ALTERED VERTICAL GROUND REACTION FORCES FOUND IN PARTICIPANTS WITH CHRONIC ANKLE INSTABILITY DURING RUNNING

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DEDICATION

The following manuscript is dedicated to John J. Kelley,
without his mentorship this journey of life
would not look even remotely similar
to the path that has been run to date

ACKNOWLEDGMENTS

The following document would not have been possible without the help and guidance of the following people: Dr. Docherty, for the constant mentorship and guidance on this document and throughout graduate school. Dr. Liu for all the help in getting this project off the ground and keeping it simple from the start. Dr. Schrader for the advice along the way and the life values on how to get through it.

ABSTRACT

Altered gait kinematics and kinetics have been examined in subjects with chronic ankle instability (CAI). Altered vertical ground reaction forces (GRF) have been found in individuals with CAI compared to control subjects, in different movement patterns but not running. Running is a common component of numerous sporting events where ankle sprains occur. The purpose of this investigation was to determine if subjects with CAI produced altered vertical GRF compared to uninjured subjects while running. Specifically, we examined if differences existed in impact peak forces, time to the impact peak force, active peak forces, time to the active peak force and average loading rate between groups. Twenty-four subjects with previous running experience were recruited from a Midwestern community. Subjects were determined to have CAI if they met the following criteria: (1) a history of at least one self-reported lateral ankle sprain that occurred 12 months prior to study enrollment, (2) a history of recurrent sprains or feelings of "giving way" during functional activity, (3) a score of 11 or higher on the Identification of Functional Ankle Instability (IdFAI) Questionnaire. Control subjects had no history of lateral ankle sprains. All subjects were required to be active runners and rear foot strikers. Also, subjects had no previous lower extremity injuries in the last three months besides a lateral ankle sprain for the CAI group. All subjects had no history of fractures or surgeries to the lower extremities. Active runners were defined as consistently running for the past year, running at least three times per week and averaging a minimum of twenty miles per week. Testing took place on an instrumented treadmill. Each subject was given an opportunity to complete his or her pre-run stretching routine following a five minute warm-up and before the testing trial. During the testing trial, subjects ran at a standardized speed trial of 3.3 $m \cdot s^{-1}$ for five minutes. Data was collected during the last 30 seconds of the trial period at 1200 Hz. Five consecutive GRF curves

of the test ankle from the last 15 seconds of the data were identified and processed with a fourth order Butterworth filter and a custom written formula in R program to identify the dependent variables.

A total of 13 control subjects and 11 subjects with CAI were included for statistical analysis. We found that subjects with CAI produced significantly higher impact peak forces, active peak forces, average loading rate and a shorter time to the active peak force compared to controls. No significant difference was found in the time to impact peak force between groups. The results of this study indicated that individuals with CAI produced altered kinetic variables compared to control subjects. Improper foot position at heel strike and strength deficits in the tibialis anterior could increase the impact peak force by striking the ground harder. Increased loading rates found in individuals with CAI could predispose individuals to lower extremity stress fractures and long-term complications such as osteoarthritis of the ankle joint. Overall, results of the study found that individuals with subjects with CAI produce altered GRFs than uninjured subjects while running.

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INTRODUCTION

A recent sampling of collegiate and high school athletes found a prevalence of chronic ankle instability (CAI) in 23.4% of athletes.[1] Chronic ankle instability is a complex injury that leads to recurrent lateral ankle sprains and instability.[2] Individuals with CAI also report of feeling of giving way occurring at the ankle joint during activity.[3] Symptoms of CAI have been found to include altered gait patterns, impaired proprioception, and neuromuscular and postural control.[4-21] Strength deficits, ankle joint laxity, degenerative changes within the ankle joint, have also been found in people with CAI.[2,4,22-25]

Recently, researchers have looked to identify specific gait differences between individuals with CAI and people without ankle instability. Individuals with CAI exhibit different lower extremity gait kinematics while walking. Specifically, these individuals walk with more rear foot inversion,[9] external rotation at the tibia,[9] inversion at the ankle joint,[6,7,15] and decreased dorsiflexion[6,9] during the terminal stance phase compared to uninjured individuals. Kinetic differences have also been found in individuals with CAI. These individuals have greater peak plantar pressure in the midfoot and lateral forefoot,[18] a laterally deviated center of pressure (COP),[12,25] and increased braking and propulsive forces[26] than control subjects.

Also, altered gait mechanics have been identified between individuals with CAI and healthy individuals while running. During running, individuals with CAI have found to have increased rear foot inversion and external rotation of the tibia[9], inversion at the ankle[8] and decreased dorsiflexion[6,27] of the ankle joint. At initial contact, individuals with CAI have increased pressure within the lateral rear foot and a lateral COP trajectory compared with a medial COP trajectory in healthy individuals during the loading response phase.[16] Also individuals with

CAI have increased peak pressure underneath the first and third metatarsal heads, increased contact area in their midfoot and decreased contact area within their forefoot.[13]

However, there is a gap in the literature in vertical ground reaction forces (GRFs) within individuals with CAI while running. Brown and colleagues[5] are the only group that has examined vertical GRFs in individuals with ankle instability, however there was no comparison to a healthy control group, therefore we do not know if these values are different from healthy individuals. Vertical GRFs provide an objective measurement of magnitude and rate of loading to the lower extremity.[28] In a vertical GRF graph, two specific peaks can be seen during running; an initial impact peak occurring during the first 50 milliseconds (ms) of the absorption period as the rear foot comes into contact with the ground[29] and a second active peak occurring during the propulsion portion of running gait.[30] The impact peak is a passive force the body must dissipate or absorb that is only seen in rear foot strikers due to the breaking motion as initial contact.[31] Up to 80% of people who run are rear foot strikers.[32] Next, the active peak is the force generated by the limb as plantar flexors contract to advance the limb forward. The average loading rate is the average rise in force production occurring from 20-80% of the time between initial contact to the impact peak.[30] Previously, researchers have found increased loading rates in subjects with a history of tibial and metatarsal stress fractures,[33] but limited information is available for individuals with CAI.

In addition, recurrent ankle sprains have been found to be the second leading cause of osteoarthritis (OA) of the ankle joint.[34] Within individuals with CAI, OA at the ankle joint has been found to be a long-term complication due to acute lesions to the chondral bones or chronic degeneration of the articular cartilage.[35] Alternations in GRF values while walking have been in found in asymmetric ankle OA patients compared to control subjects.[36] However, no study to date has identified if individuals with CAI produce different vertical GRFs than healthy individuals.

Therefore, the purpose of this investigation was to determine if differences in vertical GRFs occur in people with CAI compared to uninjured individuals. We hypothesized that people with CAI will generate higher GRFs than healthy runners due to the presence of CAI. We also hypothesized that subjects with CAI with have higher loading rates than healthy individuals.

METHODS

Subjects

Twenty-four subjects (12 males, 12 females, Age: 20.8 $\pm$ 2.7 yrs, Height: 1.74 $\pm$ 0.09 m, Weight: 67.28 $\pm$ 10.57 kg) participated in the study. Demographics of each group are reported in Table 1. All subjects were active runners, defined as running on a consistent basis for the past year, including currently running a minimum of three times a week and 20 miles per week. Subjects completed three questionnaires that included the: Physical Activity Readiness Questionnaire (PAR-Q), a health and running history questionnaire, and the Identification of Functional Ankle Instability (IdFAI) Questionnaire. The PAR-Q screened individuals for pre-disposing risk factors that indicated if they could safely participate in the physical activity associated with the study.[37] The health and running history questionnaire encompassed all of the inclusion and exclusion factors for participation within the study. All subjects signed an informed consent form that was approved by Indiana University and the University of Evansville Institutional Review Board for the Protection of Human Subjects.

Subjects were divided into two groups, subjects with CAI and healthy controls. Inclusion criteria for the CAI group included: (1) a history of at least one self-reported lateral ankle sprain that occurred at least 12 months prior to study enrollment, (2) a history of recurrent sprains or feelings of "giving way" during functional activity, (3) a score of 11 or higher on the IdFAI[38]. If the subject had bilateral CAI, the ankle with the higher self-reported IdFAI score was used as the test limb for this study. Ankles of control subjects were randomly matched to the CAI group.

Exclusion criteria for both groups included: (1) a history of surgery or fractures in the lower extremity, (2) an acute lower extremity injury within the past three months, (3) enrollment in any formal lower extremity rehabilitation program, (4) the use of orthotics while running, and (5) the presence of a mid-foot or forefoot striking pattern during running.

Procedures

Subjects warmed up on an instrumented treadmill for five minutes (Figure 1) at a self-selected pace. All subjects were shod for the study with their normal running shoes. Each subject was given an opportunity to complete his or her pre-run stretching routine between the warm-up and testing trial. During the testing trial, subjects ran at a standardized speed trial of 3.3 $m \cdot s^{-1}$ for five minutes. Data were captured during the last 30 seconds of the trial. Subjects were then given an opportunity for a five-minute cool-down period.

Instrumentation

Vertical GRF data were collected using a Bertec instrumented treadmill (Columbus, OH). The instrumented treadmill has force plates embedded beneath each of the two belts to capture GRF data. Vertical GRF data was collected at 1200 Hz. Foot strike, marking the beginning of the stance phase was identified when the force plate registered a GRF greater than 30 Newtons.[30] Toe off marked the termination of the stance phase and occurred when the force plate registered a GRF of less than 30 Newtons.[30]

Data Processing

Data collected with the instrumented treadmill was interfaced with Vicon Nexus (v1.1.17, Centennial, CO). A custom program in R (R Development Core Team, Vienna, Austria) was used to analyze the data. A fourth order low pass Butterworth filter at a cutoff of 45 Hz was applied to all GRF data.[39] Five consecutive stance phases of the test limb collected from the last 15 seconds of the test trial were used for statistical analysis.[30] Finally, all vertical GRF values were normalized to the subjects body weight.[40]

Statistical Analysis

SPSS (version 20, SPSS Inc, Chicago, IL) was used for statistical analysis of GRF data. Subjects were grouped at two levels (CAI, control). The dependent variables were impact peak force, time to impact peak force, active peak, time to active peak force, and average loading rate. The impact peak force was defined as the maximum in the vertical GRF data within the first 50 ms of the stance phase, normalized to body weight (N/BW).[29] The active peak force was defined as the greatest amount of forced produced by the subject during a gait cycle, normalized to body weight (N/BW).[30] Time to the impact peak force was the time from initial contact to the impact peak force expressed in milliseconds (ms).[30] Time to the active peak force was the time from initial contact to the active peak force expressed in ms.[30] The average loading rate was defined as the slope of the impact peak from 20-80%, expressed in body weight divided by seconds (N/BW)/s.[30] Dependent variables depicted on a vertical GRF graph is shown in Figure 2. A multivariate ANOVA was performed to determine differences between groups. Separate univariate ANOVAs were performed on each of the dependent variables. Alpha level was set at $p \leq 0.05$.

