overcome the resistance of the muscles.[28] He also added that frequent sprains due to excessive strain on the ligaments may be caused by added leverage. This added leverage could possibly due to the rotation away from the midline of the joint. The development of the muscular control by the peroneals is encouraged by Bonnin to help limit the rotation away from the midline.[28] The second theory was developed when more recent research was not able to support the finding of weakness in the evertors. The second theory involved eccentric control of the ankle invertors in an attempt to counter the lateral displacement of the lower leg during close-chain stance and movement.[28]

Vaes looked at the reaction timing of the peroneal muscles during a sudden ankle inversion.[31] They concluded that with the shorter first deceleration there is possible higher inversions speed in unstable ankles because the initially passive control is shown to be less efficient in unstable ankles, which causes a very high inversion speed.[31]

As researchers were finding that strength may not be the primary cause of CAI, they started to examine strength along with proprioception together. They found that the instability group was significantly less accurate with active position sense, using a Biodex, at a position close to maximal inversion compared to the controls. The instability group also had significantly lower relative eversion muscle strength. Willems concluded that CAI may be caused by a combination of diminished proprioception and evertor muscle weakness.[32] Kaminski found that strength and proprioception either alone or combined had no effect on the kinetic measurements.[26] What these studies found were that strength and proprioception alone or combined do not have a big impact on CAI.

Proprioception

Proprioception is defined as "the ability to determine the position of a joint in space."[2] Recently it has been suggested that proprioception deficits may be the primary cause of CAI.[22] Transitions from double-leg to single-leg stance, with eyes open and eyes closed, the results showed that participants with CAI activated their muscles later at the ankle, hip and in the hamstring muscles compared to control participants.[22] The results showed that individuals with CAI initiated muscle activity in the more proximal regions of the hip and knee, while the ankle muscles are actived last.[22] These results suggested that the muscles around the ankle are not they only ones active with unstable ankles. Van Duen also found that there was less variability in muscle activations patterns between test conditions in CAI compared to control. This could mean that control participants are able to modify their muscle activation pattern according to the changing situation, whereas participants with CAI are less flexible in the selection of an adequate response to the disturbance of postural balance.[22] With this information, treatment for CAI would broaden to incorporate the whole lower extremity and the trunk to stop help with the activation patterns.[22]

What's been tested?

Manual Muscle Tests

Bosein in 1955 reported that peroneal weakness was the most significant factor contributing to recurrent ankle sprains.[36] Manual muscles tests (MMT) revealed peroneal weakness in 22% of the 133 ankles examined and of the 35 injuries associated with both residual changes and ankle symptoms, 66% had peroneal weakness.[36] Overstretching of the peroneal muscles, disuse atrophy, or both are what caused the weakness. In Kaminski's review, he found that only 43% of the symptomatic ankles that were examined by MMT of the peroneals showed some degree of weakness.[28] These results were concluded that peroneal weakness was one causal factor that could be easily treated. Kaminski concluded in another study that he conducted that MMT provided less accurate measure and do not reflect the true dynamic nature of the inversion-eversion subtalar joint motion.[37]

Single Leg Balance

Brown used tibial nerve stimulation as perturbations to test dynamic balance deficits between individuals with stable ankles and CAI.[21] Brown analyzed the time-to-stabilization (TTS) in the A/P and the M/L.[21] The results found the A/P TTS was the only significant difference between the two groups. The CAI group took 0.78 ± 0.12 sec to return to a stable range of ground reaction forces (GRF) compared to the healthy group, who took 0.71 ± 0.09 seconds.[4] Dynamic balance in double-leg stance as measured by TTS appears to be affected in individuals with CAI only in the A/P direction. Brown concluded that this delay provided evidence for the central effects of CAI on the sensorimotor system.[21] CAI may be viewed as a constraint on the sensorimotor system, limiting its ability to quickly generate new patterns of movement to control posture and return to a steady stance after an external perturbation is applied.[21] Brown also concluded that lateral ligamentous injury may be a limitation that affects global sensorimotor responses, causing individuals with CAI to be less able to compensate and adjust after perturbation.[21]

Star Excursion Balance Test

The Star Excursion Balance Test (SEBTs) is a clinical test purported to detect functional performance deficits associated with lower extremity pathology in otherwise healthy individuals.[61] The SEBTs consists of a series of lower extremity reaching tasks in 8 directions that challenge the individual’s postural control, strength, ROM, and proprioceptive abilities. The farther an individual can reach with one leg while balancing on the opposite leg, the better functional performance they are deemed to have.[61]

Olmsted studied proprioception by using the SEBTs, as a measure of dynamic stability.[29] Olmsted found that participants with CAI have a shorter reach while standing on their injured ankle compared to the controls (78.6cm vs. 82.8 cm).[29] Reach distances were also decreased for the CAI participants when their injured ankle and their uninjured ankle were compared (78.6cm vs. 81.2cm). They concluded that the SEBTs was an effective means for detecting reach deficits between and within participants with CAI.[29]

Hertel did a study to if the SEBTs could be simplified for easier and faster use to detect deficits in individuals with CAI.[61] Hertel found that performing all 8 reach directions were unlikely necessary when evaluating for functional deficits related to CAI.[61] This conclusion was reached due to redundancy among the reach directions. The posteriomedial (PM) reach direction was the most strongly associated with performance between subjects with and without CAI; however, the PM, anteriomedial (AM), and the medial (MD) directions showed differences between limbs with and without CAI.[61]

Jump Landing

Wikstrom found that the dynamic postural stability index (DPSI) in conjunction with a functional single-leg hop stabilization test to be a reliable and accurate measure of dynamic postural stability (DPS).[35] The DPSI is a composite of the medial-lateral stability indices, anterior-posterior stability indices and vertical stability indices. The DPSI was used in conjunction with a jump landing protocol that was established by Colby.[35] The results found that the DPSI was highly reliable between test sessions (r=.96) and very accurate (SEM=.03). It was found that with the DPSI and the jump-landing protocol that a 3 second sampling interval was the best choice because it mimicked athletic performance as closely as possible[35] compared to a 5 second or 10 second sampling interval.

Wikstrom performed a study that looked at DPS deficits during a single-leg jump landing protocol.[9] The results found that individuals with CAI had significant higher DPS scores in the anterior-posterior (A/P) and vertical plane and overall DPSI score during a jump landing protocol[9], which supports that individuals with CAI have worse DPS than those with healthy ankles when transitioning from dynamic to static movement.

Time to Stabilization

Wikstrom performed a study to find which combination of landing protocol and analysis techniques are the most effective time-to-stabilization (TTS) combination for detecting dynamic postural stability (DPS) in individuals with CAI.[8] They concluded that the UTOP analysis and the jump protocol is the best combination to detect DPS deficits in participants with CAI.[8]

Ross used the same jump landing protocol and identified that there were DPS deficits in the A/P and M/L directions using the TTS measure.[23] Wikstrom did not found any significance in the M/L as Ross and other researchers.[9] Ross speculated that damage due to LAS and other ankle instabilities might be responsible for the increased DPS scores.[23] Ross believe this is due to people with CAI take longer to decelerate their COM because they allow it to reach the limits of stability, causing the external moments that act to destabilize the body.[23] They suggested that individuals with CAI may use a different landing strategy to improve stabilization time than those with healthy ankles which would explain for the increased DPS scores. Wikstrom agrees with Ross that this may be the reason but Wikstrom is not sure because it may be attributed to ankle-instability symptoms such as self-reported weakness.[9]

Balance Training

Balance training has been suspected to be an effective modality in the rehabilitation and prevent of recurrent sprains in those with CAI; however, there is limited evidence of its effectiveness.[74] McKeon found that with four weeks of balancing training program that consisted of a combination of time-to-boundary (TTB) and SEBTs, that individuals with CAI had improved self-reported function, static postural control, and dynamic postural control.[74] Self-reported disability was measured on the FADI and FADI Sports scales. The static postural control was measured by COP excursion and TTB. The anterior, posteriolateral, and posteriomedial directions of the SEBTs were used to assess dynamic postural control.

Time-To-Boundary

Postural control deficits have been shown to be a potential contributing factor in CAI. An original measurement technique derived from the dynamical systems theory of motor control known as TTB has shown promise in detecting deficits in postural control related to CAI.[74] TTB uses the relationship of individual COP data points with the boundaries of support.[74] TTB represents the amount of time it would take the COP excursion to reach the boundary of support should the direction and velocity of the COP remain unaltered.[74] McKeon and Hertel found that individuals with CAI moved closer to the spatiotemporal boundaries of stability in a more predictable manner than healthy individuals. Individuals with CAI have less time to correct their posture in the AP direction than healthy individuals.[12, 74]

Summary

CAI has been studied extensively and from different prospective. As research and technology evolves and becomes more advanced, a better understanding of what CAI is and what factors contribute to it are know. Through research we have found that just strengthening an ankle after a sprain does not help prevent recurrent sprains. We have to focus more on proprioception and add strengthening with it. We also have seen that a lot of the research has been done from a dynamic to a static movement which really does not represent what happens in athletics.

