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A Comparison of Neuromuscular Control between Subjects with and without Chronic Ankle Instability

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A Comparison of Neuromuscular Control between Subjects with and without Chronic Ankle Instability

by

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the requirements for the degree
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Each person whose signature appears below certifies that this dissertation in his/her opinion is adequate, in scope and quality, as a dissertation for the degree Doctor of Science in Physical Therapy

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ABBREVIATIONS

CAI	Chronic Ankle Instability
FI	Functional Instability
MI	Mechanical Instability
NMC	Neuromuscular Control
CAIT	Cumberland Ankle Instability Tool
AII	Ankle Instability Instrument
EMG	Electromyography
SEBT	Star Excursion Balance Test
COP	Center of Pressure
Gmed	Gluteus Medius
Gmax	Gluteus Maximus
TA	Tibialis Anterior
PL	Peroneus Longus
MVIC	Maximal Voluntary Isometric Contraction
MVC	Maximal Voluntary Contraction
AD	Anterior Direction
MD	Medial Direction
PMD	Posteromedial Direction
PLD	Posterolateral Direction
ANOVA	Analysis of Variance
SD	Standard Deviation
CI	Confidence Interval
OKC	Open Kinetic Chain
CKC	Closed Kinetic Chain
FAAM	Foot and Ankle Ability Measure
GROC	Global Rating of Change

ABSTRACT OF THE DISSERTATION

A Comparison of Neuromuscular Control between Subjects with and without Chronic Ankle Instability

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Dr. Everett Lohman, Chairperson

Ankle sprains are common and potentially disabling musculoskeletal injuries occur among physically active individuals. A subsequent problem that is commonly encountered by clinicians due to ankle sprains is the development of ongoing instability. The presence of ankle instability has been linked to impairments in postural and neuromuscular control; however, inconsistent findings have been reported. These discrepancies deem the need to further investigate and provide additional knowledge regarding postural and neuromuscular control strategies utilized by this population. This may enhance the current understanding of chronic ankle instability (CAI) and help to understand how rehabilitation can be customized to specifically target and improve patient outcomes. Therefore, the purpose of this study was to compare postural stability, as well as electromyographic (EMG) activity of hip and ankle muscles during the performance of the Star Excursion Balance Test (SEBT) in subjects with and without CAI.

Methods*:* Forty-eight physically active participants were assigned into three groups (16 control, 16 copers, 16 CAI) based on ankle sprain history and Cumberland Ankle Instability Tool score. Outcome measures included normalized reach distance, center of pressure (COP), and integrated EMG activation of the gluteus medius (Gmed), gluteus maximus (Gmax), tibialis anterior (TA), and peroneus longus (PL) during each reach direction of the SEBT.

Results: There was a significant difference in mean outcome measures between the three study groups. When compared to copers and controls, the CAI group demonstrated significantly diminished dynamic stability as quantified by reach distance and COP measures ($p<0.05$) and less EMG activity of the muscles acting on the ankle and hip ($p<0.05$).

Conclusion: Our findings indicate that individuals with CAI exhibited diminished dynamic stability and decreased EMG activity of ankle and hip musculature during functional testing. Alteration in both, the proximal and distal muscles activity appears to negatively affect measures of postural control and the quality of movement, which may lead to the prolonged functional impairments and the increased recurrence of the undesired lower extremity injuries in this population. Hence, implementing functional exercises that target hip and ankle muscles in the rehabilitation of ankle instability might benefit these patients.

CHAPTER ONE

INTRODUCTION AND REVIEW OF THE LITERATURE

Ankle Sprains

The ankle joint is the second most commonly injured part in/of the body during sports, with lateral ankle sprains being one of the most common/frequent musculoskeletal injuries among physically active individuals.[1,2] They account for approximately 25% to 30% of all sport-related injuries[2], with an incidence rate of 2.15 per person-year in the United States.[3] Although symptoms associated with ankle sprain usually resolve quickly, it is estimated that approximately 40% of individuals who encounter an initial ankle sprain will develop persisting problems/symptoms including pain, subjective instability and/or “giving way”, loss of function, and repetitive ankle injuries leading to a longstanding ankle dysfunction known as chronic ankle instability (CAI).[4,5]

Chronic Ankle Instability

CAI is a common phenomenon that is characterized by repetitive episodes of lateral ankle sprains. Traditionally, CAI has been classified into mechanical and functional ankle instability.[5] Mechanical instability (MI) is often referred to as a movement of the ankle joint that goes beyond its normal physiological or accessory range of motion as a result of pathological laxity after ankle ligament injury.[5] This damage can predispose the ankle to further episodes of instability, arthrokinematic restriction (limited joint mobility), and degenerative and synovial changes.[6] On the other hand, functional instability (FI) refers to subjectively experienced episodes of “giving way” and feeling of instability without the existence of mechanical laxity.[5,6] Evidence suggests that FI can exist separate from MI; however, the two might also coexist.[5,7] For a subject to be classified as having CAI, residual symptoms such as feeling of ankle instability or episodes of "giving way" should be present for a minimum of 1 year after the initial sprain.[5,6]

Postural Control

Postural control is an essential requirement for all motor tasks.[8] It can be classified as either static or dynamic.[9] Static postural control is the ability to maintain balance over a stable base of support, whereas dynamic postural control is the ability to keep the center of gravity above a stable base of support while maintaining stability throughout a specific movement.[9] It has been reported that postural control is altered after an acute lateral ankle sprain.[10] Evidence has suggested that CAI is often associated with poor postural control.[10,11] Impairments of postural control are usually thought to be the consequences of proprioception and neuromuscular control (NMC) deficits that occur after ligament injury.[11]

However, despite the robust body of knowledge, there are still some discrepancies in the literature regarding postural control in individuals with CAI.[12] Several studies have reported differences in postural control between individuals with CAI and controls[13,14,15]; others have not reported such differences.[16,17] When compared to healthy controls, individuals with CAI have shown more kinetic and kinematic variability during jump landing, and they took longer to regain postural stability after the jump than those with stable ankles.[15] In contrast, Wikstrom et al[16] investigated the same variable in similar groups and reported no difference.

Neuromuscular Control

NMC has been defined as "the interaction between the nervous and musculoskeletal systems to produce a desired effect or response to a stimulus."[18] Previous studies have identified altered NMC patterns in subjects with CAI when compared to healthy controls.[19,20] During a drop jump test, subjects with CAI had less anticipatory activation of PL muscle compared to healthy controls.[19] NMC also has been compared between individuals with CAI and those who have experienced ankle sprains but did not develop CAI.[21,22] This group of individuals are defined as copers. Copers have been found to have a higher activation of TA and PL during more dynamic tests such as jump landing and gait when compared to CAI subjects.[21,22] These alterations were reported to represent adaptive strategies that copers may acquire as a protective mechanism against reinjury.[22] However, Pozzi et al[17] found no significant differences in ankle muscles activation patterns between copers and subjects with CAI using the SEBT. While damage to the peripheral mechanoreceptors that provide proprioceptive input may result in altered NMC[23], disruptions in the central pathways for NMC are also thought to occur following the injury[24,25], suggesting that deficits associated with CAI may be the consequences of both peripheral and centrally mediated alterations in NMC. However, limited information exists about these alterations in this population. Most of the previous research that studied this phenomenon has focused primarily on NMC impairments at the injured ankle joint complex. Although this is a viable means for providing answers regarding changes that occur at single joint neural centers, recent research has identified disruption in proximal joints neuromuscular activation patterns in patients with CAI.[26,27] Webster and Gribble[26] reported decreased gluteus maximus (Gmax) activity in those with CAI during a single leg rotational squat exercise. Patients with CAI have also displayed a delay in onset of muscle activation and less anticipatory activation in muscles around the ankle, knee, and hip during a transition from bilateral to unilateral stance, which might indicate an involvement of multiple neural pathways.[28] However, despite previous findings, it is still unknown whether these alterations are responsible for the deficits in postural control in this population.

Star Excursion Balance Test

The SEBT has been deemed a valid and reliable clinical test of dynamic balance and has been proposed as a potential screening tool in detecting balance differences between those with and without stable ankles.[29,30] Postural control during the SEBT is reflected by the reach distance in 8 different directions, with an increase in the reach distance implies greater postural control.[29] Recent research has examined postural stability during SEBT performance. Olmstead et al[31] and Hertel et al[32] reported that subjects with CAI had significantly decreased reach distances as compared to the uninvolved limb and the reach distances of healthy controls. Nakagawa and Hoffman[33] also reported better performance in healthy control subjects as compared to CAI subjects. On the other hand, Pozzi et al[17] found no significant differences in reach distances, kinematic or kinetic data between subjects with and without CAI.

Although numerous studies have used this test to assess postural control in patients with CAI, there has been less investigation regarding muscle activation patterns necessary to complete the SEBT in patients with CAI. Gribble et al[34] examined dynamic postural stability using the SEBT following a fatiguing protocol to the ankle, knee, and hip muscles and reported that fatigue to the injured side created significantly increased postural deficit compared to fatigue of the uninjured side and healthy controls. Though muscle activity was not measured in this study, the authors suggest that proximal muscle activation may have been altered following the fatigue protocol, resulting in decreased knee and hip flexion angles and subsequent decreases in reach distance. Electromyographic (EMG) data, however, was not collected in this study, which limited their ability to fully identify the NMC strategies utilized by these individuals.

Summary

Motor control at the hip is crucial for maintaining postural stability during weight bearing activities[35,36], and maybe affected in this population. Previous research has extensively focused on alterations in the ankle musculature with less emphasis on the activity of hip muscles necessary to complete a dynamic task in CAI individuals. Hence, more research is needed to further understand the effects of proximal and distal neuromuscular alterations on postural stability in this population. Simultaneous analysis of the ankle and hip muscles activations patterns as well as dynamic stability during the performance of the SEBT in subjects with and without CAI (copers & healthy) have not been previously examined. Examining the activity of the ankle and hip muscles during the performance of a functional task can provide more insight into the neuromuscular strategies utilized by these individuals to maintain stability. Additional knowledge regarding the interaction between hip and ankle muscle function during this activity may enhance the current understanding of CAI and help in customizing rehabilitation protocols that specifically target and improve patient outcomes. Therefore, the purpose of this study was to compare postural stability and EMG activation of TA, PL, Gmed, and Gmax muscles during the performance of the SEBT in subjects with and without CAI.

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CHAPTER TWO

NEUROMUSCULAR CONTROL IN SUBJECTS WITH AND WITHOUT CHRONIC ANKLE INSTABILITY

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Abstract

Background/Purpose: Ankle sprains are common and potentially disabling musculoskeletal injuries existing among physically active individuals. A subsequent problem encountered by clinicians due to ankle sprains is the development of ongoing instability. Chronic ankle instability (CAI) has been linked to impairments in postural and neuromuscular control; however, inconsistent findings have been reported. Individuals who experience lateral ankle sprain, but do not develop instability, termed copers, may adapt different neuromuscular control strategies after injury. This study aimed to compare postural stability and electromyographic (EMG) activity of hip and ankle muscles during the performance of the Star Excursion Balance Test (SEBT) in subjects with and without CAI.

Methods*:* 48 participants were assigned into three groups (16 control, 16 copers, 16 CAI) based on ankle sprain history and Cumberland Ankle Instability Tool score. Outcome measures included normalized reach distance, center of pressure (COP), and integrated EMG activation of the gluteus medius (Gmed), gluteus maximus (Gmax), tibialis anterior (TA), and peroneus longus (PL) during each reach direction of the SEBT.

Results: Compared to copers and controls, the CAI group demonstrated significantly diminished dynamic stability as quantified by reach distance and COP measures ($p< 0.05$) and less EMG activity of TA during the anterior direction (33.1% ± 10.1% vs. 44.8% ± 12.7% vs. 51.7% ± 8.4%, $p<0.01$) and Gmax in the posterolateral direction (25.6% ± 9.4% vs. 37.5% ± 13.8% vs. 40.2% ± 17.2%, $p=0.01$).

Conclusion: Alteration in proximal and distal muscles activity appears to negatively affect postural control and quality of movement, which may lead to prolonged functional

impairments. Hence, implementing functional exercises that target hip and ankle muscles in the rehabilitation of ankle instability might benefit these patients.