RESULTS

Interpretation of the multivariate ANOVA identified a significant difference between groups ($F_{5,18} = 5.74$, $p = 0.002$, $\eta_p^2 = 0.62$, power = 0.96). Comparison of a representative vertical GRF graph from each group can be found in Figure 3. Overall, impact peak forces were significantly greater in subjects with CAI than healthy individuals (mean difference = .36 N/BW, 95% CI = .18 to .54 N/BW, Figure 4). Subjects with CAI were found to have an increased average loading rate than healthy subjects (mean difference = 16.07(N/BW)/s, 95% CI = 7.21 to 24.94 (N/BW)/s, Figure 5). Also, the active peak force was significantly higher in subjects with CAI than controls (mean difference = .19 N/BW, 95% CI = .07 to .31N/BW, Figure 6). The CAI group reached the active peak force in a significantly shorter time than healthy subjects (mean difference = 14.19 ms, 95% CI = 9.06 to 19.31 ms, Figure 7). No significant difference was found in the time to reach impact peak force between groups (mean difference = .04 ms, 95% CI = -1.49 to 1.56 ms, Figure 8). Comparison of the means, standard deviations, p-values and effect sizes from each group can be found in Table 2.

DISCUSSION

The principal findings of this study were individuals with CAI presented with altered kinetic variables compared to healthy subjects while running. Individuals with CAI presented with increased peak forces, loadings rates and a shorter time to the active peak force that healthy individuals. This is the first study to report vertical GRFs in individuals with CAI matched with healthy individuals while running.

Impact Peak Forces

The CAI group was found to have a higher impact peak force than the control group. Also, no significant changes in the time for subjects to reach their impact peak force occurred. On average, the CAI group reached the impact peak force at 38.11 ms compared to the control group at 38.07 ms. In the literature, only one other study examined the impact peak force in subjects with CAI. Dayakidis and Boudolos[41] found a significant shorter time to the impact peak and an in increase impact peak force in subjects with CAI during a v-cut maneuver but not during lateral shuffling. Differences in results between our studies could be contributed to the different tasks studied. The increase in impact peak force seen in the CAI group could be contributed the role of tibialis anterior. During this time period, the tibialis anterior eccentrically contracts to lower the foot to the ground.[31] If the tibialis anterior is unable to control the decent of the foot during initial contact than the foot will strike the ground with a greater magnitude causing an increased impact peak. Individuals with CAI have been found to have functional strength deficits during isokinetic muscle testing in the tibialis anterior.[22] The tibialis anterior was found to have a 24% decrease in eccentric strength compared to control subjects.[22] The decrease of strength in tibialis anterior could contribute to the increased impact peaks seen in individuals with CAI.

Altered foot positioning during gait could also contribute to the increase in impact peak force seen in the CAI group. As the foot strikes the ground, individuals with CAI have been found to have an increased pressure along the lateral rearfoot upon initial contact.[13] Subjects with CAI have been found to have altered joint positioning.[42] From there, a lateral deviated center of pressure trajectory has been found while running.[13,16] After initial contact has occurred, the foot will display a medial center of pressure trajectory which correlates with pronation of the foot and ankle complex in healthy individuals.[6] Theoretically, the altered joint position could be leading to the change in gait causing the increased impact peak forces seen in our results. Therefore, if the surrounding musculature cannot counteract the increase magnitude of force on the ankle joint, recurrent sprains may occur.

Active Peak Forces

After the impact peak occurs, the COP continues to move forward shifting the body weight over the stance limb. The active peak force marks the movement as the body begins to accelerate and begins to push off the ground.[31] The CAI group was found to have an increased active peak force than the control group. Haung et al.[13] reported individuals with CAI have an increased pressure underneath the first and third metatarsal heads. This increased pressure are similar our results that subjects with CAI push off the ground harder.[13] The increase in force within the active peak may be contributed to the muscles attempting to provide dynamic stability to the foot and ankle complex as a compensatory mechanism to prevent additional ankle sprains from occurring. Peroneal longus muscle activity has been found to be increased at toe off in individuals with CAI compared to control subjects.[25] Individuals with CAI have been found to have a lateral COP during mid and late stance, the time at which the active peak is produced.[13,16,17] Due to the active nature of the active peak force, this could explain the increase in active peak production in subjects with CAI.

The CAI group reached the active peak force in a shorter amount of time compared to the control group. On average, it took subjects with CAI 117.27 $\pm$ 5.96 ms to reach the active peak compared with 131.46 $\pm$ 6.09 ms for the control group. Interestingly, no other study has found a difference in time to peak force values while running. Different pathological gaits have seen asymmetries produced between the affected and unaffected limb. Due to the feelings of instability present, subjects with CAI could be more reliant on the unaffected side during gait. Future research could determine if vertical GRF forces and temporal-spatial parameters of gait are different between limbs in subjects with CAI.

Clinical Relevance

Clinically, the increased loading rates seen in individuals with CAI place the structures of the ankle under more stress.[33] If the body does not compensate for this increase in stress by altering joint mechanics, injury could potentially occur. Subjects with CAI are more inverted at the ankle joint while jogging.[9] A meta-analysis has correlated increased loading rates in vertical GRFs to other lower extremity injuries such as tibia and metatarsal stress fractures.[33] Increased loading rates found in the CAI group could potentially place these individuals at an increased risk for developing a lower extremity stress related injury within that limb. Also, due to the increased loading rates and peak forces, CAI could be a factor in placing abnormal stress within the ankle joint causing them to be more susceptible to the development of OA due to their athletic activity.

In theory, if increased movement of the talus were present as the amount of force increased within the ankle joint, this would increase the shearing and rotational forces acting upon the cartilage, which could over time lead to degeneration. One study found 66% of patients with CAI had lesions present within the cartilage.[43] An increase in force translation within the ankle joint could lead to further degeneration of these lesions if activity level is maintained. In additions, a link has also been found between varus malalignment of the ankle joint and CAI.[43] Malalignment of the ankle joint would cause increased stress to be placed on the superficial articular cartilage, a key layer of cartilage in preventing OA.[34] Over time, chronic structural changes in the ankle along with increased in loading of the joint could lead to OA.[34] Future research should examine if increased vertical GRFs are related to the development of OA or predispose individuals to an increase risk of stress fractures.

Lastly, clinicians may be able to use vertical GRF within the rehabilitation of individuals with CAI. Gait retraining has been shown to be an effective tool in decreasing loading rates in subjects with previous stress fractures.[29] Subjects were provided with feedback over a one month period with instructions to run softer and provided instant feedback with a tibial accelerometer.[29] Following one month of gait retraining, subjects had a significant decrease within the impact peak force and average loading rates.[29] In individuals with CAI, short-term rehabilitation programs have been found to improve function and gait within subjects with CAI.[44] These study have shown that interventions can alter the gait of individuals with CAI. Future research should consider what rehabilitative techniques would provide the best outcomes for decreasing loading rates in subjects with CAI.

Limitation

A limitation in this study is that we did not control for shoe type of each individual subject. We asked subjects to run in their normal shoes to simulate their normal activity. Although shoe type can alter GRF[39], subjects running in their normal running shoes best simulates the normal activity of athletes. All sports normally see their participants within shoes and shoe type varies among individuals. All shoes worn by subjects were similar within the amount of cushioning present; therefore, we do not believe this had a significant impact on our results.

CONCLUSION

In conclusion, kinetic differences were found between individuals with CAI and healthy individuals while running. This is the first study to report differences in vertical GRFs while running in individuals with CAI. Increased loading rates and peak impact peaks may be contributed to improper foot positing at initial contact and strength deficits found in subjects with CAI. Additionally, increased loading rates and vertical GRF could be predisposed subjects with CAI to increased risk of stress related and the potential onset of OA.