COP-COM

Researchers have been trying to find ways to provide insight into postural control deficiencies. One method utilized to assess postural control was the quantification of the movement of the center of pressure (COP).[38] Corriveau defined COP as "a weighted average of all the pressures over the surface area in contact with the ground."[39-40] During quiet stance, the COP was located slightly anterior to the ankles' malleloli.[41] Martin stated that the anterior/posterior (A/P) and the medial/lateral (M/L) translations of the COP are influenced by 2 separate factors.[38] The A/P movements are influenced by the net ankle moments associated with postural control and the M/L translations are influenced by hip control in the frontal plane.[38] Corriveau found there was one major disadvantage with using COP to assess postural stability; COP does not actually assess it.[42] Rather, COP measures the secondary consequences of the swaying movements, i.e. center of mass measurements and not the movements' themselves.[42-43]

Center of mass (COM) was defined by Martin as "the point on the body that moves in the same way that a single particle would move if subjected to the same external force, or the point at which the weight of the body can be considered to act."[38] The average vertical position of the COM is about 55% of the subject's height, which is approximately located at the upper border of the pelvis during quiet stance.[41] Researchers observe the COM in the transverse plane in order to see how it interacts with the COP. The COM is kept at a fairly constant position between the feet by the COP.[40, 44] The COP oscillates either side of the COM, so if the COP is more anteriorly to the COM, the COM accelerates posteriorly. If the COP is to the right of the COM then the COM accelerates to the left.[44]

Researchers proposed that a new biomechanical variable be used to better understand postural control, the COP-COM separation.[35, 42-43] The COP-COM separation is the distance between the vertical projection of the COP and the COM in the transverse plane.[38] The peak of the COP-COM separation, which occurs at the last moment before heel strike of the swing limb (HS^{-1}), has been reported to be measured at varying distances based on the population being studied. For healthy young adults and the elderly adults, the COP-COM separation ranges from 21-32 cm.[43, 45] The COP-COM separation ranges from 16-30 cm in those with Parkinson's disease or other disabilities.[43, 45] Hass stated that the COP-COM separation when measured at any given time may enhance our understanding of the COP and the COM displacements and provided better insight into postural control.[43]

Chang suggested that the magnitude of the separation between COP and COM relates to a participants tolerance of dynamic unsteadiness and generation of forward momentum.[45] Therefore, the COP-COM separation is a valid tool for discriminating unsteady older adults from healthy older adults or from those with balance dysfunctions.[45-46] Martin and Corriveau both found that combined analysis of the COP and COM distances during quiet stance provided a better understanding into the assessment of balance then interpreting either variable alone.[38], [39] Corriveau had a major argument for using the COP-COM separation since it is highly correlated or proportional to the horizontal acceleration of the COM during quiet stance.[39, 40]

The purpose of the COP-COM separation is that it has been found to be sensitive enough to the changes or problems of dynamic postural stability (DPS).[43] DPS requires the central nervous system to integrate multiple sensory and motor pathways so that the body can coordinate both postural and intentional movement components during locomotion.[45] Martin found that individuals with less effective DPS are likely to reduce the COP-COM separation during transitional movements in an effort to reduce the need for active postural control.[38] Martin also demonstrated those with intact postural control can more readily tolerate a larger COP-COM distance during walking.[38] Martin suggested that with the shortening of the COP-COM separation during gait initiation may reflect a need to preserve stability because impairments in DPS and an inability to generate enough momentum using the COP "shift mechanism" during the S1 phase.[38]

Gait Initiation

Gait initiation (GI) is a "functional task that challenges the balance control system by forcing an individual from a state of stable balance to a continuously unstable posture during walking."[38] Chang conducted a study that determined if the COP-COM separation during GI was sensitive enough to differentiate healthy individuals from disabled individuals.[45] The results of Chang's study found that the peak COP-COM separation and steady-state gait were both greater in the healthy elderly than in the elderly with vestibular hypofunction (VH) during GI.[45] According to Chang this implies that a decreased gait speed was a sign of balance impairment in the VH group.[45] After analyzing and interpreting the results of his study, Chang made the suggestion that different variables from different tasks, such as GI and steady-state gait, might reflect various levels of DPS and should be interpreted carefully.[45]

During GI, the COP and COM each follow a very distant path, or trace, that can be observed and compared. This trace has been divided into 3 segments by 2 distinct landmarks.[43, 46] In order for the COP and COM to begin moving, they first must uncouple.[47] The first segment (S1) begins with the initiation of movement and ends with COP located at its most posterior and lateral position towards the initiation swing leg.[43, 46] This posteriolateral position of the COP is known as landmark 1.[41, 43, 46] As the COP is moving posteriorly and laterally, the COM moves anterolaterally towards the initial stance limb.[38] The second segment (S2) is characterized by a translation of the COP medially towards the initial stance limb ending at landmark 2, which is the point where the COP is completely under the initial stance leg.[41, 43, 46] During the S2 phase, the COM continues to move anterolaterally towards the initial stance limb. The third segment (S3) extends from landmark 2 until toe-off of the initial stance leg as COP moves anteriorly.[41, 43, 46] The COM continues to move anteriorly during S3 but as the initial stance leg begins to toe-off, the COM shifts medially slightly towards the initial stance limb to prepare for heel strike of the initial swing leg.[47]

Gait Initiation has been utilized to assess postural control in many studies, but they generally have been limited to straight ahead walking.[48] Many activities of daily living (ADLs) require lateral movement; therefore it is surprising that there has not been any research done on the effects of changing direction during GI. Rogers stated that “impairments in lateral stability are an important aspect of balance dysfunction and falls” and older adults are known to have problems turning and moving laterally.[48] Athletes change direction daily while initiating gait in order to block a shot on goal in soccer or box out during a free throw in basketball. Examining CAI with directional GI may lead to a better understanding of CAI and how to prevent further problems. Recently, Hass found that when initiating gait laterally, transitional frail individuals produced larger and more coordinated movement of the COP in a directionally appropriate manner during lateral and forward directed GI compared to Parkinson's disease individuals.[48]

The activation of the lower leg muscles are done in a certain pattern that creates moments of force about the ankles and hips that rotate the body like an inverted pendulum.[47] At the start of GI, there is an inhibition of the soleus muscle, which is active during quiet stance, followed by the onset of the tibialis anterior muscle of both the swing and stance limbs.[47, 49, 50] The decoupling of the COM and COP is due to this interaction of the soleus and the tibialis anterior at the beginning of GI.[47] The movement of the COP toward the swing limb is created by the hip abductors of the swing leg.[47] The muscle activity at the ankle and hip tend to propel the COM forward and towards the initial stance limb.[47] The COP moves anteriorly and posteriorly primarily under the control of the plantarflexor muscles, like the soleus.[44] In the M/L direction, the COP-COM separation was mainly explained directly by strength according to Corriveau.[42] The hip abductors are suggested to be important in the M/L direction.[42] Winter found that the M/L COP is virtually in phase with fraction of body weight taken by the individual feet. [44] This mechanism of M/L has been described as a "load/unload" mechanism because it's controlled by the simultaneous loading of one limb and unloading of the opposite limb by the hip abductor and adductor muscles.[44]

Before gait is initiated, the horizontal and vertical ground reaction forces (GRF) are constant. As a person initiates gait, the HGRF stay pretty steady but the VGRF begins to decrease which means the stance limb is unloading. This all occurs as the COP moves posteriolateral under the swing limb. Peak VGRF occurs about the time the COP reaches landmark 1. At the peak VGRF, the stance limb is unloaded. As the COP begins to move towards the stance limb, the HGRF and VGRF begin to increase. The increase in HGRF means an anterior movement and the increase in VGRF is the loading of the stance limb. As toe off of the swing limb happens the HGRF peaks, which occurs around landmark 2 of COP. During the S3 phase of COP, the HGRF decreases slightly or propels you backward to control the falling forward action caused by momentum. At heel strike of the swing limb, the HGRF peaks again which makes sense because there is a need to be propelled forward to drive the stance limb through.

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APPENDEX C

Georgia Southern University
Office of Research Services & Sponsored Programs

Institutional Review Board (IRB)

Phone: 912-681-0843 | Veazey Hall 2021
P.O. Box 8005
Fax: 912-681-0719 | IRB@GeorgiaSouthern.edu | Statesboro, GA 30460

To: Thomas Buckley
P.O. Box 8076

CC: Charles E. Patterson
Associate Vice President for Research

From: Office of Research Services and Sponsored Programs
Administrative Support Office for Research Oversight Committees
(IACUC/IBC/IRB)

Date: April 1, 2008

Subject: Status of Application for Approval to Utilize Human Subjects in Research

After a review of your proposed research project numbered: **H08198** and titled **"Dynamic Postural Stability during Gait Initiation in Individuals with Chronic Ankle Instability"**, it appears that (1) the research subjects are at minimal risk, (2) appropriate safeguards are planned, and (3) the research activities involve only procedures which are allowable.

Therefore, as authorized in the Federal Policy for the Protection of Human Subjects, I am pleased to notify you that the Institutional Review Board has approved your proposed research.