Key words: ankle sprains; copers; hip muscles; electromyography; postural control; Star Excursion Balance Test

Introduction

The ankle joint is the second most commonly injured part of the body during sports, with lateral ankle sprains being one of the most common musculoskeletal injuries among physically active individuals.[1,2] They account for approximately 25% to 30% of all sport-related injuries[2], with an incidence rate of 2.15 per person-year in the United States.[3] Although symptoms associated with ankle sprain usually resolve quickly, it is estimated that approximately 40% of individuals who encounter an initial ankle sprain will develop persisting symptoms including pain, subjective instability or “giving way”, loss of function, and repetitive ankle injuries leading to a longstanding ankle dysfunction known as chronic ankle instability (CAI).[4,5]

Postural control is an essential requirement for all motor tasks.[6] It can be classified as either static or dynamic.[7] Static postural control is the ability to maintain balance over a stable base of support, whereas dynamic postural control is the ability to keep the center of gravity above a stable base of support while maintaining stability throughout a specific movement.[7] It has been reported that postural control is altered after an acute lateral ankle sprain.[8] Evidence has suggested that CAI is often associated with poor postural control.[8,9] Impairments of postural control are usually thought to be the consequences of proprioception and neuromuscular control (NMC) deficits that occur after ligament injury.[9]

Neuromuscular deficits, specifically alterations in the lower extremity muscle activation patterns have been considered as major contributing factors to the impairments that affect stability and perceived function in patients with CAI.[10] Patients with CAI have demonstrated altered NMC strategies during functional activities.[11,12] During walking, patients with CAI exhibited an increase in peroneus longus (PL) activity after initial contact (IC) with a slight trend prior to IC compared to healthy individuals.[11] Whereas, during a unipedal drop jump, they demonstrated less anticipatory PL muscle activity compared to healthy controls.[12] These alterations in motor control were suggested as possible contributors to the inversion injuries in this population.[12] NMC also has been compared between individuals with CAI and those who have experienced ankle sprains but did not develop CAI.[13,14] This group of individuals are defined as copers.[14] When compared to CAI patients and healthy controls, copers had an increase in PL activity during jump landing[13] and tibialis anterior (TA) activity during the pre and post touchdown phases of stepping down in continuous gait.[14] The authors concluded that copers might have acquired these adaptive strategies as a protective mechanism to prevent reinjury.[13,14] However, limited evidence exists to support this conclusion.

While damage to the peripheral mechanoreceptors that provide proprioceptive input may result in altered NMC[15], disruptions in the central pathways for NMC are also thought to occur following the injury[16,17], suggesting that deficits associated with CAI may be the consequences of both peripheral and centrally mediated alterations in NMC. However, limited information exists about these alterations in this population. Most of the previous research that studied this phenomenon has focused primarily on NMC impairments at the injured ankle joint complex. Although this is a viable means for providing answers regarding changes that occur at single joint neural centers, recent research has identified disruption in proximal joints neuromuscular activation patterns in patients with CAI.[18,19] Webster and Gribble[18] reported decreased gluteus maximus (Gmax) activity in those with CAI during a single leg rotational squat exercise. Patients with CAI have also displayed a delay in onset of muscle activation and less anticipatory activation in muscles around the ankle, knee, and hip during a transition from bilateral to unilateral stance, which might indicate an involvement of multiple neural pathways.[20] However, despite previous findings, it is still unknown whether these alterations are responsible for the deficits in postural control in this population.

Different testing protocols have been used to quantify postural control in patients with CAI, including the Star Excursion Balance Test (SEBT).[21,22] The SEBT has been deemed a reliable and valid clinical test in distinguishing dynamic postural control differences between subjects with and without stable ankles.[23,24] Postural control during the SEBT is reflected by the reach distance in 8 different directions, with an increase in the reach distance while maintaining a stable unilateral base of support implies greater postural control.[23] Although numerous studies have used this test to assess postural control in patients with CAI, there has been less investigation regarding muscle activation patterns necessary to complete the SEBT in patients with CAI. Gribble et al[22] examined dynamic postural stability using the SEBT following a fatiguing protocol to the ankle, knee, and hip muscles and reported that fatigue to the injured side created significantly increased postural deficit compared to fatigue of the uninjured side and healthy controls. Though muscles activity was not measured in this study, the authors suggest that proximal muscle activation may have been altered following the fatigue protocol, resulting in decreased knee and hip flexion angles and subsequent decreases in reach distance. Electromyographic (EMG) data, however, was not collected in this study, which limited their ability to fully identify the NMC strategies utilized by these individuals.

Proximal motor control at the hip, specifically the gluteus medius (Gmed) and Gmax, is crucial for maintaining postural stability during weight bearing activities[25,26], and maybe affected in this population. Previous research has extensively focused on alterations in the ankle musculature with less emphasis on the activity of hip muscles necessary to complete a functional task in CAI patients. Hence, more research is needed to further understand the effects of proximal and distal neuromuscular alterations on postural stability in this population. Simultaneous analysis of the ankle and hip muscles activations patterns as well as dynamic stability during the performance of the SEBT in subjects with and without CAI (copers & healthy) have not been previously examined. Examining the activity of the ankle and hip muscles during the performance of a dynamic task can provide more insight into the neuromuscular strategies utilized by these individuals to maintain postural stability. Additional knowledge regarding the interaction between hip and ankle muscle function during this activity may enhance the current understanding of CAI and help in customizing rehabilitation protocols that specifically target and improve patient outcomes. Therefore, the purpose of this study was to compare postural stability and EMG activity of the TA, PL, Gmed, and Gmax muscles during the performance of the SEBT in subjects with and without CAI.

Methods

Participants

A sample of forty-eight physically active volunteers (23 males, 25 females) with mean age 27.7±4.5 years, height 171.0±7.9 cm, weight 73.2±12.9 kg, and body mass index 25.0±3.6 kg/m^2 participated in this study. All subjects read and signed an informed consent approved by the Institutional Review Board of Loma Linda University prior to participation. All subjects met the following inclusion criteria: 1) were between 18 and 35 years of age; 2) had a history of at least 1 significant lateral ankle sprain to the same side that resulted in pain and loss of function of more than one day (for CAI and coper groups); 3) had no history of ankle sprains (for the control group); and 4) participate in recreational activity for at least 90 minutes each week. Subjects were excluded if they reported: 1) bilateral ankle instability; 2) a history of neuromusculoskeletal or vestibular disorders; 3) previous lower limb surgeries; 4) trauma to the lower limbs for at least 3 months prior to the study; 5) physiotherapy within the last 3 months or current participation in supervised physical rehabilitation; and 6) consumed drugs or alcohol within 24 hours prior to testing that could interfere with performance. Subjects completed self-reported questionnaires that included the Cumberland Ankle Instability Tool (CAIT) (minimum score 0, maximum score 30) and the Ankle Instability Instrument (AII). The CAIT is valid and reliable in assessing the perceived symptoms of ankle instability[27], and the combination of the two instruments (the AII and CAIT) was reported to be most accurate in classifying CAI.[28] Subjects were classified as having CAI if they scored 24 or less on CAIT, which was confirmed with the AII. Scores of 28 or higher were defined as functionally stable ankles (copers or controls). Subjects who scored between 24 and 28 were excluded from the study to control for any potential effect on the results. Subjects were then placed in CAI, coper, or control group based on the history of lateral ankle sprain and the presence/absence of ankle instability. All measurements were taken on the injured limb for the CAI and copers groups, and on the dominant limb for the control group, which was defined as the limb used to kick a ball.

Instrumentation

Postural Control

Postural control was quantified by reach distance and the magnitude of the center of pressure (COP) movement and excursion. A computerized force platform (SCIFIT Systems Inc., Tulsa, Oklahoma, USA) was used to acquire COP measures during the performance of the SEBT. The center of the SEBT grid was aligned with the center of the force plate.

Electromyography (EMG)

A 6-channel MyoMuscle 1200 EMG system (Noraxon USA, Inc, Scottsdale, AZ) was used to record muscle activity during SEBT testing. Because we were interested in dynamic postural control during sagittal and frontal plane stability, we chose to record the activity of the hip and ankle muscles that contribute to sagittal plane stability (Gmax & TA) and those that contribute to frontal plane stability (Gmed & PL). EMG signals were acquired at a sampling rate of 1000 Hz.

Procedures

Electrode Placement

Subjects' skin was shaved, abraded, and cleaned with isopropyl alcohol wipes prior to electrode placement. Surface electrodes (dual, 2 mm diameter, 2 cm apart, Noraxon USA, Inc) were placed parallel to the muscle fibers over the midsection of the muscle bellies in accordance with the SENIAM research group recommendations and previous research.[29,30] The Gmed electrode was placed one half of the distance between the iliac crest and the greater trochanter, while the Gmax electrode was placed midway between the second sacral vertebrae and the greater trochanter. TA electrode was placed at one-third the distance of a line between the head of the fibula and the medial malleolus, while PL electrode was placed on the line between the head of the fibula to the lateral malleolus, approximately 4cm distal to the fibular head. The same tester positioned all electrodes to maintain consistency. Electrodes and EMG sensors were further secured to the skin with an adhesive tape to prevent slippage during testing and minimize movement artifacts. Electrodes' placement was confirmed by viewing EMG signals during a manual muscle test to minimize crosstalk between muscles.

MVIC Evaluation

Prior to testing, subjects performed a 3-minute, submaximal warm-up on a stationary bicycle. For the Gmed testing, subjects were positioned in sidelying on the untested leg with the tested leg in a neutral position, supported by pillows between the lower extremities. The hip and knee of the untested leg were slightly flexed. For the Gmax testing, subjects were positioned in a half-pronelying position with both hips flexed to 90° while the knee of the tested leg in 90° of flexion and the opposite knee positioned in slight flexion. An immovable strap was placed around the lower thigh of the tested leg and the plinth to resist hip abduction and extension. A towel was placed between the strap and the subject's leg for comfort. For testing, subjects produced a maximum voluntary isometric contraction (MVIC) using the make test.[31] They were instructed to avoid explosive contraction and to increase their effort gradually to their maximum once they hear the word "Go!". Standard verbal encouragement was given during each trial. Subjects performed 1 practice sub-maximal contraction trial prior to the measurement trials to ensure adequate performance and stabilizations. Three 5-second measurement trials were completed for each muscle group with a 30-second rest period in between each trial. An additional trial was taken if more than 10% of variation was noted between trials to avoid large variability. The same tester performed all measurements to maintain consistency, and the order of muscle testing was randomized to account for any potential bias. Gmed and Gmax MVICs were collected to enable normalization of the EMG data.

SEBT Protocol

Following MVIC testing, subjects had a 5-minute rest period. After words, they were instructed to stand barefoot on the tested leg with their midfoot positioned over the center of a tape grid and slowly reach with the contralateral leg as far as possible, touch the line on the floor lightly with the tip of the foot of the reaching limb in four different directions with respect to the stance limb (anterior, medial, posteromedial and posterolateral directions) while keeping the heel of the stance foot on the ground and their hands resting on their waist, then return to the starting position while maintaining single-leg stance balance for about 10 seconds before resting. Subjects were instructed to stand as motionless as possible during the last 10 seconds of single leg stance balance. Three practical trials in each reach direction were allowed to familiarize subjects with the test followed by three measurements trials. An additional practice trial was given when necessary. Thirty seconds of rest were given between each reach trial and 60 seconds between each direction to minimize fatigue. The test was demonstrated to each participant by one of the research team members prior to the practice trials. Subjects were verbally encouraged to reach as far as possible. A stopwatch was used at a rate of 60 beats/min to ensure consistent timing of each reach trial. The trial was discarded and repeated if subjects lifted the heel of the stance limb off the floor, did not keep their hands on their waist, touched down with their reach foot (weight bearing with the reaching limb), lost balance, or could not return to the starting position. The order of the reach directions was randomized to account for any potential bias. EMG and COP data were recorded simultaneously during the procedure.

Data Processing

EMG Activation Amplitudes

EMG signals were filtered at 10-500 Hz using a fourth order bandpass filter. All EMG data were then full wave rectified and smoothed using the root-mean-square algorithm with a 50-millisecond time constant. Peak amplitudes were averaged over a 500 ms time window, 250 ms prior to peak and 250 ms after the peak. For Gmed and Gmax, the highest peak value out of the three trials for each muscle was automatically selected, recorded as MVIC and used for normalization. The highest maximal voluntary contraction (MVC) of the TA and PL during all SEBT trails was used to normalize data between subjects.[32] To establish %MVIC and %MVC, peak amplitude values were calculated for each muscle during the period from toe off to touch down and return to starting position of each SEBT trial, which was determined visually. For each reaching direction, the averaged peak value out of the three trials was normalized to the reference values (MVIC/MVC), expressed as percentage %MVIC/%MVC, and used for the analysis.