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TABLES

Table 1: Demographics of subjects by group. (n= 24)

	Gender	Age (yrs) Mean (SD)	Height (m) Mean (SD)	Weight (kg) Mean (SD)	MPW Mean (SD)	IDFAI Mean (SD)
Control Group	7 Males; 6 Females	20.4 (3.6)	1.75 (.08)	66.49 (10.38)	37.75 (22.51)	.08 (.23)
CAI Group	5 Males; 6 Females	21.2 (1.3)	1.73 (.09)	68.07 (11.16)	46.02 (19.58)	16.00 (6.63)

MPW = Average Mileage per Week, IDFAI = Identification of Functional Ankle Instability

Table 2: Peak GRFs, Time to peak GRFs and loading rates between groups while running

	Control Group Mean (SD)	CAI Group Mean (SD)	p-value	Effect Size
Impact Peak (N/BW)	1.69 (0.20)	2.05 (0.24)*	<0.001	0.434
Time to Impact Peak (ms)	38.11 (2.07)	38.07 (1.49)	0.962	0.000
Active Peak (N/BW)	2.52 (0.08)	2.71 (0.18)*	0.002	0.347
Time to Active Peak (ms)	131.46 (6.09)	117.27 (5.96)*	<0.001	0.600
Average Loading Rate (N/BW)/s	77.77 (10.04)	93.84 (10.89)*	0.001	0.391

BW = Body Weight, ms = milliseconds, s = seconds

* Significant difference between the groups

LEGEND OF FIGURES

Figure 1: Running on a Instrumented Treadmill

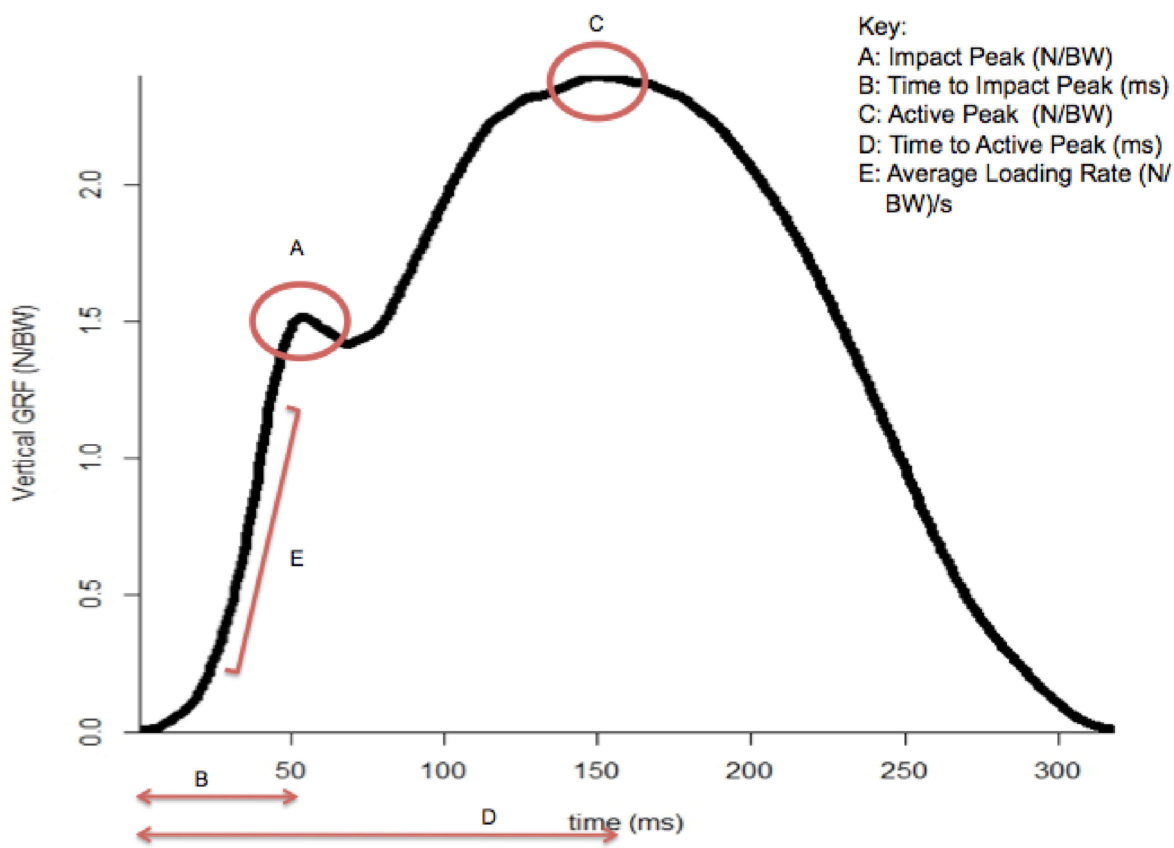

Figure 2: Dependent variables of the vertical GRF curve

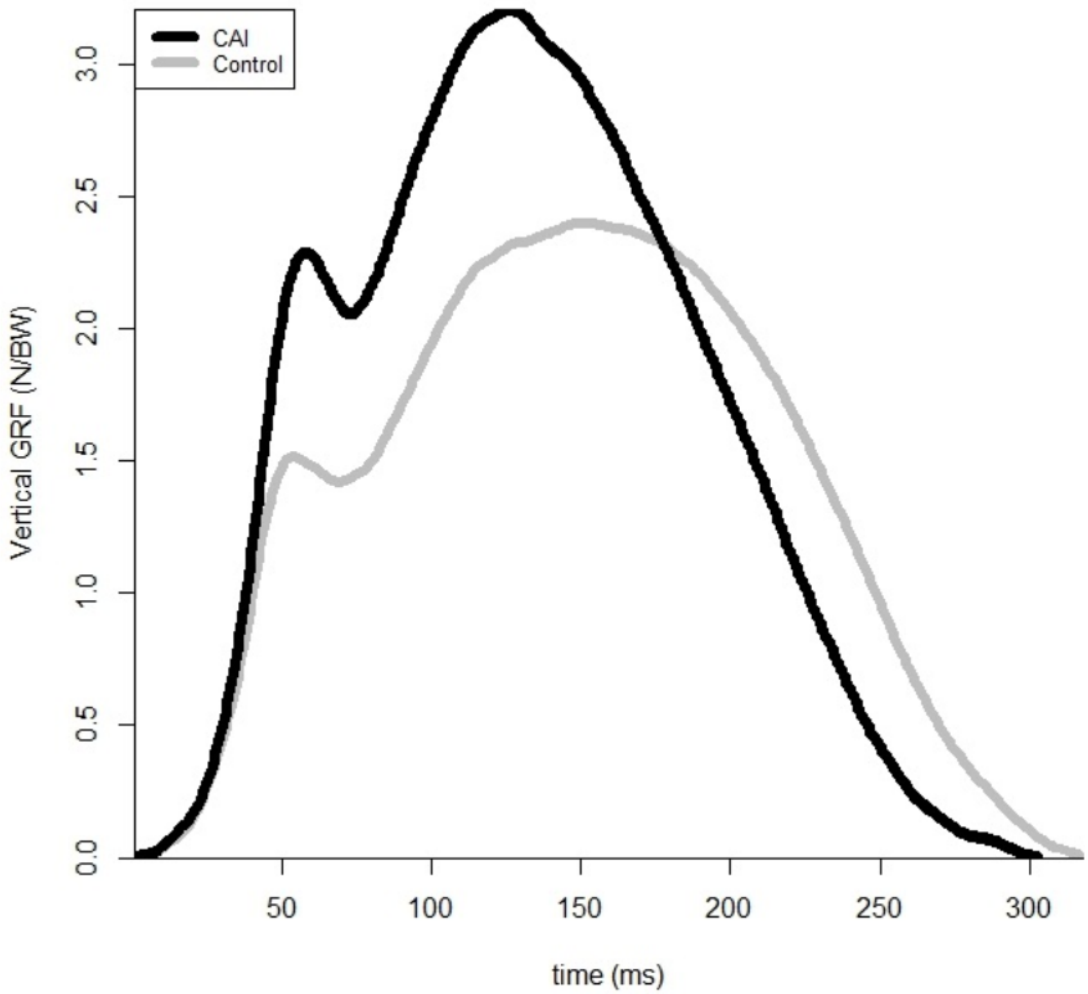

Figure 3: Comparison of two vertical GRF curves between groups

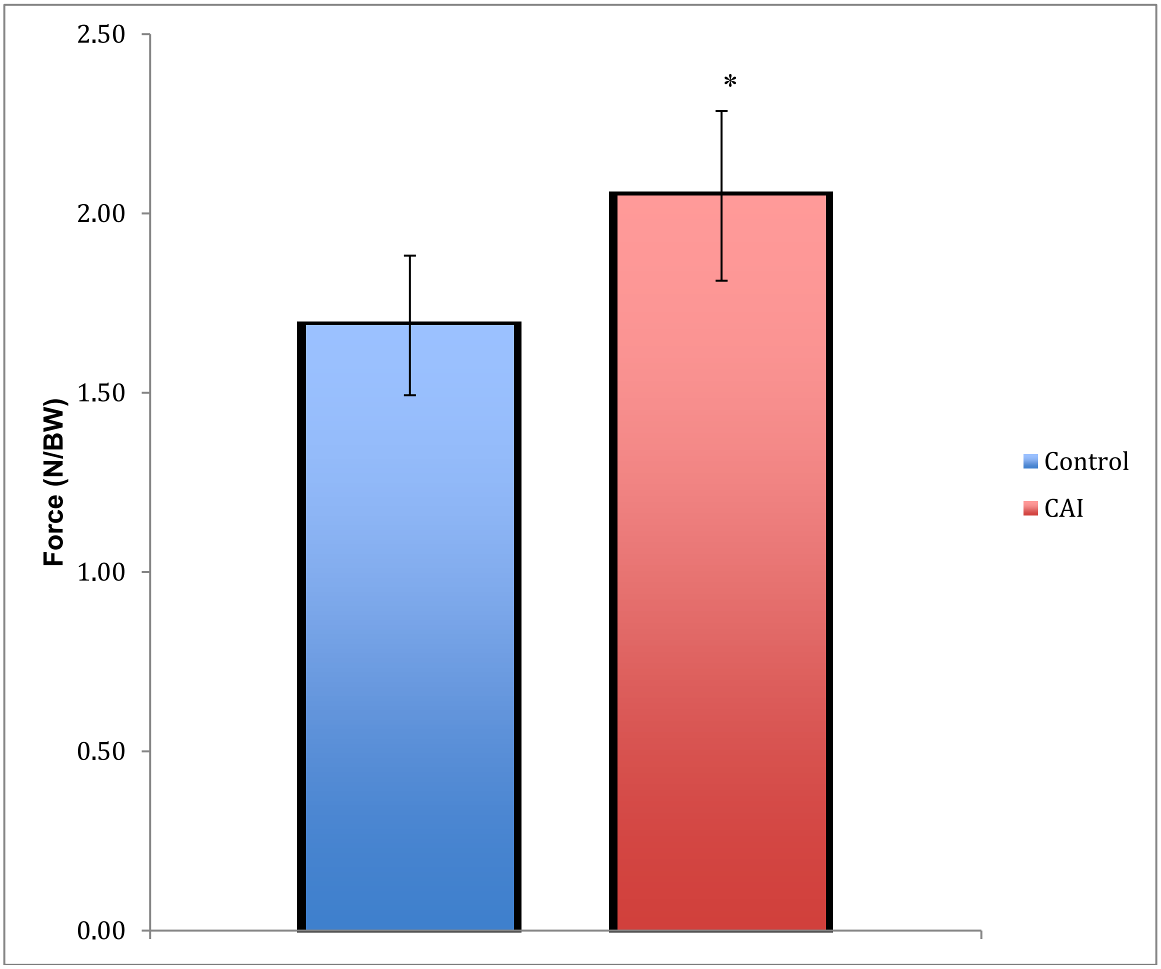

Figure 4: Average impact peak force between groups. * indicates a significant difference between groups.