This IRB approval is in effect for one year from the date of this letter. If at the end of that time, there have been no changes to the research protocol; you may request an extension of the approval period for an additional year. In the interim, please provide the IRB with any information concerning any significant adverse event, **whether or not it is believed to be related to the study**, within five working days of the event. In addition, if a change or modification of the approved methodology becomes necessary, you must notify the IRB Coordinator **prior** to initiating any such changes or modifications. At that time, an amended application for IRB approval may be submitted. Upon completion of your data collection, you are required to complete a *Research Study Termination* form to notify the IRB Coordinator, so your file may be closed.

Sincerely,

Eleanor Haynes

Eleanor Haynes
Compliance Officer

Research Compliance Consolidated Cover Page

Georgia Southern University

For electronic submission: Your proposal narrative should already be completed and saved. Next complete cover page and "Save As" a word document to your computer or disk named "Coverpage_Year_Month_Date_lastname, First initial.doc". Then open and complete Informed Consent Checklist. Email the entire package to ovrsight@georgiasouthern.edu. Original signature pages may follow by mail.

Application for Research Approval

Investigator Information:		
Name of Principal Investigator: Thomas Buckley, Ed.D., ATC	Email: TBuckley@GeorgiaSouthern.edu	**For Office Use Only:** Protocol ID: ________ Date Received:
Phone: 912.478.5268	Address: 2121C Hollis Building P.O. Box 8076	
Department: Health and Kinesiology		
Name(s) of Co-Investigators: Barry Munkasy, Ph.D.	Title of Co-Investigator(s): Assistant Professor of Biomechanics	

Personnel and/or Institutions Outside of Georgia Southern University involved in this research: None

Project Information:

Title: Dynamic Postural Stability during Gait Initiation in Individuals with Chronic Ankle Instability

Brief (less than 50 words) Project Summary: This project will examine the initiation of walking in individuals with chronic ankle instability. Participants will be fitted with motion monitor sensors and proceed to walk at varying speeds and directions across embedded forceplates. Relationships between of center-of-pressure and center-of-mass will be assessed as an indicator of dynamic postural stability.

Compliance Information:

Please indicate which of the following will be used in your research:

- ☒ Human Subjects (Complete *Section A: Human Subjects* below)
- ☐ Care and Use of Vertebrate Animals (Complete *Section B: Care and Use of Vertebrate Animals* below)
- ☐ Biohazards (Complete *Section C: Biohazards* below)

Section A: Human Subjects

Number of Subjects: 30	Project Start Date: April 1, 2008 Project End Date: March 30, 2009 (no more than 1 year)
*Date of IRB education completion: 1/21/2008	**(attach copy of completion certificate)**
Purpose of Research: ☐ For use in thesis/dissertation ☐ Completion of a class project ☒ Publication (journal, book, etc.) ☒ Poster/presentation to a scientific audience ☐ Results will **not** be published ☐ Other	*Please indicate if the following are included in the study:* ☒ Informed Consent Document ☐ Greater than minimal risk ☐ Research Involving Minors ☐ Deception ☒ Generalizable knowledge (results are intended to be published) ☐ Survey Research ☐ At Risk Populations (prisoners, children, pregnant women, etc) ☐ Video or Audio Tapes ☐ Medical Procedures, including exercise, administering drugs/dietary supplements, and other procedures

Consolidated Application Cover Page

Check one: ☐ Student ☒ Faculty/Staff *If student project please complete advisor's information below:*	
Advisor's Name:	Advisor's E-mail:
Advisor's Phone:	Advisor's Department: P.O. Box:
Signature of Applicant: X	Date:
Signature of Advisor (if student): X	Date:

Section B: Care and Use of Vertebrate Animals		
Project Start Date:	Project End Date:	(no more than 1 year)

Purpose of use/care of animals:	*Please indicate if the following are included in the study:*
☐ Research ☐ Teaching ☐ Exhibition ☐ Display	☐ Physical intervention with vertebrate animals ☐ Housing of vertebrate animals ☐ Euthanasia of vertebrate animals ☐ Use of sedation, analgesia, or anesthesia ☐ Surgery ☐ Farm animals for biomedical research (e.g., diseases, organs, etc.) ☐ Farm animals for agricultural research (e.g., food/fiber production, etc.) ☐ Observation of vertebrate animals in their natural setting

Check one: ☐ Student ☐ Faculty/Staff *If student project please complete advisor's information below:*	
Advisor's Name:	Advisor's E-mail:
Advisor's Phone:	Advisor's Department: P.O. Box:
Signature of Applicant: X	Date:
Signature of Advisor(if student)/Dept. Chair(if faculty): X	Date:

Section C: Biohazards		
Project Start Date:	Project End Date:	(no more than 3 years)

Biosafety Level:	*Please indicate if the following are included in the study:*
☐ Exempt ☐ BSL 1 ☐ BSL 2	☐ Use of rDNA
*Signature of Applicant **(Faculty ONLY)**:* X	Date:

Please submit this protocol to the Georgia Southern University Compliance Office, c/o The Office of Research Services & Sponsored Programs, P.O. Box 8005. The application should contain all required documents specific to the committee to which you are applying. Questions or comments can be directed to (912)681-5465 or ovrsight@georgiasouthern.edu

Consolidated Application Cover Page

Georgia Southern University

Checklist for Developing An Informed Consent Form

REQUIRED FOR SUBMISSION

For electronic submission: You should have already completed the proposal narrative and cover page and saved them to your computer or disk. Now complete the Informed Consent Checklist and "Save As" a word document to your computer or disk named "infconchecklist_day/month/yearyourlastname, First initial.doc". Informed consent, parent informed consent, and/or minor informed consent documents must also be submitted with the proposal narrative, cover page, and informed consent checklist. You may use the informed consent template and sample informed consent documents to assist you in creating these necessary forms. The informed consent documents will also be saved as a word document to your computer or disk named "informedconsent_day/month/yearyourlastname, First initial.doc", "parentinfconsent_day/month/yearyourlastname, First initial.doc", and "minorinfconsent_day/month/yearyourlastname, First initial.doc". After all necessary informed consent documents are completed, please go to the Forms web page to submit all parts of your IRB application.

The Informed Consent Form must include these required elements:

- ☒ Title of the study, exactly as it appears on the human participants application
- ☒ Affiliation with Georgia Southern University (clearly identify who you are and your role in project)
- ☒ Investigator contact information (and advisor contact information, if investigator is a student)
- ☒ Purpose of the study
- ☒ Procedures to be followed
- ☒ Discomforts or risks (if none are known, state as such)
- ☒ Benefits of the study to participants and society
- ☒ Duration/timeframe of participation
- ☒ Compensation (if applicable)
- ☒ Statement that participation is voluntary
- ☒ Statement that participants may withdraw their participation at any time (if data collection is not anonymous)
- ☐ Statement that participants can decline to answer specific questions, if applicable.
- ☒ Confidentiality assurances, procedures (How the data will be kept secure and confidential. Please remember that Georgia is an "Open Records" state and you cannot guarantee confidentiality.)
- ☒ Statement that participants must be 18 years of age or older to participate. If subjects are minors, parental consent and minor's consent is required.
- ☒ Signature and date lines (for participants and investigators), unless using *passive consent*
- ☒ Connecting page numbers if more than one page (e.g. Page 1 of 2, Page 2 of 2)
- ☒ To contact the Office of Research Services and Sponsored Programs for answers to questions about the rights of research participants please email ovrsight@georgiasouthern.edu or call (912) 681-0843.

*A **parental informed consent form** used when minors are involved must also contain the above elements, but will need to be reworded to reflect that the parents are consenting for their children to participate.

Additional Considerations of Informed Consent:

1. All wording must be at an 8th grade reading level or below. A layperson or someone unfamiliar with your research should easily understand it. Avoid highly technical terms, jargon, etc.
2. Injury clause should be included if any risk of injury exists (physical or psychological): *"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."

*Referral information (including a phone number) for those who wish to seek assistance should also be included (e.g. Counseling and Psychological Services)

3. For surveys that are anonymous, also known as <u>*passive consent*</u>, the Informed Consent Form does not need to be signed, but the following statement must be included. *"Completion and return of the survey, questionnaire, etc. implies that you agree to participate and your data may be used in this research."* (If there is any means of identifying a participant, a signed consent form is required.)
4. If surveys are to be administered electronically, but not anonymously,
   a. state that there is only limited assurance of confidentiality due to the technology of the Internet;
   b. space for participants to type their names and the date will replace the signature lines
5. If audio- or videotaping will be used, state:
   a. where tapes will be stored;
   b. when tapes will be destroyed (within a definitive timeframe such as "by the year 2005");
   c. who will have access to the tapes.
6. If deception is involved and the full purpose of the study will not be disclosed to participants until their participation has ended, a statement such as the following needs to be included: *Because the validity of the results of the study could be affected if the purpose of the study is fully divulged to me prior to my participation, I understand that the purpose of the study cannot be explained to me at this time. I understand that I will have an opportunity to receive a complete explanation of the study's purpose following the completion of the study.*
7. Participants must receive a copy of the consent document for their records. Therefore, it cannot be attached to or be part of the instrument.
8. If extra credit or course credit is offered as compensation for participation, the consent form must state what the alternatives to participating are to earn equivalent extra credit or course credit.
9. If compensation is offered, the following statement may need to be included in the consent form, *"If you are an employee of Georgia Southern University, the compensation you receive for participation will be treated as taxable income and therefore taxes will be taken from the total amount. If you are not employed by Georgia Southern University, total payments within one calendar year that exceed $600 will require the University to annually report these payments to the IRS. This may require you to claim the compensation that you receive for participation in this study as taxable income."*

**For samples of informed consent forms, please go to the <u>forms</u> webpage. Do *not* simply copy a sample if your study is significantly different from the sample provided.