Reach Distance

During each trial, the examiner marked the point of maximal reach touched on the tape measure with an erasable ink and then manually measured the distance in centimeter from the center of the grid to each marked point with a tape measure. Measurements from the 3 trials were averaged and normalized to subject's leg length, which was measured manually from the anterior superior iliac spine to the distal tip of the medial malleolus.[33] The average reach distance for each direction was expressed as a percentage of leg length and used for analysis. Composite reach distance of the 4 directions was also analyzed. Composite reach distance was the sum of the 4 reach directions divided by 4 times limb length and then multiplied by 100.

COP Data

COP measures were collected during the SEBT test including the COP excursions sway area (95% ellipse area), mean sway velocity, path length, and the total COP excursion in the anteroposterior and mediolateral directions. The area represented the magnitude of distribution of COP excursions during a trail, whereas velocity represented the average speed of COP movement during a trail. COP length was the traveling distance of COP trajectory from the starting position to the maximal position of the COP during each trial. Data were collected during each reaching trial from the moment subjects lifted their limb until they returned to the starting position. Data were recorded at 100Hz. Data collected from the three reaching trials in each direction was averaged and analyzed in respect of the average reaching distance within each direction.

Statistical Analyses

A sample size of 51 participants was estimated using an effect size of 0.4, level of significance 0.05, and power of 0.80. We were able to recruit 48 participants, 16 in each group. Data was summarized using mean and standard deviation (SD) for quantitative variables and counts for qualitative variables. The normality of continuous variables was examined using Shapiro Wilk's test. The distribution of subjects' characteristics was evaluated using chi-square for qualitative variables and One Way Analysis of Variance (ANOVA) for quantitative variables. Outcome variables were compared among groups using One Way ANOVA. Post hoc comparisons using Bonferroni test and effect size were computed to identify specific differences when significant group main effects were detected. Effect size was calculated using GPower software (version 3.1.2, University of Dusseldorf, Dusseldorf, Germany). The level of significance was set at $p \leq 0.05$. All statistical tests were performed using IBM SPSS Statistics Software version 24 for Windows (Chicago, IL, USA).

Results

Subjects' characteristics are summarized in Table 1. The distribution of all quantitative variables was approximately normal. There was no significant difference in characteristics of subjects by study group ($p > 0.05$).

Table 1. Mean (SD) of Baseline Characteristics by Study Group (N=48)

	CAI (n_1=16)	**Copers (n_2=16)**	**Control (n_3=16)**
Male (n)	7	11	5
Age, y	29.6 (4.2)	27.8 (4.4)	25.8 (4.4)
Height, cm	170.2 (5.9)	172.1 (7.1)	170.8 (10.5)
Weight, kg	72.6 (16.9)	73.2 (9.6)	73.9 (12.1)
BMI (kg/m^2)	24.9 (4.9)	24.6 (2.1)	25.3 (3.5)
Leg length, cm	89.6 (5.1)	90.7 (4.5)	88.6 (8.0)
MD visit for LAS (n)	11	7	n/a
Grade of LAS (II/III, n)	10/6	13/3	n/a
LAS frequency (n)	≥3 (16)	≤2 (16)	n/a
Pain during sport (n)	13	3	5
Previous rehab (n)	2	3	n/a
Sport participation, hours per week	5.8 (2.3)	6.4 (2.1)	7.3 (3.2)
CAIT score	16.3 (3.4)	28.1 (0.3)	29.4 (0.9)

Abbreviation: SD, Standard Deviation; CAI, Chronic Ankle Instability; BMI, Body mass index; MD, Medical Doctor; LAS, lateral ankle sprain; CAIT, Cumberland ankle instability tool; n/a, not applicable.

SEBT Reach Distance

Results are displayed in Tables 2 and 3. There was a significant difference in mean reach distance during the anterior direction (AD) among the three study groups ($p=0.02$, $\eta^2=0.37$). Bonferroni's post hoc comparison revealed that difference was significant between CAI and controls ($p=0.01$, $\eta^2=0.35$) and between CAI and copers ($p=0.02$, $\eta^2=0.30$); however, this difference was not significant between copers and controls ($p= 0.40$, $\eta^2=0.04$). For the other three reach directions, medial direction (MD), posteromedial direction (PMD), and posterolateral direction (PLD), there was no significant difference in mean reach distance among the study groups ($p>0.05$), yet, post hoc comparisons showed a significant difference in mean MR distance between CAI and controls ($p=0.04$, $\eta^2=0.26$). Overall, there was no significant difference in mean composite reach distance among the three study groups ($p=0.08$, $\eta^2=0.29$), however, post hoc comparisons showed a significant difference in mean composite distance between CAI and controls ($p=0.03$, $\eta^2=0.28$).

Table 2. Mean (SD) of Postural Control by Reach Direction among Study Group

	Reach Direction	**CAI (n_1=16)**	**Copers (n_2=16)**	**Control (n_3=16)**	***F* value**	***P* value***	**Effect size (η^2)**
Reach Distance, %	Anterior	82.1 (7.8)	89.1 (7.6)	90.1 (12.4)	4.0	0.02	0.38
	Medial	87.2 (9.6)	91.0 (7.1)	93.0 (10.5)	2.0	0.10	0.26
	Posteromedial	90.8 (8.0)	93.9 (8.5)	95.4 (10.8)	1.2	0.18	0.21
	Posterolateral	82.0 (15.6)	85.4 (12.0)	86.9 (12.0)	0.5	0.30	0.15
Sway Velocity (mm/sec)	Anterior	70.5 (16.3)	60.6 (10.7)	55.4 (19.5)	3.7	0.02	0.40
	Medial	68.1 (16.2)	58.2 (18.0)	58.5 (16.1)	1.8	0.09	0.27
	Posteromedial	73.8 (23.4)	66.0 (18.7)	58.6 (18.7)	2.2	0.05	0.31
	Posterolateral	75.5 (15.9)	65.8 (14.6)	56.4 (16.8)	5.9	<0.01	0.50
95% Confidence Ellipse Area (mm^2)	Anterior	3602.9 (1789.0)	3419.7 (1176.4)	2897.6 (1215.7)	1.2	0.18	0.21
	Medial	2643.7 (1040.8)	2729.8 (1184.9)	2580.3 (1111.2)	0.07	0.47	0.06
	Posteromedial	2998.7 (1803.4)	2767.1 (1238.4)	2372.5 (979.1)	0.8	0.22	0.19
	Posterolateral	2321.0 (902.1)	2330.4 (1373.8)	1998.9 (660.5)	0.5	0.29	0.15
Path Length (mm)	Anterior	977.9 (245.9)	844.1 (148.2)	767.3(282.6)	3.4	0.02	0.37
	Medial	913.6 (228.9)	796.8 (229.3)	818.0 (229.3)	1.2	0.16	0.22
	Posteromedial	1011.6 (329.0)	920.6(234.0)	823.7 (260.2)	1.8	0.09	0.28

Table 2 *continued*. Mean (SD) of Postural Control by Reach Direction among Study Group

	Posterolateral	1037.2 (247.7)	904.0(169.1)	791.3 (203.2)	5.5	<0.01	0.50
Anteroposterior Deviation (mm)	Anterior	18.8 (8.5)	16.8 (9.7)	11.9 (10.4)	2.2	0.06	0.30
	Medial	17.1 (10.3)	12.7 (9.1)	15.1 (11.5)	0.7	0.25	0.17
	Posteromedial	15.6 (11.2)	12.1 (6.1)	10.7 (7.1)	1.4	0.13	0.25
	Posterolateral	16.5 (8.5)	10.3 (5.7)	10.9 (5.8)	3.8	0.02	0.41
Mediolateral Deviation (mm)	Anterior	41.9 (19.7)	41.4 (12.3)	32.2 (17.2)	1.7	0.10	0.27
	Medial	37.9 (16.2)	38.5 (14.1)	28.7 (18.2)	1.9	0.08	0.28
	Posteromedial	42.5 (14.8)	40.3 (15.3)	31.8 (17.8)	2.0	0.05	0.30
	Posterolateral	45.4 (11.1)	44.1 (20.0)	30.5 (19.1)	3.7	<0.01	0.40

Abbreviation: SD, Standard Deviation; CAI, Chronic Ankle Instability

For all variables except reaching distance, reduction in scores means improvement in postural stability

*****One-way analysis of variance (ANOVA)**;** level of significance was set at $P \leq 0.05$

Table 3. Mean (SD) of Composite Score of Postural Control by Study Group

	CAI (n_1=16)	95% CI	Copers (n_2=16)	95% CI	Control (n_3=16)	95% CI	*F* value	*P* value*	Effect size (η^2)
SEBT Composite Reach, %[a]	85.5 (9.0)	80.7, 90.3	89.9 (7.0)	86.9, 93.6	91.4 (10.4)	85.9, 97.0	1.9	0.08	0.29
Composite Sway Velocity (mm/sec)[b]	72.0 (15.4)	63.8, 80.2	62.7 (13.3)	55.6, 69.7	57.2 (15.6)	48.9, 65.5	4.1	0.01	0.41
Composite 95% Confidence Ellipse Area (mm^2)	2891.6 (1132.9)	2287.9, 3495.2	2811.7 (1031.4)	2262.2, 3361.3	2462.3 (992.4)	2040.1, 2884.5	0.8	0.22	0.18
Composite Path Length (mm)[c]	985.1 (228.2)	863.5, 1106.7	866.4 (161.0)	780.6, 925.1	800.1 (210.0)	688.2, 912.0	3.5	0.03	0.40
Composite Anteroposterior Deviation (mm)[d]	17.0 (7.4)	13.1, 20.9	13.0 (5.1)	10.2, 15.7	12.2 (7.0)	8.5, 15.9	2.5	0.05	0.32
Composite Mediolateral Deviation (mm)[e]	41.9 (14.3)	34.3, 49.5	41.1 (12.5)	34.4, 47.8	30.8 (17.0)	21.7, 39.8	2.9	0.04	0.34

Abbreviation: SD, Standard Deviation; CAI, Chronic Ankle Instability; CI, Confidence Interval; SEBT, Star Excursion Balance Test
For all variables except reaching distance, reduction in scores means improvement in postural stability
[a] Significant difference between CAI and controls (p= 0.03)
[b] Significant difference between CAI and controls (p<0.01); CAI and copers (p= 0.04)
[c] Significant difference between CAI and controls (p= 0.02); CAI and copers (p= 0.03)
[d] Significant difference between CAI and controls (p= 0.02); CAI and copers (p= 0.05)
[e] Significant difference between CAI and controls (p= 0.02); copers and controls (p= 0.03)
*****One-way analysis of variance (ANOVA)**;** level of significance was set at $P \leq 0.05$

COP Sway Velocity

Results are summarized in Tables 2 and 3. Examining each direction separately, a significant difference was found among the study groups during AD ($p=0.02$, $\eta^2=0.40$), PMD ($p=0.05$, $\eta^2=0.31$), and PLD ($p<0.01$, $\eta^2=0.50$). Post hoc comparison for the AD showed a significant difference in mean COP sway velocity between CAI and controls ($p<0.01$, $\eta^2=0.39$) and between CAI and copers ($p=0.04$, $\eta^2=0.25$), but no significant difference was detected between copers and controls ($p=0.20$, $\eta^2=0.13$). For PMD, a significant difference in mean COP sway velocity was found between CAI and controls ($p=0.02$, $\eta^2=0.32$); however, no significant difference was found between CAI and copers ($p=0.14$, $\eta^2=0.16$) or between copers and control ($p=0.16$, $\eta^2=0.16$). For the PLD, a significant difference in mean COP sway velocity was found between CAI and controls ($p<0.001$, $\eta^2=0.50$), CAI and copers ($p=0.05$, $\eta^2=0.25$), and between copers and controls ($p=0.05$, $\eta^2=0.24$). However, for MD, a significant difference in mean COP sway velocity was detected between CAI and controls (0.05, $\eta^2=0.23$) and between CAI and copers ($p=0.05$, $\eta^2=0.24$), but not between copers and control ($p=0.50$, $\eta^2=0.01$). Overall, there was a significant difference in mean COP sway velocity composite score among study groups ($p=0.01$, $\eta^2=0.41$). Specifically, post hoc comparison showed a significant difference between CAI and controls ($p<0.01$, $\eta^2=0.41$) and between CAI and copers ($p=0.04$, $\eta^2=0.26$). However, no difference was found between copers and controls ($p=0.15$, $\eta^2=0.15$).