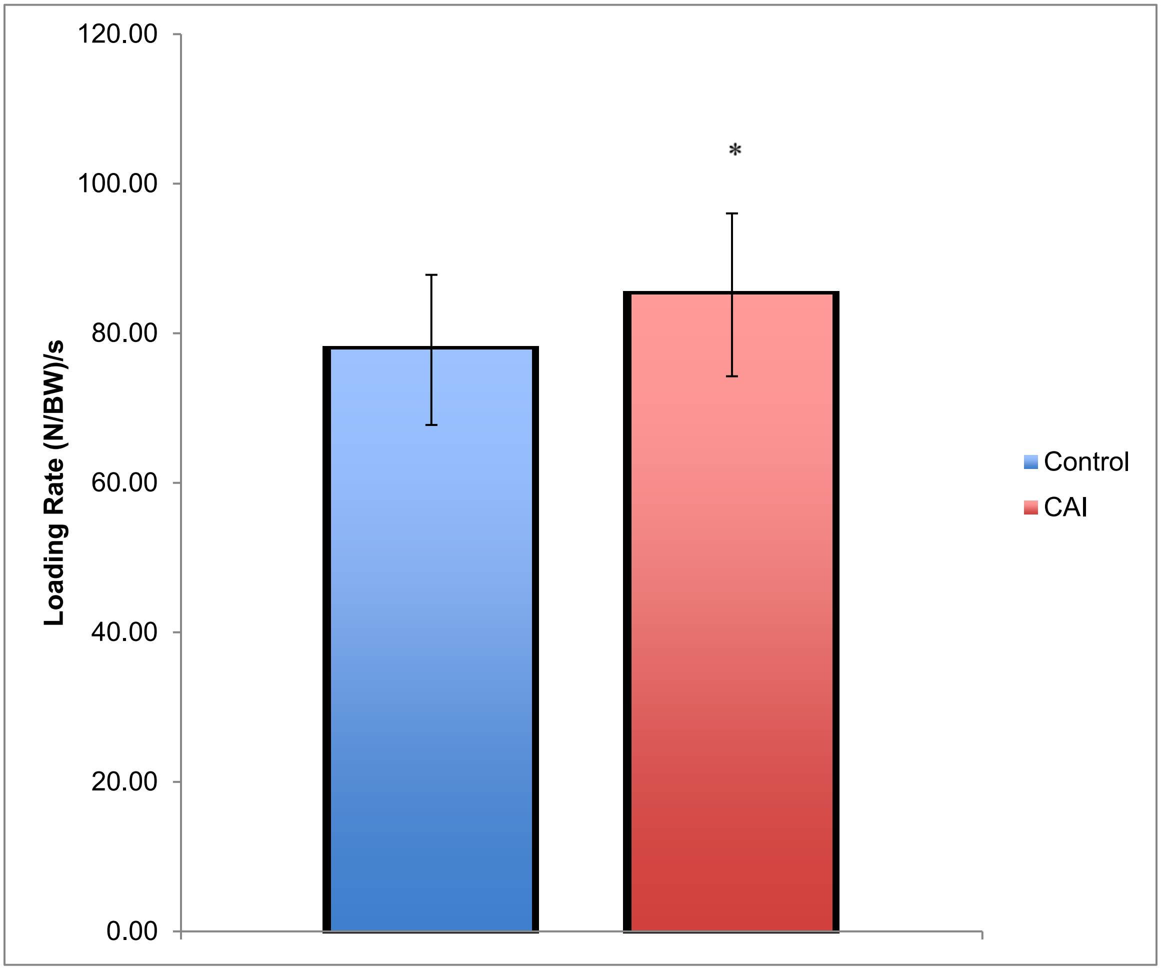

Figure 5: Average loading rate between groups. * indicates a significant difference between groups.

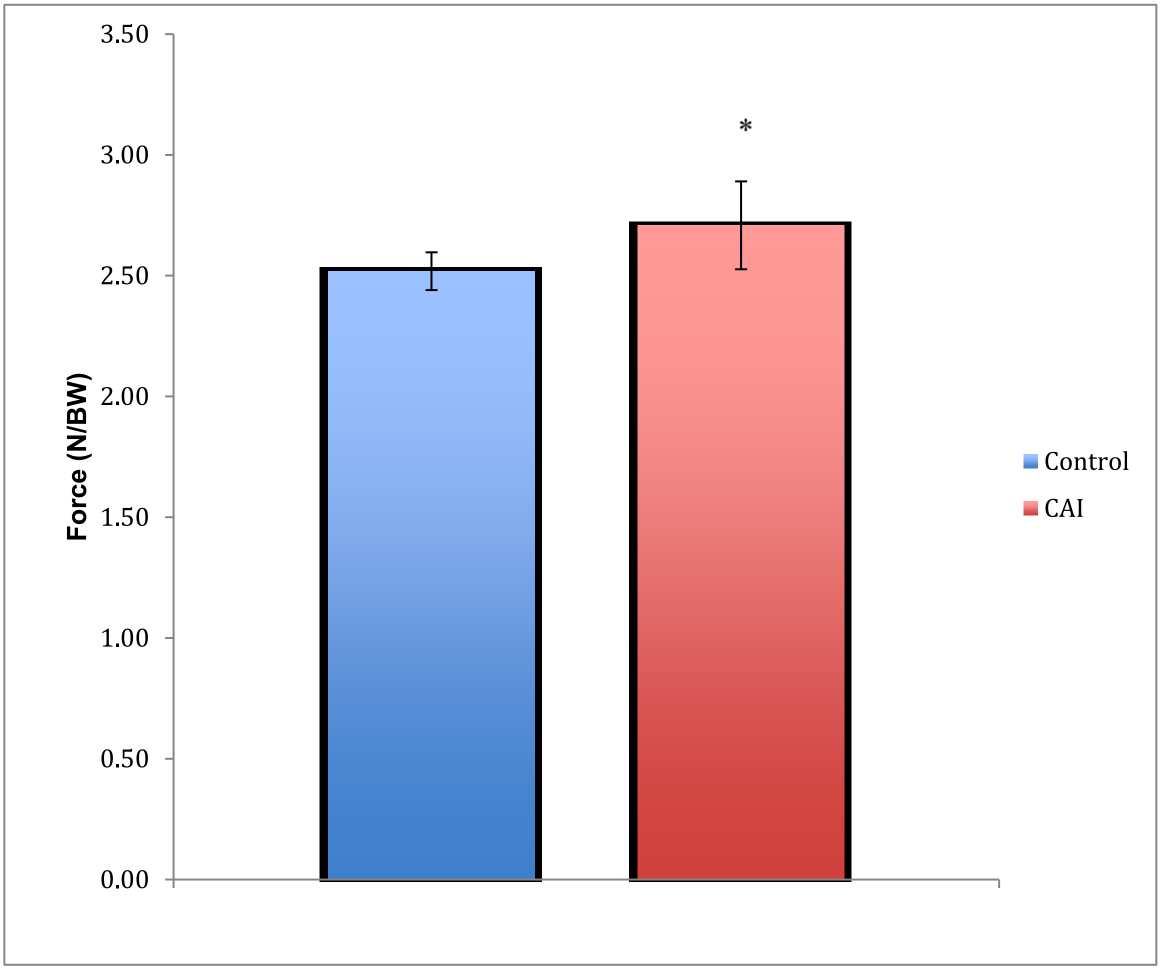

Figure 6: Average active peak force between groups. . * indicates a significant difference between groups.