GEORGIA SOUTHERN UNIVERSITY INSTITUTIONAL REVIEW BOARD
INSTRUCTIONS FOR PREPARATION OF PROPOSAL NARRATIVE

<u>For electronic submission:</u> First complete the proposal narrative in entirety and "Save As" a word document to your computer or disk named "propnarr_Year_Month_Date_lastname, First initial.doc". Open and complete Cover page. Email both to <u>oversight@georgiasouthern.edu</u> . Documents that require signature may be faxed to 912-681-0719 or uploaded in PDF. (Electronic submission is not required.)

Please respond to the following as briefly as possible, but keep in mind that your responses will affect the actions of the Board. Clearly label your responses in sections that correspond to the specific information requested. Make sure the narrative clearly explains aspects of the methodology that provide protections for your human subjects. You may insert your responses in each section on this page, leaving a space between the question and your answers. Narrative should not exceed 4 pages.

The application should be submitted electronically or 2 duplicate copies sent to the Office of Research Services and Sponsored Programs, at P. O. Box 8005, Statesboro, GA 30460, and should contain, in this order: <u>a signed cover page</u>, <u>the informed consent checklist page</u>, <u>the project proposal narrative</u>, and <u>the informed consent that you will use in your project</u>. Additional information, such as copies of survey instruments, advertisements, or any instruments used to interact with participants should be attached at the end of the proposal clearly designated as an Appendix.

Personnel.
Thomas Buckley, Ed.D. Assistant Professor of Athletic Training, College of Health and Human Sciences
Barry Munkasy, Ph.D. Assistant Professor of Biomechanics, College of Health and Human Sciences
Elizabeth Raycraft, B.S. Graduate Student, Department of Kinesiology
Jennifer Tolson, B.S. Graduate Student, Department of Kinesiology

Dr. Buckley is the primary investigator and will contribute to the conception and design of the project, subject recruitment, and acquisition and analysis and interpretation of the data. Dr. Munkasy will contribute to the design of the project as well as acquisition, analysis and interpretation of the data. Ms. Raycraft and Ms. Tolson will contribute to the design of the project, subject recruitment, and acquisition and analysis and interpretation of the data. All investigators have completed the National Institute of Health Human Participant Protections Education for Research Teams and the completion certificated are included with this document.

Purpose. Ankle sprains are a common sports related injury and it is estimated there are 8 – 9 million ankle sprains per year (Kannus 1991) and upwards of 75% of these individuals will suffer recurrent sprains and develop chronic ankle instability (CAI) (Yeung 1994). The cost of ankle sprains in the United States is estimated to be about $3.65 billion dollars annually (Osborne 2003). Potential short-term complications of ankle instability are decreased balance and proprioception (the ability to determine the position of a joint in space; Prentice 1999) and impaired postural stability. In the long-term, recurrent ankle sprains increases the risk of damaging articular surfaces within the joint as well as increased likelihood of developing osteoarthritis (Hintermann 2002). These complications can limit the individual on both activities of daily living and athletic activities (Hubbard 2007).

Numerous tests exist to assess balance, performance, strength, and laxity in individuals with CAI. Many of these tests are static in nature, e.g., stationary postural stability tests, while others are dynamic such as jump landing tests. Static testing is inherently limited as ankle stability is unlikely to be stressed in a static position. As such, dynamic testing is currently considered a more appropriate assessment tool. The most strenuous dynamic assessment involves "time to stabilization" of a static posture following a dynamic movement (Wikstron 2007). However, many activities of daily living and athletic activities are transitions from static positions to dynamic movements. One such example of this is gait initiation (GI) in which the individual transitions from a static stable support to a continuously unstable posture during locomotion. During GI an uncoupling of the center of pressure (COP) and center of mass (COM) must occur to allow momentum generation and the initiation of movement to occur (Jian 1993). The ability to separate the COP and COM has major implications on momentum generation and balance control and can be utilized as a measure of dynamic postural stability. The greater the separation, the greater the moment arm for the ground reaction forces to act for momentum generation (Hass 2005). However, the larger the separation, the greater the demand for active postural control to maintain stability (Hass 2005). The distance between the COP and COM (COP-COM) can been used to capture the interplay between momentum generation and dynamic stability and has served as an indicator of disability during GI. (Chang 1999).

Therefore, the purpose of this study is to assess dynamic postural stability during gait initiation at various speeds and directions in individuals with CAI. We hypothesize that individuals with CAI will self-select a more posturally conservative movement pattern resulting in decreased stepping characteristics (step length and step velocity) and a limitation in the separation of the COP and COM. Our improved understanding of dynamic postural stability in individuals with CAI can help further our understanding of this common and costly condition as well as provide a scientific rationale for developing rehabilitative programs.

Outcome. As previously discussed, we expect to find decreased dynamic postural stability in individuals with CAI. Specifically, we expect to find decreased stepping characteristics and a restriction in the separation of the COP and COM during gait initiation. We expect these differences to be most prominent in fast-paced and directional GI.

The results of this study will improve our understanding functional limitations resulting from CAI. Additionally, the knowledge gained from this study may facilitate improvements in rehabilitative protocols for individuals with CAI. Participants will receive no direct immediate benefit from participating in this study.

Describe your subjects. Approximately 30 students (18 – 23 years old) will be recruited from the student population at Georgia Southern University to volunteer as participants in this study. Those individuals with history of CAI will complete the "Ankle Instability Instrument" (Docherty 2006, Appendix 1). The Ankle Instability Instrument has been shown to be valid and reliable in the assessment of CAI. The control subjects will have neither history of ankle sprains nor any history of lower extremity surgery, metabolic or neurologic disorders, vestibular or balance deficits, or current use of medications which affect the central nervous system. Control subjects will be selected as matches based on height, weight, and gender.

Methodology (Procedures). On the day of testing, the principal investigator or a member of the research team will explain the study in detail to the subject. Subjects will be assured that their participation in the study is voluntary, anonymous, and they are free to withdraw at any time. Following the explanation, the subject will be provided the informed consent document and granted ample time to read, review, and ask any questions prior to agreeing to participate and signing the informed consent.

The research team will utilize an electromagnetic tracking system (Ascension Technologies; Burlington, VT) with the Motion Monitor commercially available acquisition and analysis software for kinematic data collection. Additionally, two nonconducting forceplates (Model OR6-5, Advanced Mechanical Technology, Inc., Watertown, MA) will be used to collect ground reaction forces and moments. Surface electromyographic data will be collected via 16-channel Bagnoli EMG System (Delsys, Inc, Boston, MA). The electrodes used will be DE-2.1, single differential electrodes, with two parallel-bar contacts (Delsys, Inc, Boston, MA).

The testing session will begin with the research team taking basic anthropometric measurements (age, height, weight). The research team will attach surface sensors from the electromagnetic tracking system to both lower extremities on the dorsum of the foot, superior medial tibial tuberosity, lateral thigh (midway between the anterior superior iliac spine and the lateral epicondyle of the femur), sacrum, and C7 using double sided tape and Velcro straps. Joint centers of the ankle, knee, and hip will be calculated with respect to the secured foot, shank, and thigh sensors by taking the midpoint between two points digitized on contralateral aspects of the joint. Surface electrodes will be attached to the muscle bellies of the tibialis anterior, soleus, peroneals, and gluteus medias.

The participant will begin the trial standing stationary on a single forceplate. The participants' stance width will be self-selected and marked allowing the foot placement to be standardized throughout the experiment. There will be three testing conditions; self-selected pace, fast pace, and directional. In all three conditions, the participant will begin walking following a verbal command with their uninjured limb serving as the initial swing leg and they will walk for at least 5 steps. In both the self-selected and fast pace trials, the individual will begin walking straight ahead such that their first step impacts the second forceplate. In the directional condition, the individual will walk at a 45° angle towards their uninjured extremity as seen in Figure 1.

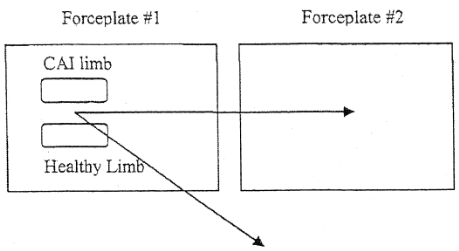

Figure 1. Schematic layout of Gait Initiation Trials

Special Conditions:

Risk. There is minimal risk of physical injury to the participant while performing this experiment, however this risk is not greater than the individual would experience during activities of daily living. These risks include tripping or falling while walking. There is potential minimal risk in acquiring the participant's medical history for inclusion/exclusion in this study. Participants will be assured that all records will remain confidential and be stored in a locked filing cabinet in the office of a faculty member who is a member of the research team. Additionally, all medical history forms will be destroyed once all aspects of the project are completed.