COP Sway Area

Results are presented in Tables 2 and 3. There was no significant difference in mean COP 95 % confidence ellipse area during all directions or for the composite score among the three study groups ($p>0.05$, $\eta^2=0.18$). Post hoc comparisons did not reveal any significant differences between groups ($p>0.05$). Though not significant, controls did demonstrate less sway as compared to other groups.

COP Path Length

Results are displayed in Tables 2 and 3. There was a significant difference in mean COP path length during AD ($p=0.02$, $\eta^2=0.37$), PMD ($p=0.09$, $\eta^2=0.28$), and PLD ($p<0.01$, $\eta^2=0.50$) among the study groups. Post hoc comparison showed a significant difference in mean COP path length during AD between CAI and controls ($p<0.01$, $\eta^2=0.37$) and between CAI and copers ($p=0.05$, $\eta^2=0.23$); however, no difference was found between copers and controls ($p=0.12$, $\eta^2=0.13$). For PMD, a significant difference in mean COP path length was found between CAI and controls ($p=0.03$, $\eta^2=0.28$); however, no significant difference was found between CAI and copers ($p=0.12$, $\eta^2=0.13$) and between copers and controls ($p=0.16$, $\eta^2=0.14$). For PLD, a significant difference in mean COP path length was found between CAI and controls ($p=0.001$, $\eta^2=0.50$) and between CAI and copers ($P=0.04$, $\eta^2=0.26$); however, no difference was found between copers and controls ($p=0.07$, $\eta^2=0.22$). No significant difference was found in the mean COP path length during MD among the study groups ($p=0.16$, $\eta^2=0.22$). Overall, there was a significant difference in mean COP path length composite score among the three study groups ($p=0.03$, $\eta^2=0.40$). Post hoc comparison showed a significant difference in mean COP path length composite score between CAI and controls ($p=0.02$, $\eta^2=0.37$) and between CAI and copers ($p=0.04$, $\eta^2=0.25$); however, no difference was found between copers and controls ($p=0.20$, $\eta^2=0.13$).

COP Anteroposterior (AP) Deviation

Results are summarized in Tables 2 and 3. There was a significant difference in mean COP AP deviation during PLD ($p=0.02$, $\eta^2=0.41$) among the study groups. This difference was significant between CAI and controls ($p=0.02$, $\eta^2=0.34$) and between CAI and copers ($p<0.01$, $\eta^2=0.40$), but not between copers and controls ($p=0.40$, $\eta^2=0.04$). However, there was no significant difference in mean COP AP deviation during AD, MD, and PMD among the study groups ($p>0.05$), yet, post hoc comparison showed a significant difference in mean COP AP during AD ($p=0.03$, $\eta^2=0.30$) and PMD ($p=0.05$, $\eta^2=0.24$) between CAI and controls. Overall, there was a significant difference in mean COP AP deviation composite score among the study group ($p=0.05$, $\eta^2=0.32$). This difference was significant between CAI and controls ($p=0.02$, $\eta^2=0.30$) and between CAI and copers ($p=0.05$, $\eta^2=0.25$), but not between CAI and copers ($p=0.37$, $\eta^2=0.05$).

COP Mediolateral (ML) Deviation

Results are presented in Tables 2 and 3. There was a significant difference in mean COP ML deviation during PMD ($p=0.05$, $\eta^2=0.30$) and PLD ($p<0.01$, $\eta^2=0.40$) among the study groups. For PMD, this difference was significant between CAI and controls ($p=0.03$, $\eta^2=0.27$) and between copers and controls ($p=0.04$, $\eta^2=0.22$), but not between CAI and copers ($p=0.29$, $\eta^2=0.06$). For PLD, this difference was significant between CAI and controls ($p<0.01$, $\eta^2=0.35$) and between copers and controls ($p<0.01$, $\eta^2=0.32$), but not between CAI and copers ($p=0.37$, $\eta^2=0.03$). However, there was no significant difference in mean COP ML deviation during AD and MD among the study groups ($p>0.05$). Overall, there was a significant difference in mean COP ML deviation composite score among the study group ($p=0.04$, $\eta^2=0.34$). This difference was significant between CAI and controls ($p=0.02$, $\eta^2=0.31$) and between copers and controls ($p=0.03$, $\eta^2=0.28$), but not between CAI and copers ($p=0.44$, $\eta^2=0.02$).

EMG Activation Patterns

Results for the SEBT EMG activity in the anterior, medial, posteromedial, and posterolateral directions are summarized in Table 4. There was a significant difference in mean EMG activity of TA during AD ($p<0.01$, $\eta^2=0.71$) and Gmax during PLD ($p=0.01$, $\eta^2=0.50$) among the three study groups. When compared to copers and controls, CAI group had significantly less TA activity during AD ($p=0.01$, $\eta^2=0.44$ and $p<0.01$, $\eta^2=0.70$, respectively). During the PLD, the CAI group had less Gmax activation than controls ($p<0.01$, $\eta^2=0.43$) and copers ($p=0.02$, $\eta^2=0.35$). Though not significant among groups, post hoc comparison revealed copers had higher activation in PL during the PLD as compared to controls ($p=0.04$, $\eta^2=0.31$). However, there were no other significant differences identified between the groups for the other directions.

Table 4. Mean (SD) of EMG Activation by Reach Direction among Study Group

Muscles	Reach Direction	CAI (n_1=16)	95% CI	Copers (n_2=16)	95% CI	Controls (n_3=16)	95% CI	*F* value	*P* value*	Effect size (η^2)
Tibialis Anterior (%MVC)	Anterior[a]	33.1 (10.1)	38.6, 47.7	44.8 (13.4)	37.7, 51.9	51.7 (8.4)	47.2, 56.1	12.1	<0.01	0.71
	Medial	49.7 (9.6)	44.6, 45.8	53.9 (9.4)	48.9, 58.9	55.7 (7.8)	51.5, 59.9	1.9	0.08	0.28
	Posteromedial	56.2 (11.0)	50.4, 62.0	52.9 (9.1)	48.1, 57.8	59.1 (8.8)	54.4, 63.8	1.6	0.10	0.26
	Posterolateral	57.3 (9.7)	52.1, 62.5	60.9 (4.8)	58.3, 63.4	60.7 (11.0)	54.8, 66.6	0.8	0.23	0.18
Peroneus Longus (%MVC)	Anterior	44.8 (11.8)	38.6, 51.1	51.7 (7.5)	47.7, 55.7	46.2 (13.8)	38.9, 53.6	1.6	0.10	0.26
	Medial	50.6 (11.1)	44.7, 56.5	53.1 (11.6)	46.9, 59.3	50.9 (9.0)	46.1, 55.7	0.3	0.40	0.10
	Posteromedial	49.0 (10.0)	43.7, 54.3	52.3 (9.9)	47.5, 58.1	49.0 (9.6)	43.9, 54.2	0.8	0.23	0.16
	Posterolateral	51.0 (10.7)	45.3, 56.7	57.2 (10.2)	51.8, 62.6	48.7 (13.0)	41.7, 51.6	2.4	0.10	0.32
Gluteus Maximus (%MVIC)	Anterior	15.3 (7.7)	11.2, 19.4	19.7 (11.4)	13.6, 25.8	21.1 (14.4)	13.4, 28.8	1.1	0.20	0.21
	Medial	32.2 (12.2)	25.7, 38.7	36.1 (13.7)	28.8, 43.4	40.7 (19.6)	30.3, 51.1	1.2	0.20	0.22
	Posteromedial	38.0 (13.0)	31.0, 44.9	41.2 (16.1)	32.6, 49.8	44.0 (17.4)	34.8, 53.3	0.6	0.30	0.16

Table 4 *continued*. Mean (SD) of EMG Activation by Reach Direction among Study Group

	Posterolateral[b]	25.6 (9.4)	20.6, 30.6	37.5 (13.8)	30.1, 44.8	40.2 (17.2)	31.0, 49.3	5.3	0.01	0.50
Gluteus Medius (%MVIC)	Anterior	28.3 (12.9)	21.4, 35.2	28.2 (10.9)	22.4, 34.0	27.0 (13.7)	19.7, 34.3	0.1	0.48	0.05
	Medial	45.1 (12.9)	38.2, 51.9	43.7 (11.8)	37.4, 50.0	45.5 (13.8)	38.1, 52.8	0.1	0.46	0.06
	Posteromedial	53.2 (11.8)	47.0, 49.4	46.2 (11.8)	39.9, 52.5	49.2 (14.4)	41.6, 56.9	1.2	0.20	0.23
	Posterolateral	39.7 (11.1)	33.8, 45.6	45.9 (11.3)	39.9, 51.8	42.0 (13.4)	34.8, 49.1	1.1	0.20	0.21

Abbreviation: SD, Standard Deviation; CAI, Chronic Ankle Instability; CI, Confidence Interval; MVC, Maximal Voluntary Contraction; MVIC, Maximal Voluntary Isometric Contraction

[a] Significant difference between CAI and controls (p<0.01) and between CAI and copers (p=0.01)

[b] Significant difference between CAI and controls (p<0.01) and between CAI and copers (p=0.02)

*****One-way analysis of variance (ANOVA)**;** level of significance was set at $P \leq 0.05$

Discussion

To our knowledge, this is the first study that simultaneously examines postural control and EMG activation patterns of the ankle and hip muscles during the performance of the SEBT in individuals with and without CAI. We identified group differences in postural control measures and EMG activity during the performance of SEBT. The CAI group demonstrated diminished dynamic stability and less activity of the muscles acting on the ankle and hip than the other groups. No significant differences were observed between copers and controls except for mean COP sway velocity in the PLD, mean COP ML deviation in the PMD and PLD, and PL activation in PLD. These findings further support the importance of hip exercise as part of a comprehensive rehabilitation program for this patient population.

Postural Control

Our analysis of outcome measures revealed that patients with CAI exhibited poor postural control performance as demonstrated by reach distance and COP measures than healthy individuals. Patient with CAI had less reach distance than the other groups during all directions; however, the difference was significant in the AD. Similar findings were reported by previous researchers.[21,22,34] In our study, we found no significant differences in the PMD reach distance among groups, and this was in line with the results reported by Pozzi et al.[35] The PMD was reported to be “most representative” of all other directions in the SEBT[34]; however, it appears that using this direction alone might not be sensitive enough to show differences between stable and unstable ankles. Thus, a combination of more than one direction such as the Y balance test, which consists of three directions (AD, PMD and PLD), may be more applicable.

Postural control was also quantified by the magnitude of the COP movement and excursion during the performance of the SEBT. Though the SEBT has been shown to be sensitive in detecting balance deficits associated with CAI[21,23,24], we anticipated that relying on the reach distance alone might not be sensitive enough to detect differences, especially with the controversial findings reported in previous research.[35] Reach distance was only significantly different in the AD, however, COP measures showed many significant differences among the groups in most of the directions, suggesting that relying on the reach distance alone might not provide the full picture of the postural control deficits if they are indeed present. The ability to maintain good balance while reaching is essential. An individual with an unstable ankle might be able to complete a functional task as well as a person with stable ankle depending on the severity of his/her condition; however, the completion pattern might be altered, creating the potential threat of reinjury. In this study, CAI patients were able to reach as far as healthy subjects, however, they demonstrated a higher sway, which implies an impaired postural stability. Though significant differences in COP measures were identified during the PMD, the AD and PLD in our study, PLD showed to be more challenging for CAI patients. During testing, it was observed that most of the participants had difficulty maintaining stability when reaching in the PLD even after practice trials were given.