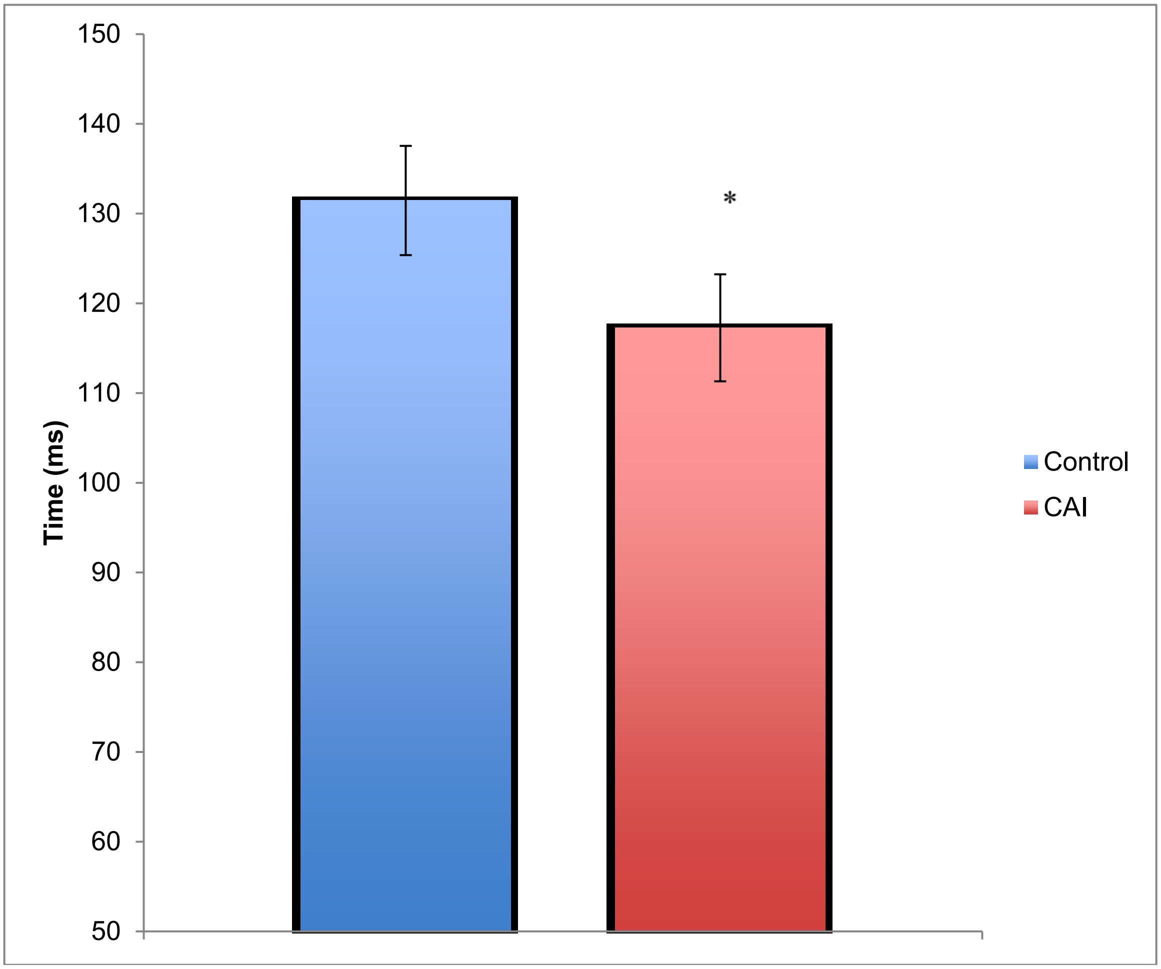

Figure 7: Average time to active peak force between groups. * indicates a significant difference between groups.

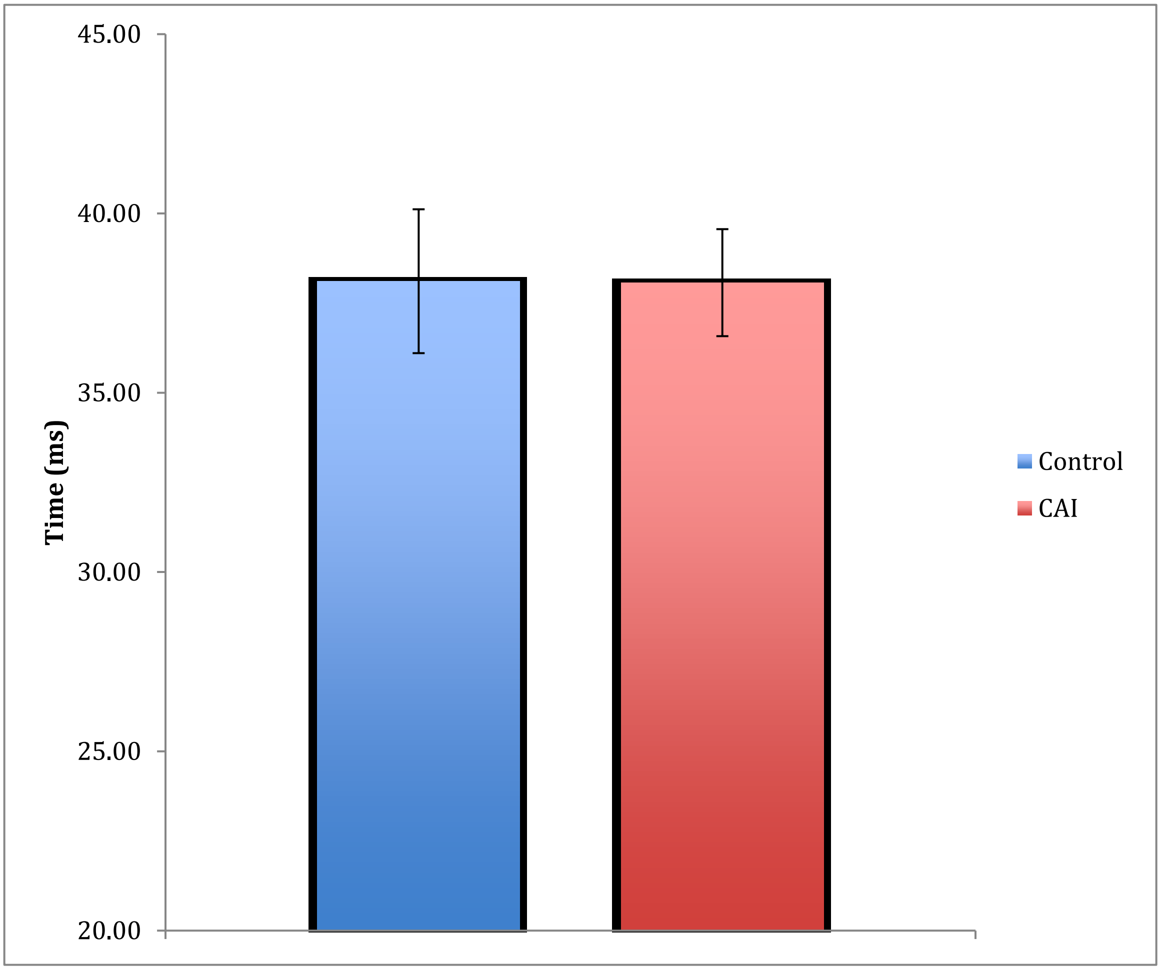

Figure 8: Average time to impact peak force between groups

APPENDICES

APPENDIX A

Operational Definitions, Assumptions, Delimitations, Limitations, Independent Variables, Dependent Variables, Research Hypothesis, Statistical Hypothesis, Null Hypothesis

Operational Definitions

Active Runner: An active runner is classified as an individual who runs for a minimum of three days and 20 miles per week. Individuals must have consistently ran for the past year.

Acceptable Trial: An acceptable trial during running is when at least five consecutive stance phases are captured and recorded directly on the force plate.

Active Peak Force: The greatest amount of force produced by the subject during the stance phase, normalized to body weight (N/BW).[1]

Average Loading Rate (ALR): The slope of the impact peak from 20-80%. Expressed in (N/BW)/s.[2]

Chronic Ankle Instability (CAI) Subjects: Subjects that have been diagnosed with a significant ankle sprain at least one-year prior to testing, a current feeling of giving way in the ankle joint.[3] Subjects will have a score of 11 or higher on the IdFAI and be an active runner. Also, subjects will have no other lower extremity injuries within the last three months, history of surgery or fractures to the lower extremity or enrolled in any rehabilitation for any injury.

Control Subjects: Subjects who fall within the active population criteria and have no previous incident of an ankle sprain occurring. Also, subjects will have no other lower extremity injuries within the last three months, history of surgery or fractures to the lower extremity or enrolled in any rehabilitation for any injury.

Double Flight: A stage in the running cycle where both feet are off the ground simultaneously.

Ground Reaction Force (GRF): The force exerted by the ground on the foot during contact. Normalized to body weight (N/BW).

Force Plate: An instrument that uses load cells to measures force produced by the body as it moves across the plate. Measured in Newtons (N).

Identification of Functional Ankle Instability Questionnaire (IdFAI): A questionnaire developed to determine the presence of ankle instability in subjects. Scores of 11 of more indicate the presence ankle instability within that ankle.

Initial Contact: The initial moment when subjects make contact with the treadmill.

Impact Peak Force: The maximum in the vertical GRF data within the first 50 ms of the stance phase, normalized to body weight (N/BW).[4]

Mid-foot Striking: An individual making contact with the ground with the middle 1/3 of their foot. On a GRF graph, the absence of an initial impact force is indicative of a mid-foot striker.[5]

Newton (N): The unit of force, equal to the amount of force required to move a mass of one kilogram at the rate of 1 meter per second squared.

Meters per Second (m/s): The value for the speed at which subjects ran.

Physical Activity Readiness Questionnaire (PAR-Q): A questionnaire developed to determine if subjects between the ages of 15-69 are able to safely engage in physical activity.[6]

Rear foot Striker: An individual striking the ground with the distal 1/3 aspect of his or her foot. Commonly known as of a “heel strike”. On a GRF graph, the presence of an impact peak force during the first 50 ms of the stance phase is indicative of a rear foot striker.[4,5]

Running Gait: the following phases and event markers define a running cycle: stance phase (foot strike, mid-support, toe off) and swing phase (follow through, forward swing, foot descent). Individuals exhibit a double flight gait pattern during activity.

Stance Phase: The moment from initial contact to directly before the foot is completely off of the ground.

Swing Phase: The moment from toe off to initial contact of the foot.

Standardized Running Speed: A set speed that is easily accomplished by the subject’s given the set inclusion criteria and by gender. The standardized speed was set to 3.3 meters per second.

Time to Active Peak Force: Time from heel strike to the active peak force, in ms.[1]

Time to Impact Peak Force: Time from heel strike to impact peak force, in ms.[1]

Assumptions

The following assumptions will apply to this study:

1. All subjects will follow directions during each trial
2. All subjects state they will be truthful on the questionnaire
3. Different running shoes will not have a major impact on the dependent variables

Delimitations

The following delimitations will apply to this study:

1. Subjects will all be active runners
2. Subjects will all be free of acute injury
3. Subjects will all be running at least three days a week
4. Subjects will all be running at twenty miles
5. Subjects will all be in their regular running shoes
6. Subjects data will all be collected on the same instrumented treadmill
7. The same examiners will collect all data sets
8. Only complete stance phases collected by the force plate will be analyzed

10. Kinematic data and EMG activity will not be collected
11. Subjects with CAI will be identified using a cut off score on the IdFAI
12. Subjects will be examined on a stable surface
13. All subjects will not be using orthotics
14. Only subjects with a rear foot strike will be analyzed
15. Testing time will be standardized per subject

16. All subjects will follow their pre-run stretching routine
17. Subjects will run at a standardized running speed
18. All subjects will receive the same instructions
19. Only subjects who identify that they are not receiving physical therapy will be included
20. Only subjects who identify that they have not had a history of lower extremity fractures will be included
21. All subjects will be blinded to the point of data collection

Limitations

1. Data will only be taken over a short time period and not over a specific training run
2. Bilateral subjects with CAI will have the most severe ankle tested
3. Only rear foot strikers will be examined
4. Data can only be associated with an active population
5. Results cannot be applied to forces produced by running on an unstable surface

Statement of the Problem

Subjects with CAI suffer reoccurring lateral ankle instability that can lead to long-term complications at the ankle joint. Researchers are looking to understand how CAI affects movement patterns in these individuals. Researchers have found kinematic and kinetic difference in subjects with CAI while walking. However, few studies have quantified if differences exist in a running. Running gait is more common within various sports than walking. If differences exist, the use of this data could give researchers a way to track the resolution of functional deficits associated with subjects with CAI. Therefore, the purpose of this study is to determine if subjects with CAI exhibit different vertical GRFs from healthy individuals.