Research involving minors. No minors will be used in this study.

Deception. No deception will be used in this study.

Medical procedures. No medical procedures will be used in this study.

Human Participant Protections Education for Research Teams

Completion Certificate

This is to certify that

Thomas Buckley

has completed the **Human Participants Protection Education for Research Teams** online course, sponsored by the National Institutes of Health (NIH), on 01/21/2008.

This course included the following:

- key historical events and current issues that impact guidelines and legislation on human participant protection in research.
- ethical principles and guidelines that should assist in resolving the ethical issues inherent in the conduct of research with human participants.
- the use of key ethical principles and federal regulations to protect human participants at various stages in the research process.
- a description of guidelines for the protection of special populations in research.
- a definition of informed consent and components necessary for a valid consent.
- a description of the role of the IRB in the research process.
- the roles, responsibilities, and interactions of federal agencies, institutions, and researchers in conducting research with human participants.

National Institutes of Health
http://www.nih.gov

Human Participant Protections Education for Research Teams

Completion Certificate

This is to certify that

Jennifer Tolson

has completed the **Human Participants Protection Education for Research Teams** online course, sponsored by the National Institutes of Health (NIH), on 08/26/2007.

This course included the following:

- key historical events and current issues that impact guidelines and legislation on human participant protection in research.
- ethical principles and guidelines that should assist in resolving the ethical issues inherent in the conduct of research with human participants.
- the use of key ethical principles and federal regulations to protect human participants at various stages in the research process.
- a description of guidelines for the protection of special populations in research.
- a definition of informed consent and components necessary for a valid consent.
- a description of the role of the IRB in the research process.
- the roles, responsibilities, and interactions of federal agencies, institutions, and researchers in conducting research with human participants.

National Institutes of Health
http://www.nih.gov

GEORGIA SOUTHERN UNIVERSITY

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

APPENDIX D

Georgia Southern University

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

Subject Initials: ____________ (First MI Last) Subject ID #__________

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: ______________________________

GEORGIA SOUTHERN UNIVERSITY

Subject ID: __________________ Date: ___________

Investigator: __________________

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 ☐ 1-2years 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

Adapted from: Docherty CL, Gansneder BM, Arnold BL, Hurwitz SR. Development and Reliability of the Ankle Instability Instrument. *J Athl Train*. 2006 Apr-Jun;41(2):154-8.

APPENDIX E

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

Please answer <u>**every question**</u> with <u>**one response**</u> 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 <u>not applicable (N/A).</u>

	No Difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable To Do	N/A
Standing						
Walking on even ground						
Walking on even ground w/o 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 min. or less						
Walking approx. 10 min.						
Walking 15 min. or more						

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

	No Difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable To Do	N/A
Home Responsibilities						
Activities of daily living						
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%

Foot and Ankle Ability Measure (FAAM)
Sports Subscale

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

	No Difficulty	Slight Difficulty	Moderate Difficulty	Extreme Difficulty	Unable To Do	N/A
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 sport for 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 F

Table 1 Demographics for Healthy Young Adults

	GENDER	AGE(yrs)	HEIGHT(cm)	WEIGHT(kg)	ASIS(mm)	BMI
	M	21	183.40	66.56	93.50	19.79
	M	21	181.30	82.21	90.00	25.01
	M	21	176.60	60.90	86.00	19.53
	M	22	191.40	84.06	98.00	22.95
	F	18	175.00	62.60	90.00	20.44
	M	21	195.60	80.80	104.50	21.12
	M	19	188.50	75.20	99.00	21.16
	M	20	179.80	104.86	93.00	32.44
	F	21	168.60	63.50	85.00	22.34
	F	19	177.00	61.70	89.00	19.69
	F	19	168.80	56.03	85.50	19.66
	M	19	180.00	93.60	90.00	28.89
	F	20	177.60	55.80	89.50	17.69
	F	19	179.10	80.90	87.50	25.22
AVG		20.00	180.19	73.48	91.46	22.57
STD		1.18	7.68	14.86	5.65	4.08

Table 2 Demographics for Chronic Ankle Instability

	GENDER	AGE(yrs)	HEIGHT(cm)	WEIGHT(kg)	ASIS(mm)	BMI
	M	21	181.20	76.79	89.00	23.39
	F	18	177.90	65.90	89.00	20.82
	M	21	191.20	87.32	101.00	23.89
	M	22	191.60	86.56	94.25	23.58
	M	18	183.70	71.34	97.00	21.14
	M	21	184.40	83.65	89.00	24.60
	M	20	193.30	86.50	101.00	23.15
	M	19	192.40	91.70	97.00	24.77
	F	19	171.80	51.10	91.50	17.31
	F	20	176.20	56.80	89.00	18.30
	F	20	165.30	49.20	85.50	18.01
	M	19	191.80	79.60	99.00	21.64
	F	20	166.90	62.90	84.00	22.58
	F	20	176.10	73.40	87.00	23.67
AVG		19.86	181.70	73.05	92.38	21.92
STD		1.17	9.66	14.02	5.79	2.49

Table 3 Descriptive statistics and independent t-test results

	HYA		CAI					
	M	*SD*	*M*	*SD*	*t*	*p*	*d*	Observed Power
Forward GI								
COP-COM separation at HS^{-1} (cm)	23.4	2.8	21.7	1.0	1.20	0.24	0.47	0.22
Posterior displacement of COP (cm)	4.8	0.3	4.0	0.3	1.60	0.12	0.63	0.36
Lateral displacement of COP (cm)	4.0	0.3	3.9	0.3	0.19	0.85	0.08	0.05
Step Length (m)	0.6	0.1	0.6	0.2	0.92	0.36	0.36	0.15
Step Velocity (m/s)	0.5	0.1	0.5	0.1	0.92	0.36	0.39	0.17
Posterior velocity of COP (cm/s)	11.2	1.3	8.8	2.3	1.40	0.15	0.58	0.32
Lateral velocity of COP (cm/s)	9.9	1.2	8.9	2.3	0.53	0.60	0.21	0.08
Directional GI								
COP-COM separation at HS^{-1} (cm)	33.6	0.8	33.5	1.1	0.57	0.96	0.22	0.09
Posterior displacement of COP (cm)	0.4	0.2	0.4	0.2	0.76	0.99	0.29	0.12
Lateral displacement of COP (cm)	0.7	0.5	0.6	0.4	0.76	0.57	0.29	0.12
Step Length (m)	0.4	0.1	0.4	0.1	0.96	0.84	0.38	0.16
Step Velocity (m/s)	0.4	0.1	0.3	0.1	0.19	0.27	0.39	0.05
Posterior velocity of COP (cm/s)	1.1	0.3	1.1	0.4	0.60	0.96	0.24	0.09
Lateral velocity of COP (cm/s)	2.0	2.4	1.4	0.7	0.11	0.29	0.05	0.05

Figure 1 Transverse plane view of the path of the COP and COM during Forward Gait Initiation when stepping with the right foot.[17] The arrow represents the calculated distance between the COP and COM.

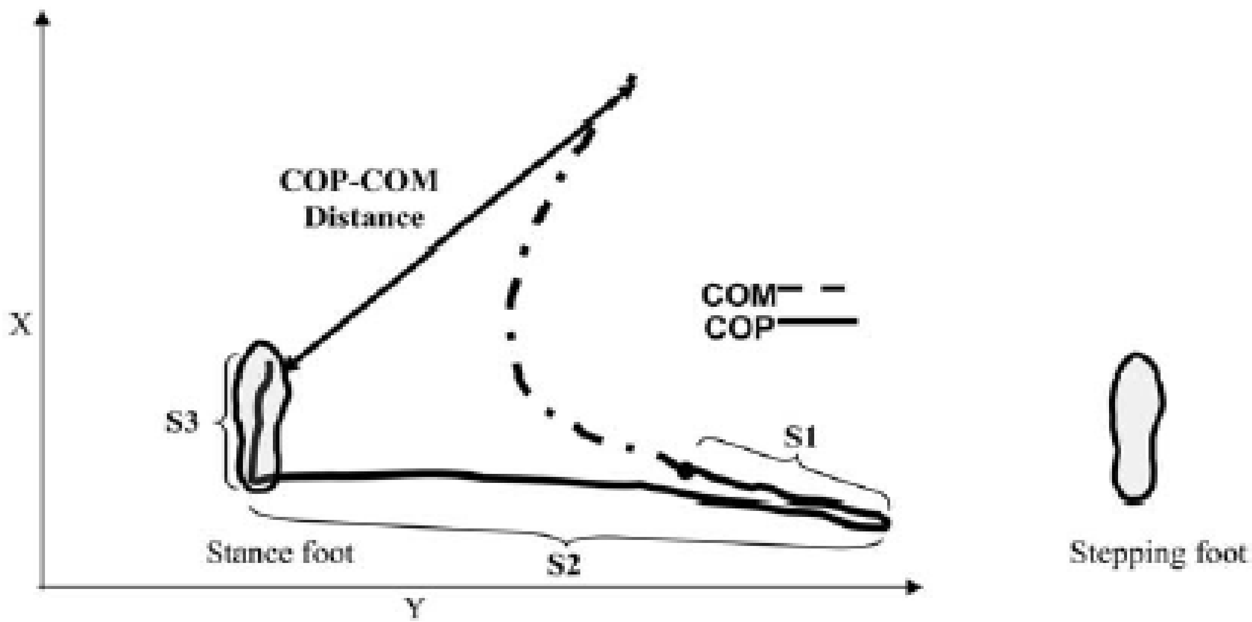

Figure 2 COP Trace for Forward and Lateral Gait Initiation.[14] Exemplar record of an overhead view of the path of the COP during forward (left) and lateral (right) oriented gait initiation when stepping with the left foot. Landmark 1 and Landmark 2 were identified separating the COP trace into defined sections S1, S2, and S3.