Neuromuscular Control

Altered NMC patterns in proximal and distal joint muscles have been previously identified in patients with CAI during functional tasks.[11,12,18,19,20] Patients with CAI have demonstrated a delay in hamstring, Gmax (bilaterally), and erector spinae activation during a prone hip extension testing when compared to healthy controls.[36] CAI patients also have exhibited decreased ankle and hip muscles activity during the performance of functional rehabilitative exercises.[18,19] Similar to our findings, when compared to controls, patients with CAI had reduced TA activity during the AD of the SEBT, with no differences reported for the Gmed activity.[19] However, Gmax activity was not recorded in that study. CAI patients in our study presented with less Gmax activity during PLD of the SEBT. This further supports the findings reported by Webster and Gribble[18] during a single leg rotational squat exercise, which were considered as a potential factor for the continual instability. Reaching in the PLD is especially challenging, as individuals have to maintain a level pelvis on the stance leg. As individuals reach backward across the stance leg, they shift their trunk anteriorly to maintain the center of mass within the base of support. Flexion in the trunk produces flexion moment at the hip, which is controlled by contraction of the hip extensors.[37] Thus, the elevated activation of Gmax might be needed in this situation to counteract the sagittal plane flexion of the trunk and hip. It seems that patients with CAI did not fire the Gmax enough to counteract this motion, resulting in overcompensation to maintain the body's center of mass within the base of support, which may have led to the higher sway during the PLD. The higher activation in the Gmax might also have occurred in order to control for the internal rotation of the femur during the PLD. These explanations, however, are hypothetical given the fact that kinematic data were not examined in our study. The turning or twisting movement such as that in the PDL is crucial to athletic activity and is usually a common mechanism of lower extremity injuries.[18]

Nonetheless, in the above studies[18,19], balance data was not collected. We collected balance and EMG data simultaneously during the performance of the SEBT to examine potential sources of performance deficits and to further understand the NMC strategies utilized by each group to maintain stability. In our study, CAI group demonstrated poorer performance mainly during the AD and PLD of the SEBT. Interestingly, during both directions, CAI group had less activation in the TA and Gmax than the other groups, which might indicate a relationship between performance and altered NMC at the hip and ankle. The higher activation seen in controls and copers could be interpreted as a strategy used by these individuals to maintain stability where the task is more challenging. Thus, the poorer performance noted in the CAI group during these directions could be attributed to the lack of such strategy. Furthermore, it was noted that during the PLD, controls and copers used both ankle and hip muscles, which was not the case for the CAI group who only relied on the ankle muscles to complete the task. This reliance on ankle strategy to maintain balance could explain the increased risk of injury in this population. Gribble and Hertel[38] previously reported that fatigue to the proximal musculature of lower extremity created significantly increased postural control deficits compared to fatigue of the distal muscles. However, we identified alterations in the proximal and distal joint muscles activity in CAI patients without administrating a fatiguing protocol, which might be responsible for the postural control deficits in this population.

Theoretically, the reaching distance could influence muscle activation patterns. However, there was no significant difference in mean reach distance during the PLD among the groups, yet CAI group had the lowest Gmax activity and the higher sway. This finding minimizes the likelihood that differences in reach distances may have contributed to the different patterns of muscle activation. In general, reaching far on the SEBT while maintaining good balance is an indication of greater neuromuscular control. Hence, if reaching far while maintaining steadiness requires an individual to produce higher muscle activity, then lacking such ability could increase the likelihood of injury.

During weight bearing activities, the muscles around the hip work to maintain pelvis stability and control the movement of the femur, which subsequently affects positioning of the ankle and foot.[39,18] This control of the pelvic motion is critical to maintain total body balance.[40] Small errors in balance are usually corrected distally by the musculature of the foot and ankle, whereas large errors are rectified at the hip.[40] In the absence of good motor control at the hip joint, the reliance on the ankle musculature to do the work increases, which puts more load on the ankle joint and hence, may lead to future episodes of injury. Moreover, patients with CAI showed decreased activity of the ankle muscles, which might double the load on the ankle joint.

While previous studies[13,14,35] reported copers had higher activation in TA and PL than CAIs and controls, in our study, copers displayed greater activation of the TA (AD) and Gmax (PLD) as compared to CAIs but not to the controls and had higher activation of PL (PLD) as compared to controls only. The different testing protocols implemented by the studies might have led to such dissimilarity. However, it is unknown whether these NMC patterns exhibited by the copers were already present before injury or developed after the injury as a protective strategy against instability. In respective of that, such patterns might help copers to maintain postural stability as indicated by our results and therefore minimize the risk of developing instability. Furthermore, perhaps the time allowed for healing after incurring an initial injury prior to return to sports might has an effect on the level of neuromuscular adaptations. Future research should examine whether time and process of healing after an initial sprain is associated with ankle instability. Examining postural control early after acute lateral ankle sprain could also provide information about the neuromuscular adaptations acquired by this population.

Traditionally, there has been a focus on the distal ankle musculature, mainly the peroneal, for their capacity to provide dynamic stability and for the goal of preventing subsequent ankle injuries. Interestingly, our results showed an alteration in both, the distal and proximal musculature activation patterns in patients with CAI. These findings substantiate that deficits associated with CAI may be the consequences of both peripheral and centrally mediated alterations in NMC.[16-19] Hip musculature plays a major role in maintaining postural stability during single leg activities such that in SEBT. Clinically, this is important, as single leg activities are a key component of almost all functional movements. Alteration in the proximal muscles activity appears to negatively affect measures of postural control and the quality of movement, which may lead to prolonged functional impairments and increased recurrence of the undesired lower extremity injuries in this population. Overall, with the diminished hip and ankle muscles activation, the body's ability to maintain balance is compromised, thus the ability to perform functional skills might be limited in this population.

Study Limitations

Limitations of this study include the lack of kinematic data to further support the findings of this study. In addition, since most injuries occur unpredictably, including an unexpected perturbation to the SEBT may provoke different NMC patterns and therefore should be examined. Finally, the smaller sample size with large standard deviations may have resulted in a type II error when statistical significance was not noted. Future research with a larger sample size that examines muscles activity and balance during more functional tasks such as running is needed.

Implications for Practice

Findings from this study have provided additional insight regarding the NMC deficits in this population. The authors' current data support that clinicians, in addition to examining ankle joint function, should also examine and address hip impairments for the treatment of CAI. Incorporating hip exercises into the rehabilitation program can improve hip muscles activation patterns and dynamic stability, which may help to reduce the risk of reinjury and improve functional performance in this population. Another important point to consider is that the posterolateral direction was found to be more challenging for CAI subjects. This could be important for clinicians to use when examining balance in patients with CAI or when using the SEBT as an intervention to improve stability. However, using a combination of more than one direction such as the Y balance test is recommended in a clinical setting to detect such problems.

Conclusion

We were able to identify alterations in proximal and distal NMC in patients with CAI. These alterations appear to negatively affect measures of postural control in this population. Overall, patients with CAI exhibited poorer stability and diminished hip and ankle muscles activity. However, caution should be taken when interpreting these findings, since it is not known whether these alterations are the cause of or a result of CAI. In addition to ankle muscles activity, improving hip muscles activity might help the body to produce functional movements while maintaining pelvis stability. Thus, targeting hip muscles in the conditioning and rehabilitation program might benefit this population.

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Conflict of Interest

No external funding sources were received to assist this study. No conflicts of interest are reported.

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CHAPTER THREE

THE EFFECTS OF OPEN VERSUS CLOSED KINETIC CHAIN EXERCISES ON ANKLE JOINT FUNCTION IN ATHLETES WITH CHRONIC ANKLE INSTABILITY

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Abstract

Background/Purpose: Lateral ankle sprains are one of the most common musculoskeletal injuries among physically active individuals, and often result in subsequent structural and functional alterations that lead to chronic ankle instability (CAI) and an increased risk of ankle reinjury. Insufficiencies in proprioception, neuromuscular control, and strength are suggested as contributing factors to CAI. Open kinetic chain (OKC) and closed kinetic chain (CKC) exercises often constitute the core of ankle specific training before progression to more advance dynamic training. Though these exercises are commonly used in the management of ankle instability, there is no consensus regarding their efficacy on physical therapy outcome measures. Thus, the purpose of this pilot study was to compare the effect of OKC and CKC exercises on dynamic postural control, self-reported function, and subjective sense of instability in subjects with CAI.

Methods: Subjects with unilateral CAI were randomly assigned into three groups: OKC (n= 5), CKC (n= 6), and control (n=6). Baseline and post intervention outcome measures included the star excursion balance test (SEBT) reach distance, center of pressure (COP) sway velocity, sway area, and path length, and Foot and Ankle Ability Measure (FAAM-Sports Subscale). All groups completed 6 weeks of exercises. In addition, subjects completed a global rating of change (GROC) form at week 6 post-intervention.

Results: Following intervention, both OKC and CKC groups had a significant improvement in the SEBT composite reach distance, COP measures, and FAAM-Sports Subscale scores, indicating an improvement in dynamic postural stability and subjective function; however, CKC had greater improvements than OKC. The control group did not show any improvements and got worse for most of the outcome variables. GROC revealed a significant difference in the median score for the CKC group when compared to the OKC and control groups (p=0.04 and p=0.03, respectively).

Conclusion: The 6-week of OKC and CKC exercise programs improved parameters of postural control and subjective function in subjects with CAI. CKC, however, showed to be more effective than OKC at improving all of the outcome variables. Hence, exercise programs should become more functional and task oriented. Further research is needed in a larger cohort of subjects with CAI to determine the effects of both training programs on ankle joint injury risk factors.

Key words: Chronic ankle instability; Ankle sprains; Open kinetic chain; Closed kinetic chain; Postural control; Star Excursion Balance Test

Introduction

Lateral ankle sprain is a common phenomenon for individuals engaging in vigorous sports activities.[1,2] They account for approximately 25% to 30% of all sport-related injuries[1], with a recurrence rate of as high as 70% in most of the cases.[3] Following a lateral ankle sprain, approximately 40% of the cases will develop persisting symptoms resulting in a longstanding dysfunction known as chronic ankle instability (CAI).[4,5] Two of the most frequently encountered residual symptoms include a recurring sensation of ankle instability and reported episodes of giving way, which result in repetitive injuries, increased self-reported disability, activity limitations, and participation restrictions.[5] Despite the high recurrence rate, nearly 55% of those who experience ankle sprains do not seek medical attention.[6] If left untreated, however, repetitive sprains may cause damage to the articular surface of the ankle joint, thus increasing the likelihood of developing degenerative changes such as ankle osteoarthritis.[7,8]

Subjects with CAI typically present with diminishing neuromuscular control and are unable to carry out their routine activities with the affected limb.[4,9,10] In addition, the impaired joint position sense and accompanying muscle weakness results in altered function.[11,12] Moreover, the presence of pain can also affect the performance of tasks and the demonstration of the specific skills. Affected individuals also demonstrate deficiency in postural control owing to the affected musculature of the affected joint.[4,9,10] Alterations in balance when carrying out activities is seen as the greatest contributor to lateral ankle sprains.[11,13,14,15] Furthermore, with the presence of these alterations, one may develop prolonged functional ankle instability even after healing has taken place.[16]

Previous literature suggest that subjects with CAI symptoms often exhibit deficits in evertor strength that affects their capacity to maintain balance of the body.[17] In addition, subjects with CAI were shown to have a lower activation of the peroneus longus (PL) and tibialis anterior (TA) associated with pre-landing when performing a jump[18,19], and during pre and post touchdown phases of stepping down in gait.[20] Thus the risk of injury is high during such activities in the presence of poor ankle stabilization. Specifically, ambulatory and exercise capacity of subjects with CAI is severely affected. Previous research studies have also suggested hip muscle activation and strength is altered in subjects with CAI.[21,22,23] Friel et al. reported significantly less gluteus medius muscle strength (Gmed) on the affected side than the unaffected side in subjects with CAI.[21] Subjects with CAI demonstrated decreased gluteus maximus (Gmax) activity as compared to healthy individuals during a single leg rotational squat exercise.[22] During a transition from bilateral to unilateral stance, those with CAI have also displayed a delay in onset of muscle activation and less anticipatory activation in muscles acting around the ankle, knee, and hip joints.[23] These alterations in the proximal muscle strength and activation, along with changes in movement patterns, were reported to negatively affect measures of postural control, leading to functional impairments and increased recurrence rates in those with CAI.[24,25,26,27]

However, the two forms of exercises that often constitute the core of ankle specific training before progression to more advanced training are open and closed kinetic chain exercises. These exercises are frequently administrated to enhance resistance training that is conducted to improve ankle stability, achieve balance, and improve functionality.[12]

In general, open kinetic chain (OKC) exercises are single joint movements in which the proximal part of the limb is often fixed while the distal aspect of the limb is allowed to move freely.[28] The exercises are performed in a non-weight bearing manner, vital in the isolation of individual muscle groups, and tend to generate rotational and distraction forces.[28] On the other hand, closed kinetic chain (CKC) exercises are multi-joint movements where the distal part remains fixed.[28] The exercises are performed in a weight bearing position and considered to be more functional.[28] The most important aspect of CKC exercises is the capacity to achieve resistance training at both the distal and proximal ends concurrently.[29] Furthermore, CKC exercises have been suggested to produce eccentric contraction and co-contraction of muscles, which reduces the shearing forces while adding compressive forces to the joints, thus improving joint stability.[30,31] Moreover, CKC exercises promote proprioception by emphasizing the proprioceptive feedback to initiate and control the muscle activation patterns.[32] Kown et al., showed that CKC exercises were found to be more effective than OKC exercises at improving dynamic balance in healthy adults.[33] Electromyographic (EMG) studies have also recommended the use of weight bearing exercises over the open chain exercises to treat lower extremity injuries.[34,35] Bellew et al., reported an increased peroneus longus EMG activity with heel raises exercises as compared to conventional ankle eversion exercises using resistive therabands.[34]

OKC and CKC exercises have considerably been in practice as muscle strengthening exercises. However, there is no distinction as to which exercise would be more beneficial in improving the dynamic aspects of balance performance, self-reported function, and subjective sense of instability in subjects with CAI. There is a poverty of literature on this issue. Therefore, this pilot study aimed at comparing the effectiveness of open versus closed kinetic chain exercises on chronic ankle instability. We hypothesized that both OKC and CKC exercises would improve the outcome measures, and that CKC training would produce better improvement.