Independent Variables

Two independent variables will be evaluated in this study

1. Subjects with CAI
2. Uninjured (control) subjects

Dependent Variables

Six dependent variables will be evaluated in this study

1. Initial Peak Force (N/BW)
2. Active Peak Force (N/BW)
3. Time to Initial Peak Force (ms)
4. Time to Active Peak Force (ms)
5. Average Loading Rate (N/BW)/s

Research Hypothesis

1. There will be a significant increase in the initial peak force produced during the stance phase of gait in subjects with CAI compared to control subjects.
2. There will be a significant increase in the active peak force produced during the stance phase of gait in subjects with CAI compared to control subjects.
3. There will be a significant decrease in the initial time to peak force within subjects with CAI compared to control subjects.
4. There will be a significant decrease in the time to active peak force within subjects with CAI compared to control subjects.
5. There will be a significant increase of the average loading rate of subjects with CAI compared to control subjects.

Statistical Hypothesis

1. Initial Peak Force (N/BW): H_A: $u_c \neq u_{CAI}$

2. Active Peak Force (N/BW): H_A: $u_c \neq u_{CAI}$
3. Time to Initial Peak Force (ms): H_A: $u_c \neq u_{CAI}$
4. Time to Active Peak Force (ms): H_A: $u_c \neq u_{CAI}$
5. Average Loading Rate (N/BW)/s: H_A: $u_c \neq u_{CAI}$

Null Hypothesis

1. Initial Peak Force (N/BW): H_A: $u_c = u_{CAI}$
2. Active Peak Force (N/BW): H_A: $u_c = u_{CAI}$
3. Time to Initial Peak Force (ms): H_A: $u_c = u_{CAI}$
4. Time to Active Peak Force (ms): H_A: $u_c = u_{CAI}$
5. Average Loading Rate (N/BW)/s: H_A: $u_c = u_{CAI}$

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APPENDIX B

REVIEW OF LITERATURE

REVIEW OF LITERATURE

Numerous research articles have been devoted to the topic of understanding why individuals can occur repetitive ankle sprains and the resulting lasting effects. The following literature review will address: gross anatomy of the ankle joint, epidemiology of ankle sprains, pathophysiology of ankle sprains, chronic ankle instability (CAI), CAI questionnaires, kinematic and kinetic differences in walking and running in individuals with CAI, and a comparison of walking and running gait parameters.

Anatomy of the Ankle Joint

The ankle joint is comprised of three different joints known as the subtalar joint, talocrural joint and the distal tibiofibular syndesmosis joint.[1] The talocrural joint is made up of the articulations of the dome of the talus, lateral malleolus, medial malleolus and the tibial plafond. This joint allows plantar flexion and dorsiflexion motion to occur. A joint capsule, lateral ligaments [anterior talofibular (ATF), calcaneofibular (CF) and posterior talofibular ligaments (PTF)] and medial ligaments (deltoid ligaments) support the joint. The ATF originates from the lateral malleolus and connects to the talus at a 45 degree angle from the frontal plane.[2] The CF ligament runs from the lateral malleolus inferiorly and posteriorly at an angle of 133 degrees via the long axis of the fibula.[2] The CF attaches to the lateral aspect of the calcaneus. The PTF ligament originates from the lateral malleolus and inserts on the posterolateral corner of the talus.

The articulations among the talus, calcaneus and navicular makeup the subtalar joint. The multiple articulations between these bones allow for pronation/supination of the foot and internal/external rotation of the lower leg to occur.[3] The subtalar joint is supported by the deep ligaments of the foot (cervical, interosseous, peripheral ligaments and the retinaculum).[1]

However, these ligaments are not fully understood in the current literature regarding their role in providing dynamic support and function to the ankle joint.

In addition, the third joint of the ankle complex is the distal tibiofibular syndesmosis joint.[1] The interosseous membrane, anterior and posterior inferior tibio-fibular ligament stabilize the joint structure and allow only accessory gliding motion to occur at the joint.[1] The joint is important in forming the roof of the ankle mortise and is not commonly affected by lateral ankle sprains.[1]

The ankle joint is also supported by the surrounding musculature. The peroneal longus and brevis provide dynamic support when contracted against lateral ankle sprains.[4] When the tibialis anterior, extensor digitorum brevis and peroneal musculature contract, it leads to an increase of stiffness at the ankle joint that provides dynamic support.[1] The ankle joint is innervated by two nerves the sural and saphenous, which provide sensory information to the body along with three other mixed sensory nerves.[1] The ankle joint receives motor innervation from the tibial, superficial and deep peroneal nerves.[1]

Epidemiology

Overall, ankle sprains are a common athletic injury that continues to occur within active individuals.[1,5] Each year, ankle sprains and fractures account for 20% of injuries seen within the United States emergency rooms.[6] In high school athletics, ankle sprains have been found to account for 85% of all ankle injuries.[7] Ankle sprains were found to be the second most common injury reported by a setting of high school cross country teams.[8] 32% of girls and 28% of boys reported previously suffering an ankle sprain.[8] Other studies have reported 73% of athletes and rates of 80% in the general population of people experiencing multiple ankle sprains.[9,10] In a recent sampling of 512 collegiate and high school students, 23.4% were found to have CAI.[11]

Due to the high prevalence of ankle sprains, it is important to understand why the reoccurrence is still high.

Pathophysiology of Lateral Ankle Sprains

A lateral ankle sprain occurs due to an inversion motion combined with plantar flexion of the talocrural joint and internal rotation of the tibia.[7] This motion causes an increased stress to the lateral ligaments, which can cause damage, or rupture to these ligaments. Increased stress is placed on the ATF ligament when the foot moves into plantar flexion. The ATF is the weakest supporting ligament when placed under tensile stress and is believed to be the first ligament damaged in lateral ankle sprains.[1,7,12]

Ankle Instability

Freeman was the first to describe ankle instability in the literature as a "repetitive occurrence of lateral ankle instability resulting in numerous ankle sprains".[12] It has been reported that the notion of "giving way" of the ankle is identified in 40-60% of subjects who have a history of an ankle sprain.[13] Hiller et al noted the most common signs and symptoms associated with CAI are mechanical instability, functional instability, pain, swelling and a loss of strength in the lower leg musculature.[5] Researchers had attempted to breakdown CAI been into two subgroups.[5] Subjects with abnormal physical findings (i.e. ligamentous laxity) are deemed to have mechanical ankle instability (MAI).[1,5,9] With the use of MRI imaging, injury to the deltoid ligaments is seen in association with injury to the ATF and CF ligaments in subjects with CAI.[14] Subjects with impaired proprioception[15], impaired neuromuscular control[16,17], strength deficits[18] and impair postural control[19,20] are classified as having functional ankle instability (FAI). While previous literature has described subpopulations of the CAI group, the new recommendations by the International Ankle Consortium position statement is to use the term CAI for anyone with ankle instability.[6]

Ankle Instability Questionnaires

To identify subjects with CAI, subjective questionnaires have been developed to determine the presence of ankle instability within subjects. Subjects with CAI are typically identified through self-reported questionnaires.[13,21-23] Currently, there is no specific clinical test to determine the presence of CAI. Numerous questionnaires have been developed however, only the Cumberland Ankle Instability Tool (CAIT)[22], Ankle Instability Instrument (AII)[23], and Identification of Functional Ankle Instability (IdFAI)[13] will be discussed due to recommendations made by the International Ankle Consortium position statement.[6] These three questionnaires have been found to have a high reliability and success rate in determining the presence of CAI.[24]

Ankle Instability Instrument

The AII was developed as a first step to encompass all factors associated with FAI into one questionnaire.[23] The AII examines three different factors associated with ankle sprains: history of ankle instability, the initial severity of the ankle sprain and instability during activities of daily living.[23] A 5 out of 9 on the AII indicates subjects to have FAI.[23] The overall instrument had an $ICC_{(2,1)}$ of 0.95, cronbach coefficient of 0.89, sensitivity of 0.73 and a specificity of 0.85.[23] The $ICC_{(2,1)}$ for the individual factors were 0.93 for the severity of initial ankle sprain, 0.89 of the history of ankle instability and 0.85 for the instability noted during activities of daily living.[23] It was recommended that questions associated with these three factors to be used within future questionnaires to determine the presence of FAI.[23] The three factors were groups of questions that have been found reliable in the self-reporting of instability from subjects. Factor one determined the necessary questions to determine the severity of the initial ankle sprain. Factor two grouped the questions associated with a subjects ankle giving way and the repitive occurrence. While factor three involved the presence occurring during different tasks. Overall, the study was exploratory in nature looking into the best questions to ask in order for subjects to self identify CAI.

Cumberland Ankle Instability Tool

The CAIT questionnaire was developed specifically for addressing the severity of FAI without the need to compare the subjects left and right ankles.[22] The questionnaire is scored on a 30-point scale, with the total score stemming from nine different questions.[22] A score of 27.5 or below indicated FAI. The CAIT was found to have a strong correlation ($\rho = 0.76$, $p < 0.01$) with a visual analog scale, which measured the subjects reported pain score.[22] The CAIT also obtained a moderate correlation ($\rho = 0.50$, $p < 0.01$) with the lower extremity functional scale; which examines limitations associated with a subjects lower extremity.[22] The test had a sensitivity of 82.9% and a specificity of 74.7%.[22] To determine the CAIT test-retest reliability, 18 subjects answered the questionnaire twice within a two-week period in-between each trial, and determined that the CAIT had an $ICC_{2,1}$ of 0.96.[22] Only two out of the 36 subjects surveyed had a score that was greater than a three points difference from their original CAIT score. These results have indicated that the CAIT is an acceptable test for indicating ankle instability.