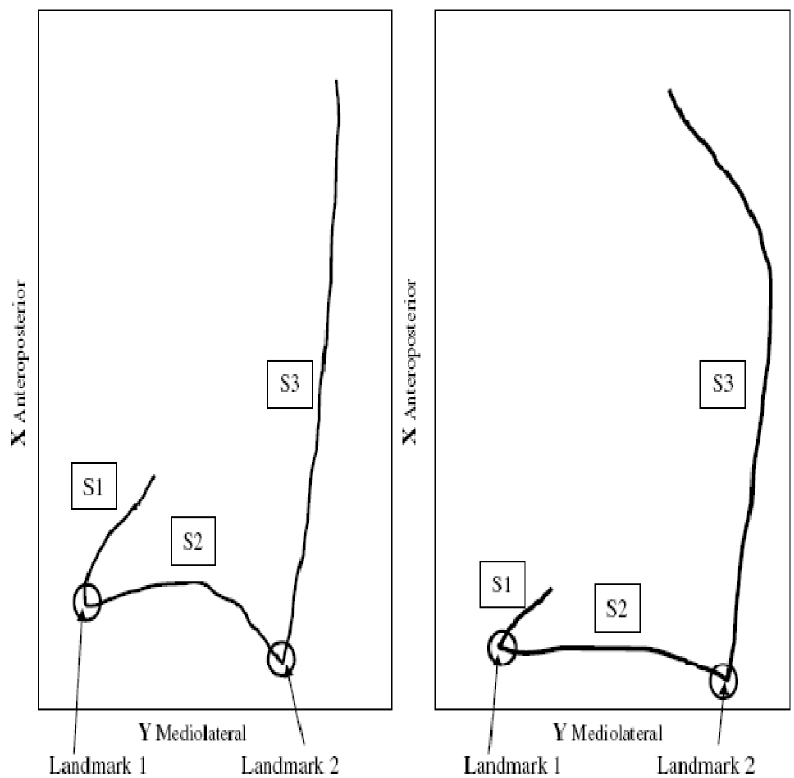

Figure 3 A lab set-up for data collection of Forward Gait Initiation. The chronic ankle instability (CAI) limb is the initial stance leg. The initial swing leg is the uninvolved limb. The arrow represents the line of progression. The electromagnetic tracking is where the box for the system is mounted.

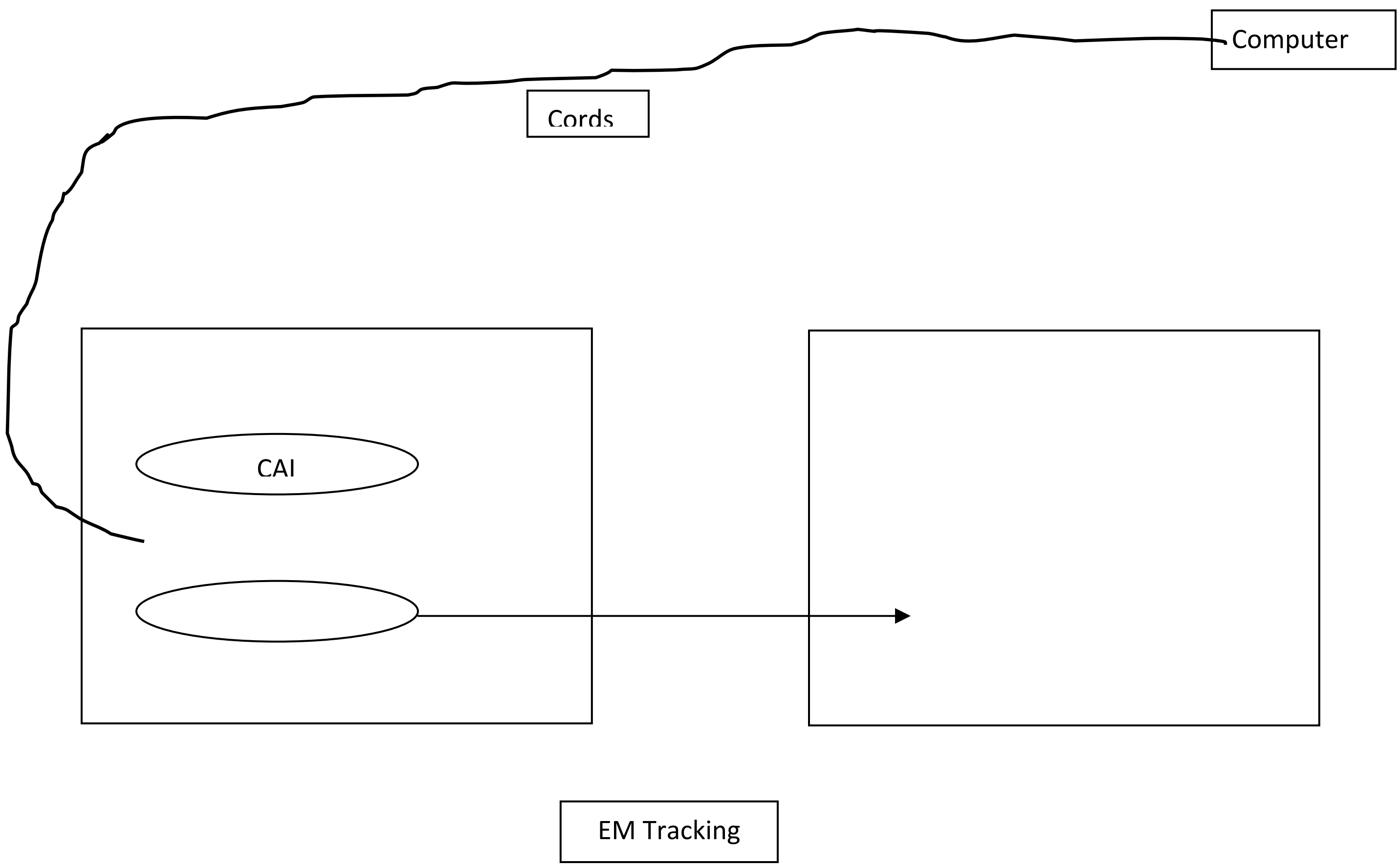

Figure 4 A lab set-up for data collection of Directional Gait Initiation. The chronic ankle instability (CAI) limb is the initial stance leg. The initial swing leg is the uninvolved limb. The arrow represents the line of progression. The electromagnetic tracking is where the box for the system is mounted.