Methods

Participants

A sample of seventeen physically active subjects (13 males, 4 females) with mean age 28.8±4.7 years, height 171.1±6.7 cm, weight 72.5±13.4 kg, and body mass index 24.6±3.5 kg/m^2) volunteered to participate in this study. All subjects read and signed an informed consent approved by the Institutional Review Board of Loma Linda University prior to participation. All subjects met the following inclusion criteria: 1) were between 18 and 35 years of age; 2) had a history of at least 1 significant lateral ankle sprains to the same side that resulted in pain and loss of function of more than one day; and 3) participate in recreational activity for at least 90 minutes each week. Subjects were excluded if they reported: 1) bilateral ankle instability; 2) a history of neuromusculoskeletal or vestibular disorders; 3) previous lower limb surgeries; 4) trauma to the lower limbs for at least 3 months prior to the study; 5) physiotherapy within the last 3 months or current participation in supervised physical rehabilitation; or 6) inability to comply with the home exercise program. In addition, subjects completed self-reported questionnaires that included the Cumberland Ankle Instability Tool (CAIT) (minimum score 0, maximum score 30) and the Ankle Instability Instrument (AII). The CAIT is valid and reliable in assessing the perceived symptoms of ankle instability.[36] The combination of the two instruments (the AII and CAIT) was reported to be most accurate in classifying CAI.[37] Subjects were classified as having CAI if they scored 24 or less on CAIT, which was confirmed with the AII. Subjects were then randomly assigned to either OKC exercise group, CKC exercise group, or control group.

Instrumentation

Postural control was quantified by the star excursion balance test (SEBT) reach distance and the magnitude of the center of pressure (COP) movement and excursion. A computerized force platform (SCIFIT Systems Inc., Tulsa, Oklahoma, USA) was used to acquire COP measures (sway area, sway velocity, and path length during the performance of the SEBT. The area represented the magnitude of distribution of COP excursions during a trail, whereas velocity represented the average speed of COP movement during a trail. COP length was the traveling distance of COP trajectory from the starting position to the maximal position of the COP during each trial. The center of the SEBT grid was aligned with the center of the force plate. The SEBT has been shown to be a valid and reliable clinical test for assessing dynamic balance and functional deficits associated with CAI.[38,39]

Procedures

After subjects read and signed the informed consent and completed the self-reported questionnaires designed to identify subjects with CAI, subjects completed baseline measurements that included Foot and Ankle Ability Measure (FAAM)-Sport Subscale, SEBT reach distance, and the COP measures, which were collected during the performance of the SEBT. Subjects in the control group were instructed to continue with their normal activities for 6 weeks then return for follow-up testing. Subjects in the other groups began the 6-week rehabilitation program the same week. Post-intervention testing included the same outcome measures that were administrated at baseline. In addition, subjects completed a global rating of change (GROC) form at week 6 post-intervention.

SEBT Protocol

To perform SEBT, subjects were instructed to stand barefoot on the test leg with their midfoot positioned over the center of a tape grid and slowly reach with their contralateral leg as far as possible in four different directions (anterior, medial, posteromedial and posterolateral directions), touch the line on the floor lightly with the tip of the foot of the reaching limb while keeping the heel of the stance foot on the ground and their hands resting on their waist, then return to the starting position while maintaining single-leg stance balance for about 10 seconds before resting. Three practice trials in each reach direction were allowed to familiarize subjects with the test followed by three measurements trials. An additional practice trail was given when necessary. Subjects were verbally encouraged to reach as far as possible. Thirty seconds of rest (sit on a chair) were given between each reach trial and 60 seconds between each direction to minimize fatigue. The test was demonstrated to each participant by one of the research team members prior to the practice trials. A stopwatch was used at a rate of 60 beats/min to ensure consistent timing of each reach trial. The trial was discarded and repeated if subjects lifted the heel of the stance limb off the floor, did not keep their hands on their waist, touched down with their reach foot (weight bearing with the reaching limb), lost balance, or could not return to starting position. The order of the reach directions was randomized to account for any potential bias. COP data were recorded simultaneously during the procedure.

FAAM-Sport Subscale

To measure the self-reported function, all subjects completed the FAAM-Sport Subscale. The FAAM consists of 8-item sports subscale. Each item is scored from 4 to 0, with 4 being (no difficulty) and 0 being (unable to do). The subscale has a total score of 32, which expressed as a percentage, with 100% representing a higher level of function.[40] The scale has shown strong evidence for validity, test-retest reliability ($ICC_{FAAM\text{-}Sport}$ =0.87), and responsiveness among individuals with CAI.[40]

GROC Scale

The GROC scale is a subjective measure of clinical changes.[41] The scale is commonly used in clinical research and is considered a useful method for assessing the participant's perception of the efficacy of a particular intervention.[42] It consists of a 15-point scale ranging from –7 (a very great deal worse) to 0 (about the same) to 7 (a very great deal better), allowing participants to rate changes experienced in a clinical parameter following the intervention.[41] The scale has been shown to have acceptable levels of validity and reliability.[41] Subjects were asked to rate their overall perception of ankle instability "giving way" at the conclusion of the 6-week intervention period. They were asked to check only one point out of the 15 points present in the scale.

Intervention

Subjects in the OKC and CKC groups underwent 6-weeks of an exercise program, 3 times per week. During the first week and following the baseline measurements, exercises were demonstrated to each participant to ensure understanding of each technique. Subjects then reported to the laboratory once a week to perform the exercises under the supervision of a physical therapist to ensure proper performance. Subjects were asked to complete the other two times of exercises at home (as a home-based exercise program). To ensure and facilitate compliance, subjects were given an exercise log sheet with a detailed description and demonstrative figures of each exercise to be completed during the week. Subjects were also contacted weekly through phone calls and text messages as a reminder to minimize lack of compliance. Subjects in the OKC group were instructed to perform OKC exercises using elastic theraband for the ankle and hip muscles, while subjects in CKC group were instructed to perform CKC exercises as prescribed. The program was gradually progressed throughout the 6-week period. Because we were interested in dynamic postural control during sagittal and frontal plane stability, we chose to strengthen hip and ankle muscles that contribute to sagittal plane stability (Gmax & TA) and those that contribute to frontal plane stability (Gmed & PL). Exercise description is summarized in Table

Table 1. Groups, Exercise Prescriptions and Progression Modes

Group	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
CKC	Double leg heel raises: (3 sets x 12 reps)	Double leg heel raises: (3 sets x 12 reps)	Single leg heel raises: (2 sets x 10 reps - each side)	Single leg heel raises: (2 sets x 10 reps - each side)	Single leg heel raises with weight (15 kg): (3 sets x 12 reps - each side)	Single leg heel raises with weight (20 kg): (3 sets x 12 reps - each side)
	SEBT Functional Reaching (1 set x 5 reps - each side)	SEBT Functional Reaching (1 set x 5 reps - each side)	SEBT Functional Reaching (2 sets x 5 reps - each side)	SEBT Functional Reaching (2 sets x 5 reps - each side)	SEBT Functional Reaching (3 sets x5 reps - each side)	SEBT Functional Reaching (3 sets x 5 reps - each side)
	Double leg squats: (3 sets x 10 reps)	Double leg squats: (3 sets x 10 reps)	Double leg squats: (3 sets x 12 reps)	Double leg squats: (3 sets x 12 reps - each side)	Single leg squats: (3 sets x 10 reps - each side)	Single leg squats: (3 sets x 10 reps - each side)
OKC	Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side)	Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side)	Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side)	Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side)	Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side)	Ankle PF, DF, eversion, inversion (Theraband progression, 3 sets x 20 reps - each side)
	Side-lying hip abduction: (2 sets x 20 reps - each side)	Side-lying hip abduction: (3 sets x 20 reps - each side, Thera-progression)	Clam-shell gluteus medius: (2 sets x10 reps - each side, Thera-progression)	Clam-shell gluteus medius: (2 sets x 10 reps - each side, Thera-progression)	Clam-shell gluteus medius: (2 sets x 20 reps - each side, Thera-progression)	Clam-shell gluteus medius: (2 sets x 20 reps - each side, Thera-progression)

Table 1 *continued*. Groups, Exercise Prescriptions and Progression Mode

	Fire Hydrant (2 sets x 10 reps - each side)	Fire Hydrant (Thera-progression, 2 sets x 10 reps - each side)	Fire Hydrant (Thera-progression, 2 sets x 10 reps - each side)	Fire Hydrant (Thera-progression, 2 sets x 10 reps - each side)	Fire Hydrant (Thera-progression, 2 sets x 10 reps - side)	Fire Hydrant (Thera-progression, 2 sets x 10 reps - each side)
Control	No Exercise					

Abbreviation: SEBT, Star Excursion Balance Test; PF, Plantarflexion; DF, Dorsiflexion

Data Processing

Reach distance was manually measured in centimeter from the center of the grid to each marked point on the grid line. Measurements from the three trials were averaged and normalized to subject's leg length, which was measured manually from the anterior superior iliac spine to the distal tip of the medial malleolus.[43] The average reach distance for each direction was expressed as a percentage of leg length and used for analysis. Composite reach distance of the four directions was also analyzed. Composite reach distance was the sum of the 4 reach directions divided by 4 times limb length and then multiplied by 100. COP data during the SEBT were recorded at 100Hz. Data collected from the 3 reaching trials in each direction were averaged and analyzed in respect of the averaged reaching distance within each direction.

Statistical Analyses

A total of 17 subjects were recruited, 6 in CKC group, 5 in OKC group, and 6 in the control group. Data was summarized using mean and standard deviation (SD) for quantitative variables and counts (%) for qualitative variables. The normality of continuous variables was examined using Shapiro Wilk's test and box plots. The distribution of subjects' characteristics by study group was evaluated using chi-square for qualitative variables and One Way Analysis of Variance (ANOVA) for quantitative variables. Outcome variables at baseline were compared among groups using One Way ANOVA. Mean postural control variables and FAAM sports subscale scores were compared by group type over time using 2x3 mixed factorial ANOVA. Post hoc comparisons using Bonferroni test were conducted to identify specific differences when significant group main effects were detected. Kruskal-Wallis ANOVA was used to compare GROC scores among the study groups. If results were significant, Mann-Whitney test was conducted to determine which groups were significantly different. The level of significance was set at $p \leq 0.05$. All statistical tests were performed using IBM SPSS Statistics Software version 24 for Windows (Chicago, IL, USA).

Results

Subjects' characteristics are summarized in Table 2. The distribution of all quantitative variables was approximately normal. There was no significant difference in characteristics of subjects by study group ($p > 0.05$).

Table 2. Mean (SD) of Baseline Characteristics by Study Group (N=17)

	CKC Group (n_1=6)	OKC Group (n_2=5)	Control Group (n_3=6)
Male (n)	4	5	4
Age, y	30.0 (5.4)	28.8 (2.6)	27.5 (5.6)
Height, cm	170.3 (6.8)	171.2 (7.4)	171.8 (7.2)
Weight, kg	65.9 (12.5)	72.2 (7.9)	79.3 (16.1)
BMI (kg/m^2)	22.7 (3.9)	24.6 (1.6)	26.6 (3.7)
Leg length, cm	88.2 (3.8)	89.5 (5.9)	92.2 (4.2)
MD visit for LAS (n)	3	1	2
Grade of LAS (II/III, n)	3/3	4/1	5/1
LAS frequency (≥3, n)	6	5	6
Pain during sport (n)	5	2	5
Previous rehab (n)	1	1	0
Sport participation, hours per week	5.7 (1.2)	7.6 (2.9)	7.3 (3.4)
CAIT score	18.5 (4.4)	22.0 (2.4)	20.3 (5.5)

Abbreviation: SD, Standard Deviation; CKC, Closed Kinetic Chain; OKC, Open Kinetic Chain; BMI, Body mass index; MD, Medical Doctor; LAS, lateral ankle sprain; CAIT, Cumberland ankle instability tool

SEBT Reach Distance

Results are presented in Table 3. There was a significant change in mean SEBT composite reach distance over time ($F_{1, 14}$= 15.7, p= 0.001). A significant group by time interaction was also noted ($F_{2, 14}$= 3.8, p= 0.04). The change was significantly different among groups ($F_{2, 14}$= 3.8, p= 0.04, η^2= 0.4). Specifically, Bonferroni's post hoc comparison revealed that the difference was significant between CKC and control groups (p= 0.01), and between OKC and control groups (p= 0.02); however, this difference was not significant between CKC and OKC groups (p= 0.43).