Identification of Functional Ankle Instability

Finally, the IdFAI was developed to create a questionnaire that was more efficient at identifying subjects with FAI.[13] The IdFAI was based off of a combination of questions from the AII and CAIT questionnaires due to their combined success rate of predicting FAI in subjects.[13,25] The questionnaire consists of 11 questions based on the feeling of instability within their ankle and previous injury to the ankle joint. It was determined that a score of 11 or higher represented the subject to have FAI.[13] The IdFAI was determined to have a sensitivity of 0.79 and a specificity of 0.94 for a discrimination score of 11.[13] The questionnaire was determined to have an accuracy of 89% in predicting subjects with FAI with the use of a 2x2 contingency table based on the minimum criteria for FAI.[13] The minimum criteria for having FAI were the history of one ankle sprain and at least one occurrence of giving way.[13,25] After a critical review of all ankle instability questionnaires, only the IdFAI was found to be able to detect the minimum criteria for having FAI.[24] Simon et al found the IdFAI to have a prediction rate of 87.8% in determining FAI.[24] It was concluded that the IdFAI has a higher accuracy rating than the combined use of both the CAIT and AII in determining the presence of ankle instability. Therefore, in this study we used the IdFAI due to high accuracy in predicting ankle instability in subjects.

Deficits Associated with Ankle Instability during Walking

Joint Kinematics

Currently, researchers have found differences within subjects with CAI gait compared to healthy individuals. Numerous studies have examined the biomechanical variables associated with ankle instability during walking gait.[17,26-31] In a cadaver study, Konradsen and Voigt[4] examined the amount of mal-alignment of the ankle joint caused by the addition of an inversion torque during the terminal swing phase and initial contact phase of the gait cycle. The study found that if a normal ankle was inverted 20 degrees during the swing phase, then the lateral border of the foot will make early contact with the ground causing the foot and ankle complex to go into inversion, plantar flexion and internal tibial rotation.[4] This is a common mechanism associated with the occurrence of a lateral ankle sprain.[1] If a subject presents with this type of biomechanics, it could lead to pre-mature contact with the ground during gait, which can predispose a subject to an ankle sprain.

The ankle joint on average was $2.07^\circ \pm 0.29^\circ$ more inverted at the subtalar joint in individuals with CAI than control subjects though the gait cycle.[28] Specifically, Drewes et al found during the terminal swing phase and initial contact, an increase of $6\text{-}7^\circ$ of inversion occurs in subjects with CAI compared to control subjects.[28] Delahunt et al reported an inverted ankle position during the terminal swing phase of gait in subjects with FAI.[17] Subjects with FAI also display a decreased vertical foot clearance as the subject transitioned from the swing to stance phase.[26,32] In subjects with CAI, no differences have been found within knee and hip joint kinematics during walking.[17,26-31] Therefore, it is believed that CAI only causes compensatory changes within the ankle joint.

Joint Kinetics

In addition, subjects with CAI have altered lower extremity joint kinetics.[16,19,20,33] Subjects with FAI displayed a more laterally deviated center of pressure (COP) trajectory than healthy subjects.[16] They concluded that the COP of subjects with FAI are more laterally deviated during heel strike between 25-90% of the stance phase.[16] The laterally deviated gait has been associated with individuals for recurrent ankle sprains.[33] Subjects with CAI were found to have a decrease maximum propulsion force and a higher maximum braking force than control subjects.[19,20] Researchers have not tied any of these alterations in gait to functional deficits reported in subjects with CAI.

Deficits Associated with Ankle Instability during Running

While the current literature on CAI has focused on many different activities such as walking, jumping and cutting, few studies have focused on running gait. Drewes et al found that subjects with CAI displayed a decrease (4.8 ± 0.6^{o}) in dorsiflexion when compared to control subjects in the first 9-25% of the stance phase.[34] In another study by Drewes and her colleagues, a significant difference was found in inversion-eversion kinematics during treadmill jogging.[28] Subjects with CAI presented with a significant increase in inversion throughout the gait cycle when compared to control subjects.[28] Drewes also noted an increase in shank rotation during 48-55% and 81-96% of their gait cycle in subjects with CAI. The previously reported studies were conducted as the subject ran barefoot on a walkway or treadmill. Only one study to date has examined subjects with CAI while running in shoes. Chinn et al found CAI to be significantly more inverted and plantar flexed than control subjects.[35] Subjects with CAI were more plantar flexed (7.2° ± 0.5°) during 54-68% of the gait cycle.[35] Inversion at the ankle was increased from 11-18%, 33-39% and 79-84% compared to controls.[35] Subjects also exhibited a decreased foot progression angle in subjects with ankle instability compared to control subjects.[36] It has been found that subjects with a decreased foot progression angle exhibit a more inverted foot position during the absorption phase of running.[36] This could potential predispose the ankle to sprains. Lastly, Brown et al found no significant results during the running trials in subjects with MAI between FAI groups in ankle joint inversion, eversion, dorsiflexion, and plantar flexion angles at initial contact in recreational runners. [26,27]

Finally, few studies have also examined different kinetic variables associated with CAI during running. No specific study has examined vertical GRFs in subjects with ankle instability and compared to them to control subjects while running.[37] Morrison et al found subjects with CAI displayed a more lateral deviated COP trajectory from when the heel makes contact with the ground to when the foot is flat. [38] Huang et al found a significant increase in contact time underneath the mid-foot while a decrease in the forefoot area occurred. [36] Compared to control subjects, an increase in the peak pressure was found underneath the first and third metatarsal heads.[36] Finally, more research is needed to determine what kinetic deficits associated with CAI are causing what specific alterations to gait while running.

Gait Parameters

While researchers have found differences in subjects with CAI while walking, these differences cannot be directly correlated with running. Studies examining gait parameters while walking and running in subjects with CAI cannot be assumed to exhibit the same differences during running. The following section describes the differences found between walking and running gait. Both walking and running gait is defined from the initial contact of the foot to the moment prior to the next initial contact.[39] However, while walking, 60% of the time the leg is in the stance phase and 40% of the time within the swing phase.[40] The stance phase is from the point of initial contact to toe off. The swing phase is from toe off to until the moment before initial contact of the same foot. During running, as the velocity of pace increases, the amount of time spent in the stance phase is decreased to 40% and time in the swing phase is increased to 60%.[41]

During running, subjects also produce different kinetic variables than they do while walking. Specifically, ground reaction forces (GRFs) are a measurement of magnitude and rate of loading to the lower extremity.[40] Force plates are used to measure three specific GRFs; vertical, medial/lateral and anterior/posterior forces. Anterior/posterior and medial/lateral forces represent a small portion of body weight during gait than vertical GRFs.[40] Vertical GRFs increase as a subject's speed increases.[39] During walking, subjects produce a vertical GRF force that is equal to 1.3-1.5 times their body weight.[40] However, GRFs can reach 2-3 times a subjects body weight during peak force production while running.[40] In running, a small peak known as the "impact peak" occurs during the first 50 ms of the stance phase while the "active peak" occurs during the mid-stance phase of gait.[42,43] The first peak represents a passive motion that occurs when the heel makes contact with the ground as weight is accepted by the stance limb.[44] The second peak is the amount of force produced while toe off occurs.[43] As speed increases, time to the active peak GRF have been found to decrease and active peak GRF increase.[45]

Additionally while running, GRFs have been found to differ due to striking patterns of each subject. Impact peaks are only seen in runners who strike the ground with their rear foot.[43] The impact peak is absence in GRF graphs in mid-foot and fore-foot strikers.[43] Also, the inclusion of running shoes can causes individuals to strike the ground predominantly on their rear foot compared to a mid-foot or forefoot strike, possibly due to elevated heels found in running shoes.[46] This leads to a more predominate impact peak. With the majority of sporting events involving some type of athletic footwear, we examined subjects in their shoes to simulate their regular activity.

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APPENDIX C

DATA PROCEDURE CHECKLIST

Before Subject Arrives:

- Turn on Lights
- Turn around treadmill safety bars
- Turn treadmill on, turn switch to the right.
- Press and hold reset button, make sure the light is steady green
- Turn on three switches on the back of the vicon unit; left of computer
- Turn on Computer
- Open Vicon Nexus and Treadmill Bertec
- In Vicon, click capture.
- Open CAI running.
- In data management, create new subject
- Highlight top level
- Click new subject
- Stand on treadmill to confirm it has synced
  - Left force plate (#4)
  - Right force plate (#3)
- On R/L control open force plates, zero out treadmill
- Take out questionnaires and informed consent and label with subject number
- Zero force plate on computer
- Fx,Fy,Fz is selected

With Subject:

- Subject reads and signs Informed consent sheet
- Subject fills out PAR-Q, Health/Activity Level Questionnaire and IdFAI
- Subject is given verbal command and instructions.