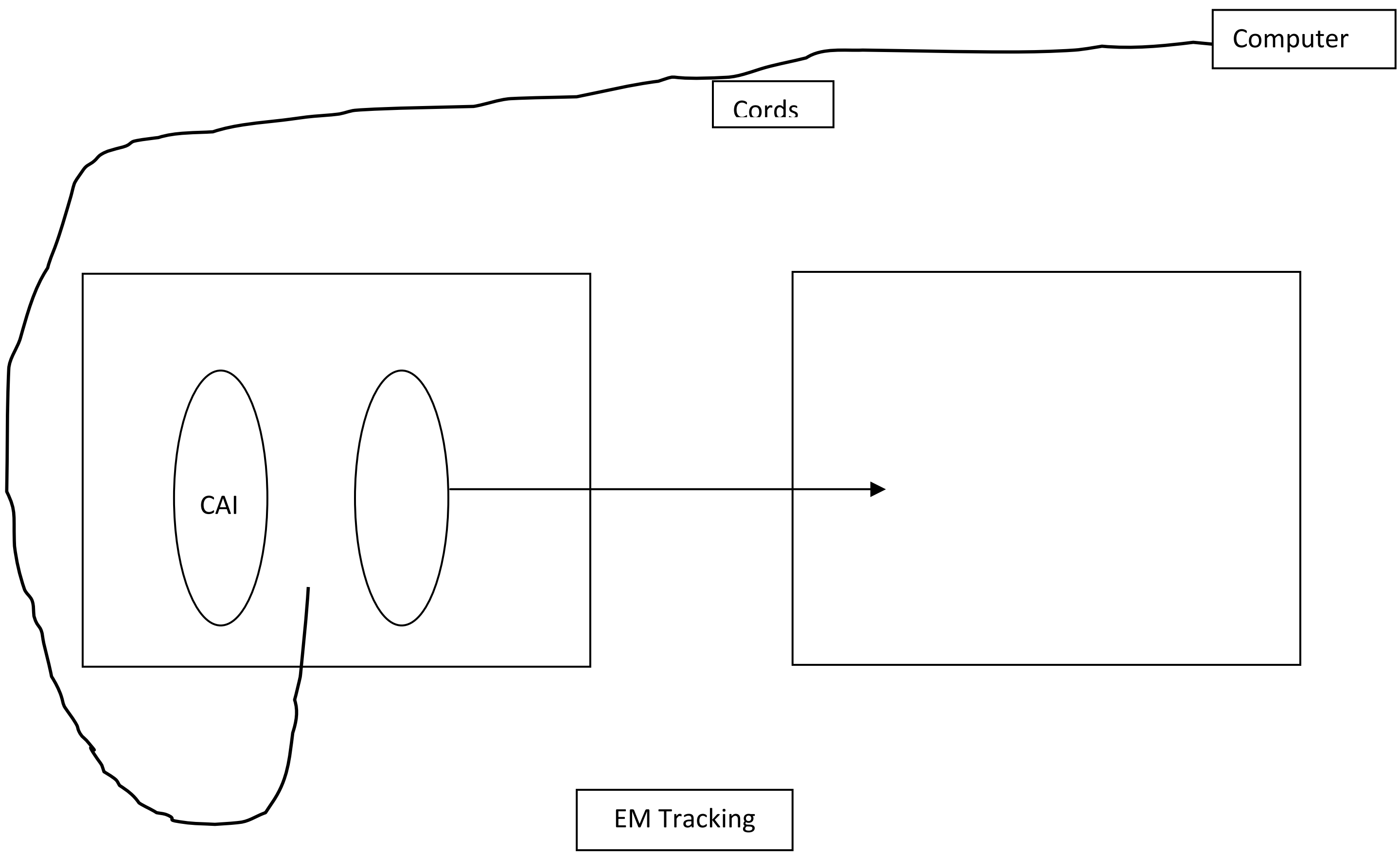

Figure 5 COP-COM separation at HS^{-1} for HYA and CAI during Forward and Directional Gait Initiation.

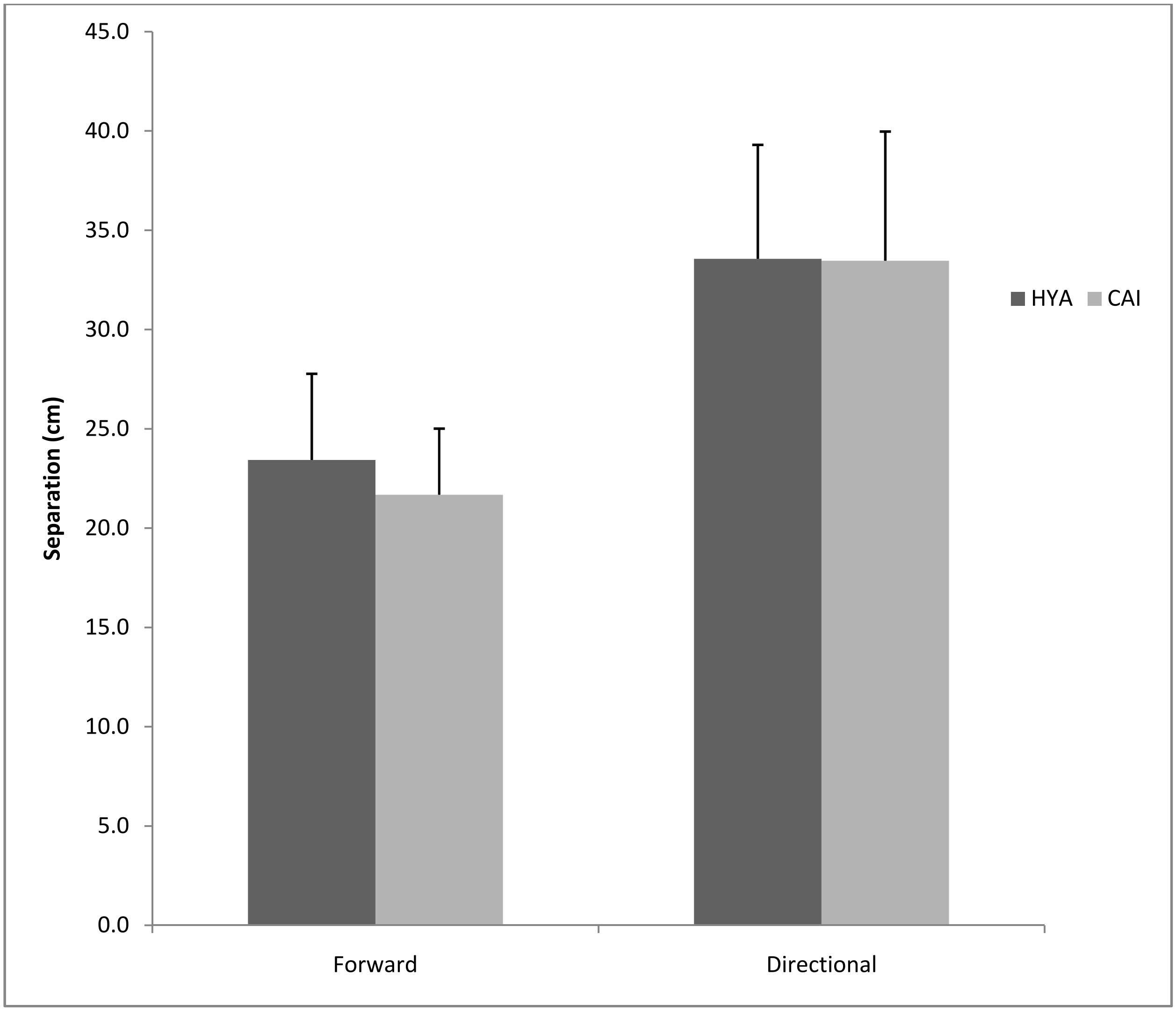

Figure 6 Exemplar trials of the COP Trace for Forward Gait Initiation representing HYA and CAI.

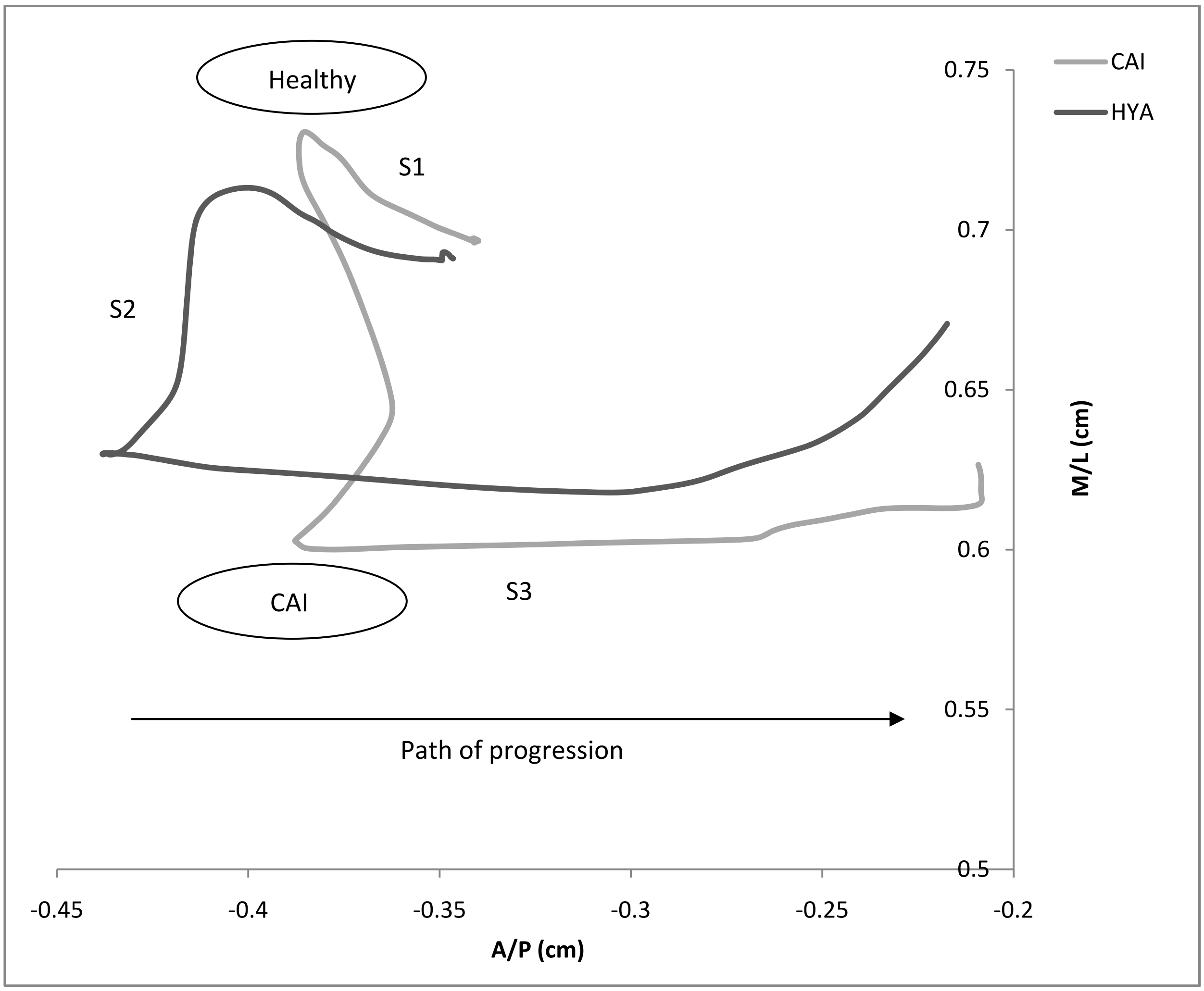

Figure 7 Exemplar trials of the COP Trace for Directional Gait Initiation representing HYA and CAI.