Table 3. Mean (SD) of postural control by study group over time

	CKC Group (n_1=6)			OKC Group (n_2=5)			Control Group (n_3=6)					
	Baseline	Post 6 weeks	Effect Size	Baseline	Post 6 weeks	Effect Size	Baseline	Post 6 weeks	Effect Size	p-value* over time	Effect Size	p-value* among groups
SEBT Composite Reach, %[a]	87.1 (9.2)	93.3 (5.1)	1.0	91.4 (6.4)	94.1 (4.0)	2.3	84.6 (5.8)	84.7 (5.4)	0.0	0.001	0.5	0.02
Composite Sway Velocity (mm/sec)[b]	68.3 (12.3)	48.8 (12.7)	2.0	66.2 (17.4)	58.8 (16.7)	0.5	70.6 (11.0)	76.4 (17.4)	0.4	0.04	0.2	0.04
Composite 95% Confidence Ellipse Area (mm^2)[c]	3117.6 (1109.0)	2295.8 (1724.9)	0.6	3667.3 (1092.3)	3007.0 (903.8)	0.7	2966.5 (1060.4)	3474.1 (1317.3)	0.5	0.14	0.1	0.03
Composite Path Length (mm)[d]	956.2 (210.5)	730.6 (191.2)	1.1	906.5 (177.6)	889.1 (244.4)	0.1	999.3 (166.0)	1164.9 (328.6)	0.7	0.65	0.0	0.03
FAAM-Sports Subscale[e]	73.3 (9.8)	93.3 (8.7)	2.2	81.8 (12.9)	86.4 (15.7)	0.3	80.0 (5.5)	80.8 (2.0)	0.2	0.004	0.5	0.01

Abbreviation: SD, Standard Deviation; CKC, closed kinetic chain; OKC, open kinetic chain; SEBT, Star Excursion Balance Test; FAAM, Foot and Ankle Ability Measure. For all variables except reaching distance and FAAM, reduction in scores means improvement in postural stability

[a] Significant difference between CKC and controls (p= 0.01), and between OKC and controls (p= 0.02); No significant difference between CKC and OKC (p=0.43)

[b] Significant difference between CKC and controls (p= 0.01); No significant difference between OKC and controls (p= 0.06) and between CKC and OKC (p= 0.13)

[c] Significant difference between CKC and controls (p= 0.01), and between OKC and controls (p= 0.03); No significant difference between CKC and OKC (p= 0.38)

[d] Significant difference between CKC and controls (p= 0.01); No significant difference between OKC and controls (p= 0.09) and between CKC and OKC (p= 0.08)

[e] Significant difference between CKC and controls (p=0.005), and between CKC and OKC (p=0.02); No significant difference between OKC and controls (p=0.5)

*****Mixed factorial analysis of variance (ANOVA)

COP Sway Velocity

Results are displayed in Table 3. There was a significant change in mean COP sway velocity over time ($F_{1, 14}$= 3.2, p= 0.04). Significant group by time interaction was also noted ($F_{2, 14}$= 3.7, p= 0.03). The change was significantly different among groups ($F_{2, 13}$= 3.7, p= 0.03, η^2= 0.4). Bonferroni's post hoc comparison showed that the difference was significant between CKC and control groups (p= 0.01); however, this difference was not significant between CKC and OKC groups, and between OKC and control groups (p= 0.13, p= 0.06, respectively). Though the difference between OKC and control groups was not statistically significant, the OKC group did show a slight improvement in sway velocity of about 11% from baseline, whereas controls' sway velocity got worse.

COP Sway Area

Results are summarized in Table 3. There was no significant change in mean COP sway area over time ($F_{1, 14}$= 2.3, p= 0.14). Significant group by time interaction, however, was noted ($F_{2, 14}$= 4.0, p= 0.03). A significant difference among groups was also found ($F_{2, 13}$= 4.0, p= 0.03, η^2= 0.1). Bonferroni's post hoc comparison showed that the difference was significant between CKC and control groups (p= 0.01), and between OKC and control groups (p=0.03); however, this difference was not significant between CKC and OKC groups (p= 0.38).

COP Path Length

Results are presented in Table 3. There was no significant change in mean COP path length over time ($F_{1, 14}$= 0.3, p= 0.65). However, significant group by time interaction was noted ($F_{2, 14}$= 4.5, p= 0.03). A significant difference among groups was also found ($F_{2, 13}$= 4.5, p= 0.03, η^2= 0.4). Bonferroni's post hoc comparison revealed that the difference was significant between CKC and control groups (p= 0.01); however, this difference was not significant between CKC and OKC groups, and between OKC and control groups (p= 0.08, p=0.09, respectively). Though the difference between OKC and control groups was not statistically significant, the OKC group did show a slight improvement in the path length from baseline, whereas controls' path length got worse.

FAAM-Sport Subscale

Results are summarized in Table 3. There was a significant change in mean FAAM-Sport Subscale score over time ($F_{1, 14}$= 12.2, p= 0.004). A significant group by time interaction was also noted ($F_{2, 14}$= 6.1, p= 0.01). The change was significantly different among groups ($F_{2, 13}$= 6.1, p= 0.01, η^2= 0.5). Bonferroni's post hoc comparison showed that the difference was significant between CKC and control groups (p= 0.005), and between CKC and OKC groups (p= 0.02); however, no significant difference was detected between OKC and control groups (p= 0.5).

GROC Scale

There was a significant difference in GROC score among the three study groups (Z= 6.8, p= 0.03). Mann-Whitney results showed that the difference was significant between CKC and control groups (median (min, max): 5 (3, 7) vs. 0 (-5, 5), p=0.04), and between CKC and OKC (median (min, max): 5 (3, 7) vs. 2 (0, 4), p=0.03); however, no significant difference was found between OKC and control groups (median (min, max): 2 (0, 4) vs. 0 (-5, 5), p=0.43).

Discussion

Open and closed kinetic chain exercises are important components of the rehabilitation programs of ankle instability. However, to our knowledge, this is the first study to examine the efficacy of OKC and CKC exercises as a method of improving dynamic balance, self-reported function, and perceived sense of instability in subjects with CAI. Results revealed that both experimental groups had significant improvements in the outcome measures; however, CKC group had greater improvements than OKC group. In contrast, the control group did not show any improvements from baseline.

Postural Control

Impaired postural control has been consistently identified in the literature as a risk factor for ankle sprains and a feature of CAI.[11,13,14,15] Following the 6-week training protocol, both OKC and CKC groups improved on all postural control variables, with higher improvement noted for the CKC group, thus emphasizing the importance of these exercises for reducing CAI symptoms.

Several studies have reported that CKC exercises elicit performance gains similar to or better than OKC exercises in healthy individuals and those with knee problems.[44,45,46,47] CKC exercises have been found to be more effective than OKC exercises at improving vertical jump performance in healthy adults.[44] Yack et al. compared the effectiveness of OKC and CKC exercises in ACL rehabilitation and reported that OKC group had more laxity than CKC group.[48] However, limited evidence exists regarding the effect of these exercises on subjects with CAI. Most of previous studies used a combination of strengthening and coordination exercises as intervention, while in this study, we sought to compare the effect of CKC and OKC exercises as a method of improving dynamic postural control.

Nonetheless, the effect of OKC and CKC exercises on dynamic stability was previously examined in healthy subjects.[33,49] Kwon et al. reported that CKC exercises showed a significant improvement in dynamic balance when compared to OKC exercises, which produced some improvement but was not significant.[33] In contrast, Dannelly et al. reported that both exercises showed significant changes in dynamic balance with CKC group had slightly better improvement.[49]

Though performed on CAI subjects, our findings are in agreement with the results reported by Dannelly et al.[49] Both exercises produced significant improvement in postural control. One possible explanation of the significant improvements seen in both groups could be attributed to the fact that the OKC group in our study received strengthening training to the hip muscles in addition to ankle muscles. With this, the effect acquired from OKC exercises would someway resemble that of CKC with the exception of the functional nature of CKC exercises, which might have led to the higher improvement in postural control and functional performance. These findings further support the contention that hip strengthening is a viable intervention for this population.[22,50] It should be noted, however, that both Kwon et al. (2013) and Dannelly et al. (20140 studies did not include control groups. We believe that adding the control group strengthened our findings and the observed changes in both experimental groups were clinically relevant.

Self-Reported Function

The FAAM-sports subscale was used to allow participants to rate their level of function during sports related activities pre and post intervention. The change in self-reported function was mainly significant for the CKC group. The CKC group showed an improvement of about 20% from baseline, whereas OKC group increased by only 5%. In contrast, the control group did not show any change from baseline. The greatest improvement seen in CKC group could be attributed to the functional nature of these exercises.

GROC Scale

The GROC scale was used to assess the participant's perception of ankle instability following the 6-weeks of intervention. The CKC group had a significant change in the subjective perception of ankle instability and a greater level of satisfaction as compared to the other groups. The functional nature of the CKC exercises may have induced some proprioceptive changes that might have led to improved sense of ankle stability.

Our hypothesis that CKC exercises would improve the performance on postural control measures and self-reported function better than OKC exercises was supported with the results of this study. The higher improvement seen in the CKC group signifies the superiority of the functional training of these exercises over regular non-weight bearing training. CKC exercises are performed in a weight bearing position. In weight bearing movements, several group of muscles work across multiple joints.[28] In addition, CKC training generates more eccentric contraction and muscular co-contraction, which produces more tension in the muscles while adding compressive forces to the joints and thereby resulting in greater joint stability.[30,31,45] This could be the primary factor in the higher improvement noted in function and dynamic stability in the CKC group as compared to the OKC group. Adding the SEBT (functional reaching) in the CKC exercise protocol may also explain the better improvement noticed in the CKC group. Traditionally, the SEBT has been used as a functional test of dynamic stability; however, Donovan and Hertel[51] have recommended using it as a functional rehabilitation exercise. The SEBT is a CKC activity; therefore we sought to include it in the CKC training protocol. Reaching on the SEBT imposes a postural control challenge that ankle, knee, and hip joints of the support limb must effectively resist to maintain balance. In addition, in a weight bearing position, the central nervous system constantly make adjustment to keep the center of mass within the base of support.[52] Thus, CKC exercise training applied in our study may have induced changes in neural control that might have led to improved postural control.

Though we were able to show that OKC and CKC exercises can improve postural control in subjects with CAI, we do not know the extent to which this improvement in postural control might lead to a reduction in the recurrence of ankle sprains in this population. Hence, a follow up study may be needed to examine the longitudinal effect of these exercises on the incidence and recurrence of ankle sprains.

Study Limitations

Limitations of this study include the relatively small sample size and the lack of follow up. Follow up was not one of our purposes in this study, however, the long-term benefits of OKC and CKC exercises training in chronic ankle instability are not known, which necessitates the need for further research. Furthermore, electromyographic activity was not recorded in our study. This might be important, as previous research has indicated that subjects with CAI have altered muscle activation patterns.[18,19,20,22,23]

Clinical Implications

On the basis of this study results, both OKC and CKC training programs had positive effects on the outcome measures with greater improvement noted for the CKC exercises. The higher improvements seen in the CKC group supports previous findings suggesting the superiority of the functional training. Though safe and effective in the early rehabilitation, OKC exercises do not challenge the performance of the muscles as CKC exercises may do. In addition, hip strengthening is a viable intervention for this population and clinicians should consider including it in the training programs. Furthermore, clinicians should incorporate the SEBT as a functional rehabilitation exercise. It is for the clinician, however, to decide when to use open or closed kinetic chain training in their rehabilitation program for this population. The longitudinal effect of exercises is usually unknown, however, evidence from previous exercise trials in other musculoskeletal conditions suggests that benefits of a training program decline over time and booster sessions are useful to maintain long-term benefits.[53]

Conclusion

The 6-week of OKC and CKC exercise programs improved parameters of postural control and subjective function in subjects with CAI. CKC, however, showed some superiority over OKC at improving postural control, self-reported function, and subjective sense of instability. CKC group demonstrated a greater level of satisfaction as compared to the other groups. The greatest improvement seen in CKC group could be attributed to the functional nature of these exercises. Hence, exercise programs should become more functional and task oriented. Further research, however, is needed in a larger cohort of subjects with CAI to determine the long-term effects of both training programs on ankle joint injury risk factors.