- Subject steps onto the treadmill
- Treadmill is brought up to speed via the computer control
- Subject begins to warm up for five minutes
- Subject is given opportunity to stretch
- Standardized trial begins
- Treadmill is brought up to speed via the computer control
- Subject is given the verbal command at the 4:30 mark
- Data collection begins for 30 seconds at the 4-minute mark.
- Condition ends at the 5:00 mark.
- Trial one is saved.
- The subject is given the opportunity to cool down for five minutes at an easy pace on the treadmill
- Data set is saved on the computer

Post-Subject

- On right hand side of Vicon, data management is selected
- Subject is selected
- Condition is selected
- Pipeline is selected
- File IO is selected
- Export ASCIII is selected
- Force Plate Data is selected
- Play is clicked
- Click to the desktop
- Open CAI running

- Click both ASCIII files
- Rename with subject number and trial
- Transfer files to thumb drive

APPENDIX D

DATA COLLECTION FORM AND ANY SURVEYS

Data Collection Form

Subject #:______

Consent Form #: _____

PAR-Q Questionnaire #: ______

Health & Activity Questionnaire #: ________

IdFAI Questionnaire Score: _____

Group: CAI Control

CAI Side: Left Leg Right Leg

Self-Selected Speed: _______ m*s

Data Set Name: _________

Condition: Self-Selected Speed OR Standardized Speed

First Foot to strike right belt: Left Foot OR Right Foot

Data Set Name: _________

Condition: Self-Selected Speed OR Standardized Speed

First Foot to strike right belt: Left Foot OR Right Foot

Modified Physical Activity Readiness Questionnaire (PAR-Q)

Subject Number:	**Date:**
Date of Birth:	**Age:**

Regular exercise is associated with many health benefits, yet any change of activity may increase the risk of injury. Please read each question carefully and answer every question honestly:

Yes	**No**	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
Yes	**No**	**2. Do you feel pain in your chest when you do physical activity?**
Yes	**No**	3. **In the past month, have you had chest pain when you were not doing physical activity?**
Yes	**No**	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
Yes	**No**	**5. Do you have a bone or joint problem that could be made worse by a change in your physical activity?**
Yes	**No**	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
Yes	**No**	**7. Do you know of any other reason you should not do physical activity?**
Yes	**No**	**8. Has your doctor ever told you that you have diabetes?**
Yes	**No**	**9. Has your doctor ever told you that you have high blood pressure?**
Yes	**No**	**10. Has your doctor ever told you that you have high cholesterol?**
Yes	**No**	**11. Has your doctor ever told you that you have high blood sugar?**
Yes	**No**	**12. Do you smoke?**
Yes	**No**	**13. Are you currently inactive?**
Yes	**No**	**14. Do you have a father, brother or son with heart disease before the age of 55 years old or a mother, sister or daughter with heart disease before the age of 65 years old?**

15. Measure height and weight to determine BMI:
Height:________
Weight:________

Health & Running History Questionnaire

Subject #: ________

Please fill in the following information:

Sex: Male or Female

Please circle your response:

Health History:

1. Have you suffered any injury to the lower extremity in the last three months? Yes No
   If yes, please explain: ______________________________
   ____

2. Are your currently receiving any treatment for any injury? Yes No
   If yes, please explain: ______________________________
   ____

3. Have you had any lower extremity surgeries? Yes No
   If yes, please explain: ______________________________
   ____

4. Have you had any fractures to the lower extremity? Yes No
   If yes, please explain: ______________________________
   ____

5. Have you ever been diagnosed by a health care professional with an ankle sprain? Yes No
   If yes, please explain: ______________________________
   ____

6. Do you suffer from a feeling of "giving way" at your ankle? Yes No
   If yes, please explain: ______________________________
   ____

7. Do you wear custom orthotics when you run? Yes No
   If yes, please explain: ______________________________
   ____

Activity Level History:

8. Have you currently been running on a consistent basis for the past year? Yes No

9. How many days per week do you run? ________

10. On average, how many miles per week do you run? ________

IDENTIFICATION OF FUNCTIONAL ANKLE INSTABILITY (IdFAI)

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

Please carefully read the following statement:

"Giving way" is described as a temporary uncontrollable sensation of instability or rolling over of one's ankle.

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

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

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

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

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

❑Have **not** seen someone ❑Mild (Grade I) ❑Moderate (Grade II) ❑Severe (Grade III)

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

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

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

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

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

❑Never ❑Once a year ❑Once a month ❑Once a week ❑Once a day

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

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

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

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

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

❑Never ❑Once a year ❑Once a month ❑Once a week ❑Once a day

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

❑Never ❑Once a year ❑Once a month ❑Once a week ❑Once a day

Version 1.0

APPENDIX E

POWER ANALYSIS

Dayakidis MK, Boudolos K. Ground reaction force data in functional ankle instability during two cutting movements. *Clin Biomech* 2006;21(4):405-411.

Ground Reaction Forces

(3.58-2.97)/((1.14+.86)/2)=.61

Power: .80

Alpha: .05

Approximate group size: ~18

Time to Impact Peak

(0.019-0.027)/((0.006+0.009)/2)=1.07

Power: .80

Alpha: .05

Approximate group size: ~12

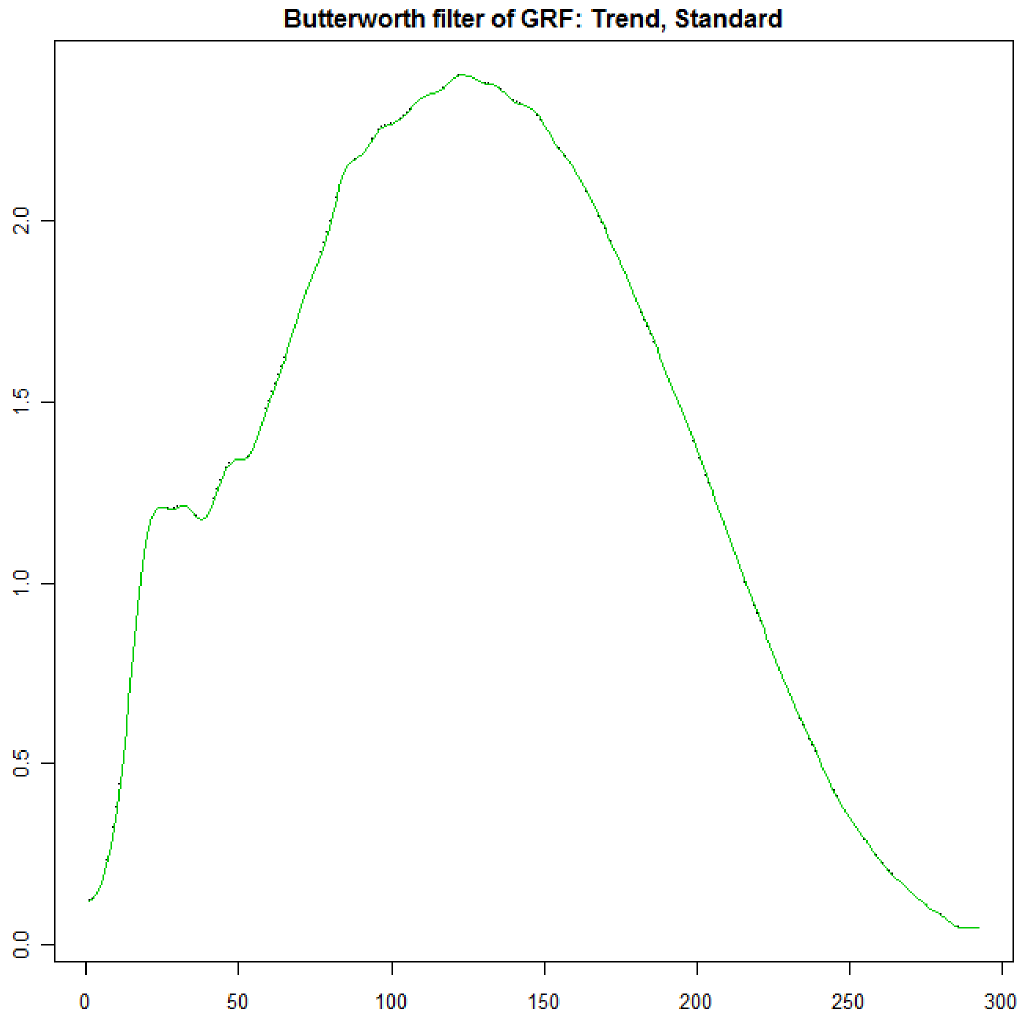
For this study I proposed that we need approximatley 15 subjects per group.

APPENDIX F

PILOT DATA

Standardized Speed

Subject	Speed (m/s)	Impact Peak (N/BW)	Time to Impact Peak (ms)	Active Peak (N/BW)	Time to Active peak (ms)	Loading Rate (N/BW)/s
1	3.33	1.4782	24.2	2.4556	97.8	91.70591
2	3.33	1.627	25.0	2.4866	113.0	95.60304
3	2.77	1.603	28.8	2.4242	119.6	66.87749
Overall Mean	**3.14**	**1.569**	**26.0**	**2.4554**	**110.1**	**84.72882**



APPENDIX G

INDIVIDUAL SUBJECT DATA

Individual Subject Data

ID	IDFAI Score	Average Impact Peak (N/BW)	Average Time to Impact Peak (ms)	Average Active Peak (N/BW)	Average Time to Active Peak (ms)	Average Loading Rate (N/BW)/s
1	0.00	1.54	41	2.50	140.40	65.19
3	0.00	1.84	42	2.41	133.00	75.76
4	0.00	1.61	36	2.48	138.00	78.34
5	0.00	1.84	36	2.56	131.60	89.85
6	0.00	1.60	38	2.42	131.60	74.36
7	0.00	1.67	40	2.54	132.00	73.78
8	0.00	1.47	37	2.48	136.00	69.16
9	19.00	2.31	38	2.77	116.20	106.62
10	0.00	1.98	36	2.63	127.60	95.29
11	22.00	2.27	37	2.82	117.20	106.53
13	0.00	1.52	38	2.49	128.20	70.73
14	19.00	2.11	37	2.54	119.60	99.53
16	11.00	1.53	36	2.66	133.60	75.35
17	1.00	2.10	38	2.69	117.60	97.14
19	0.00	1.50	37	2.52	124.00	70.36
20	19.00	2.40	38	3.16	113.20	109.52
21	27.00	1.90	40	2.51	119.80	83.55
22	20.00	1.95	36	2.61	116.60	95.11
23	11.00	1.99	40	2.62	113.60	86.33
24	0.00	1.62	38	2.49	132.60	74.36
25	14.00	2.02	39	2.69	113.00	88.11
26	1.00	1.65	38	2.53	136.40	76.69
27	14.00	1.96	39	2.59	113.20	87.13
28	15.00	2.10	39	2.82	114.00	94.52