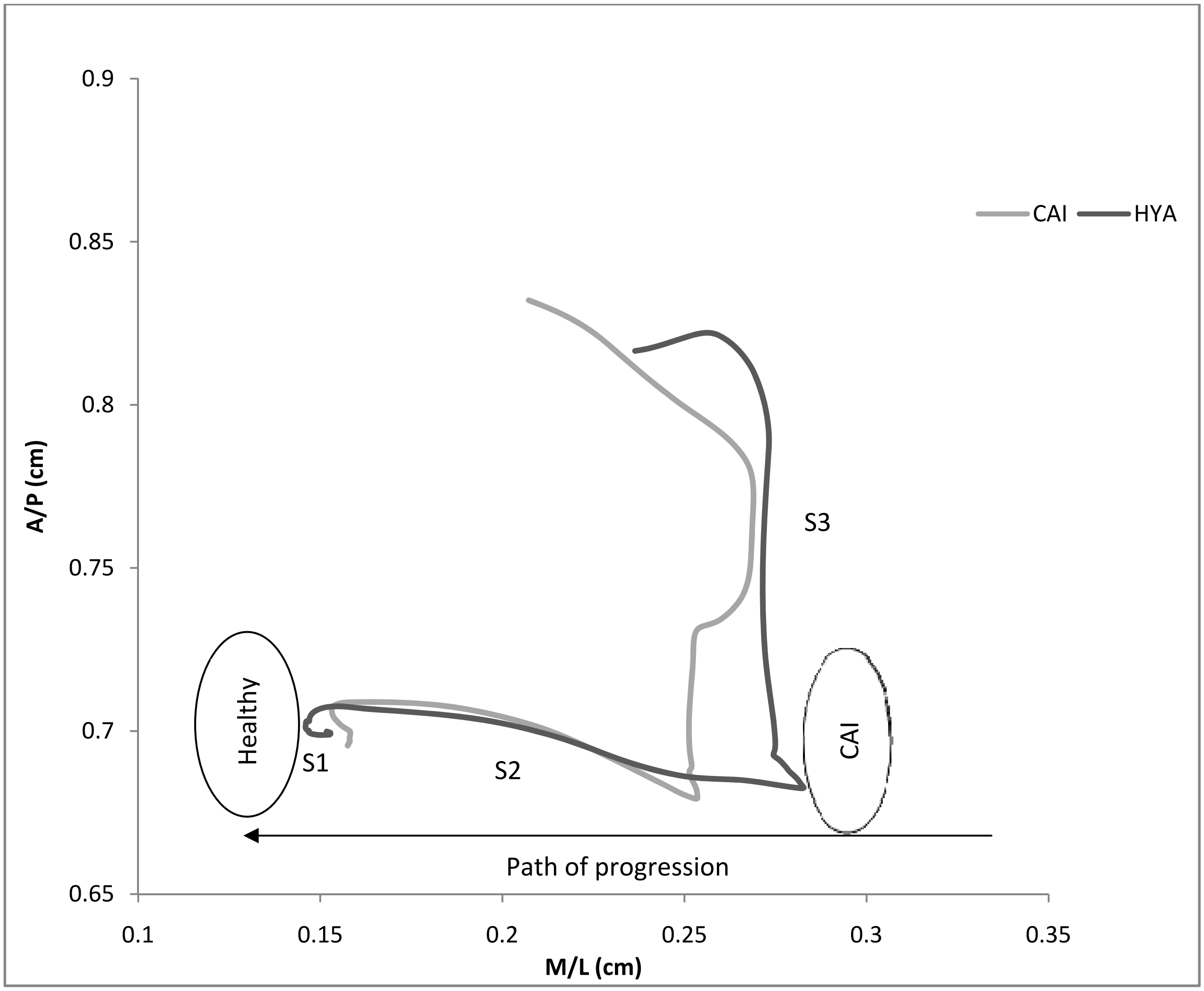

Figure 8 Step Length for HYA and CAI during Forward and Directional Gait Initiation.

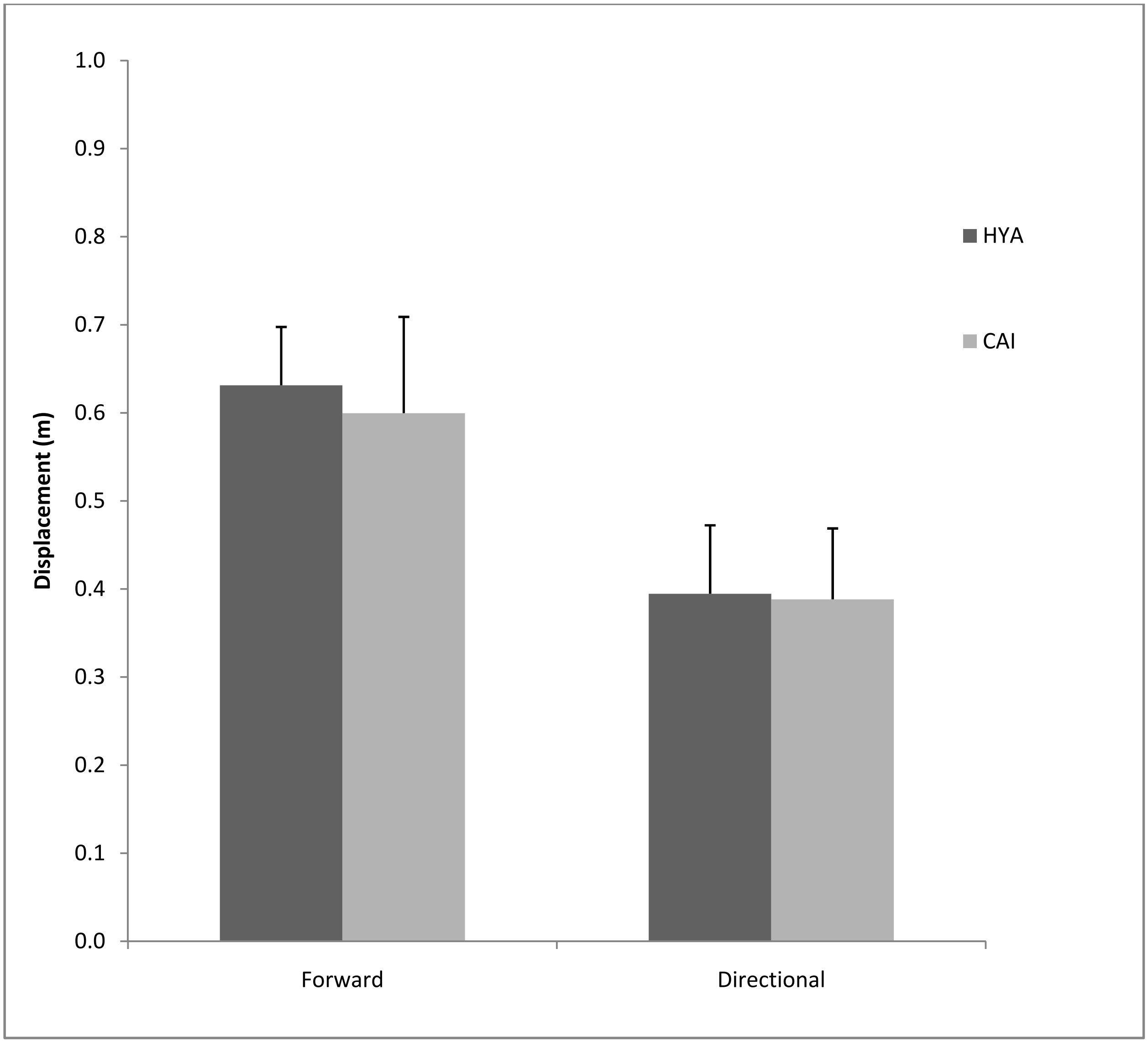

Figure 9 Step Velocity for HYA and CAI during Forward and Directional Gait Initiation.