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Conflict of Interest

No external funding sources were received to assist this study. No conflicts of interest are reported.

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CHAPTER FOUR

DISCUSSION

The primary objective of the conducted research studies was to simultaneously examine postural control as well as EMG activation patterns of the ankle and hip muscles during the performance of a dynamic task, the SEBT. These selected clinical and laboratory measures were examined in an attempt to discriminate patients with CAI from healthy individuals (copers & controls) and identify differences that might be responsible for the prolonged symptoms, the loss of function, and the increased risk of reinjury. The study aimed at providing additional knowledge regarding the interaction between hip and ankle muscle function during dynamic activities, which might help in customizing rehabilitation protocols that specifically target and improve patient outcomes. The present study identified group differences in postural control measures and EMG activity during the performance of SEBT. The CAI group demonstrated diminished dynamic stability and less activity of the muscles acting on the ankle and hip than the other groups. These findings further support the importance of hip exercise as part of a comprehensive rehabilitation program for this patient population.

Patients with CAI exhibited poor postural control performance as demonstrated by reach distance and COP measures than healthy individuals. Patient with CAI had less reach distance than the other groups during all directions; however, the difference was mainly significant in the AD. Similar findings were reported by previous researchers.[1,2,3] Postural control was also quantified by the magnitude of the COP movement and excursion during the performance of the SEBT. COP measures showed many significant differences among the groups in most of the directions, suggesting that relying on the reach distance alone might not provide the full picture of the postural control deficits if they are indeed present. An individual with an unstable ankle might be able to complete a functional task as well as a person with stable ankle depending on the severity of his/her condition; however, the completion pattern might be altered, creating the potential threat of reinjury. In this study, CAI patients were able to reach as far as healthy subjects, however, they demonstrated a higher sway, which implies an impaired postural stability. Though significant differences in COP measures were identified during the PMD, the AD and PLD in our study, PLD showed to be more challenging for CAI patients.

Patients with CAI have also demonstrated an altered NMC patterns in the proximal and distal joint muscles during the performance of the SEBT. Similar to our findings, when compared to controls, patients with CAI had reduced TA activity during the AD of the SEBT, with no differences reported for the Gmed activity.[4] However, Gmax activity was not recorded in that study. CAI patients in our study presented with less Gmax activity during PLD of the SEBT. This further supports the findings reported by Webster and Gribble[5] during a single leg rotational squat exercise, which were considered as a potential factor for the continual instability. Reaching in the PLD is especially challenging, as individuals have to maintain a level pelvis on the stance leg. As individuals reach backward across the stance leg, they shift their trunk anteriorly to maintain the center of mass within the base of support. Flexion in the trunk produces flexion moment at the hip, which is controlled by contraction of the hip extensors.[6] Thus, the elevated activation of Gmax might be needed in this situation to counteract the sagittal plane flexion of the trunk and hip. It seems that patients with CAI did not fire the Gmax enough to counteract this motion, resulting in overcompensation to maintain the body's center of mass within the base of support, which may have led to the higher sway during the PLD. The higher activation in the Gmax might also have occurred in order to control for the internal rotation of the femur during the PLD. These explanations, however, are hypothetical given the fact that kinematic data were not examined in our study. The turning or twisting movement such as that in the PDL is crucial to athletic activity and is usually a common mechanism of lower extremity injuries.[5]

In this study, balance and EMG data were collected simultaneously during the performance of the SEBT to examine potential sources of performance deficits and to further understand the NMC strategies utilized by each group to maintain stability. CAI group in this study demonstrated poorer performance mainly during the AD and PLD of the SEBT. Interestingly, during both directions, CAI group had less activation in the TA and Gmax than the other groups, which might indicate a relationship between performance and altered NMC at the hip and ankle. The poorer performance noted in the CAI group during these directions could be attributed to the lack of such activation strategy. Furthermore, during the PLD, controls and copers had activation of both, ankle and hip muscles, whereas CAI group relied mainly on the ankle muscles to complete the task. This reliance on ankle strategy to maintain balance could explain the increased risk of injury in this population. Gribble and Hertel[7] previously reported that fatigue to the proximal musculature of lower extremity created significantly increased postural control deficits compared to fatigue of the distal muscles. However, we identified alterations in the proximal and distal joint muscles activity in CAI patients without administrating a fatiguing protocol, which might be responsible for the postural control deficits in this population.

While previous studies[8,9,10] reported copers had higher activation in TA and PL than CAIs and controls, in our study, copers displayed greater activation of the TA (AD) and Gmax (PLD) as compared to CAIs but not to the controls and had higher activation of PL (PLD) as compared to controls only. The different testing protocols implemented by the studies might have led to such dissimilarity. However, it is unknown whether these NMC patterns exhibited by the copers were already present before injury or developed after the injury as a protective strategy against instability. In respective of that, such patterns might help copers to maintain postural stability as indicated by our results and therefore minimize the risk of developing instability.

Traditionally, there has been a focus on the distal ankle musculature, mainly the peroneal, for their capacity to provide dynamic stability and for the goal of preventing subsequent ankle injuries. Interestingly, our results showed an alteration in both, the distal and proximal musculature activation patterns in patients with CAI. These findings substantiate that deficits associated with CAI may be the consequences of both peripheral and centrally mediated alterations in NMC.[4,5,11,12] Hip musculature plays a major role in maintaining postural stability during single leg activities such that in SEBT. Clinically, this is important, as single leg activities are a key component of almost all functional movements. Alteration in the proximal muscles activity appears to negatively affect measures of postural control and the quality of movement, which may lead to prolonged functional impairments and increased recurrence of the undesired lower extremity injuries in this population. Overall, with the diminished hip and ankle muscles activation, the body's ability to maintain balance is compromised, thus the ability to perform functional skills might be limited in this population.

Limitations of this study include the lack of kinematic data to further support the findings of this study. In addition, since most injuries occur unpredictably, including an unexpected perturbation to the SEBT may provoke different NMC patterns and therefore should be examined. Finally, the smaller sample size with large standard deviations may have resulted in a type II error when statistical significance was not noted. Future research with a larger sample size that examines muscles activity and balance during more functional tasks such as running is needed.

The secondary objective of the conducted research studies was to examine the efficacy of OKC and CKC exercises as a method of improving dynamic balance, self-reported function, and perceived sense of instability in patients with CAI. Results of this study revealed that both experimental groups had significant improvements in the outcome measures; however, CKC group had greater improvements than OKC group. In contrast, the control group did not show any improvements from baseline.

The higher improvement seen in the CKC group signifies the superiority of the functional training of these exercises over regular non-weight bearing training. CKC training generates more eccentric contraction and muscular co-contraction, which produces more tension in the muscles while adding compressive forces to the joints and thereby resulting in greater joint stability.[13,14,15] This could be the primary factor in the higher improvement noted in function and dynamic stability in the CKC group as compared to the OKC group. Adding the SEBT (functional reaching) in the CKC exercise protocol may also explain the better improvement noticed in the CKC group. Reaching on the SEBT imposes a postural control challenge that ankle, knee, and hip joints of the support limb must effectively resist to maintain balance. In addition, in a weight bearing position, the central nervous system constantly make adjustment to keep the center of mass within the base of support.[16] Thus, CKC exercise training applied in our study may have induced changes in neural control that might have led to improved postural control. Though we were able to show that OKC and CKC exercises can improve postural control in subjects with CAI, we do not know the extent to which this improvement in postural control might lead to a reduction in the recurrence of ankle sprains in this population. Hence, a follow up study may be needed to examine the longitudinal effect of these exercises on the incidence and recurrence of ankle sprains.

Limitations of this study include the relatively small sample size and the lack of follow up. Follow up was not one of our purposes in this study, however, the long-term benefits of OKC and CKC exercises training in chronic ankle instability are not known, which necessitates the need for further research. Furthermore, electromyographic activity was not recorded in our study. This might be important, as previous research has indicated that subjects with CAI have altered muscle activation patterns.[5,6,8,9]

Conclusion

We identified alterations in proximal and distal NMC in patients with CAI. These alterations appear to negatively affect measures of postural control in this population.

Overall, patients with CAI exhibited poorer stability and diminished hip and ankle muscles activity. The 6-week of OKC and CKC exercise programs improved parameters of postural control, self-reported function, and subjective sense of instability in patients with CAI. CKC exercises, however, showed some superiority over OKC exercises. Hence, exercise programs should become more functional and task oriented.

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APPENDIX A

INFORMED CONSENT FORM

LOMA LINDA UNIVERSITY

School of Allied Health Professions

INFORMED CONSENT

TITLE: **DIFFERENCES IN HIP AND ANKLE MUSCLE STRENGTH AND ACTIVATION PATTERNS BETWEEN SUBJECTS WITH AND WITHOUT CHRONIC ANKLE INSTABILITY**

SPONSOR: **Department of Physical Therapy, Loma Linda University**

PRINCIPAL INVESTIGATOR

Everett B. Lohman III, DSc, PT, OCS
Professor, Department of Physical Therapy

Hatem Jaber, MPT, DSC-c
(215) 430-2931

You are invited to take part in a research study. Your participation in this research study is strictly voluntary, meaning that you may or may not choose to take part. Before you agree, you need to take time to carefully read and understand what your participation would involve. To decide whether or not you want to be part of this research, the purpose, procedures, risks, and possible benefits of the study are described in this form so you can make an informed decision.

1. WHY IS THIS STUDY BEING DONE?

The purpose of this study is to compare hip and ankle strength and electromyographic (EMG) activity during the performance of the Star Excursion Balance Test (SEBT) in subjects with and without chronic ankle instability (CAI).

Chronic ankle instability (CAI) is a common problem among active individuals. The recurrence rate of ankle sprains was reported to be as high as 80% among active individuals. Recent findings have suggested an association between hip muscle weakness and altered activity and increased recurrence rate of ankle sprains in subjects with CAI. However, limited data exist regarding this aspect. Additional knowledge regarding the interaction between hip and ankle muscle function may enhance the current understanding of CAI.

You are invited to participate in this research study because you are physically active adult between the ages of 18-35 with chronic ankle instability, have a history of at least 1 significant ankle sprains that resulted in swelling, pain, and temporary loss of function, have no trauma to the lower limbs for at least 3 months prior to the study, have a history of at least 2 repeated episodes of “giving way” in the past 6 months, have a chronic ankle weakness, pain, or feeling of ankle instability, or a healthy adult with no lower extremities problems. You will be excluded otherwise.

2. HOW MANY PEOPLE WILL TAKE PART IN THIS STUDY?

45 subjects will participate in this study.

3. HOW LONG WILL THE STUDY GO ON?

Your participation will last for up to two hours during two visits.

4. HOW WILL I BE INVOLVED?

- Your date of birth, height, weight and activity level (athletic or non-athletic) will be recorded.
- You will then complete a brief health questionnaire and standardized history.
- You will be required to complete self-reported measures (Questionnaires).

- The following measurements will be taken:
    - Ankle joints range of motion will be measured with a standard instrument.
    - Muscle strength will be measured using a standard instrument.
    - Muscle activity will be measured using electromyogram (EMG).

Healthy subjects will be assigned to the control group, while subjects with chronic ankle instability will be assigned to the experimental groups. We will use EMG to record the activity of the hip and ankle muscles during the performance a dynamic balance test. Your skin will be shaved (if necessary), and cleaned with alcohol prior to the electrodes placement. Surface electrodes will be placed over the muscle belly of the hip and ankle. You will need to wear comfortable clothing that can be rolled down to expose the buttocks area to place the electrodes.

5. WHAT ARE THE REASONABLY FORESEEABLE RISKS OR DISCOMFORTS I MIGHT HAVE?

Participation in this study may yield minimal risk. Some of the testing procedures will require you to stand on one leg and on your forefoot. This will put you at minimal risk to fall; however, the investigator will be standing next to you to minimize this risk and you will also rest your hands on a sturdy counter or chair in front of you for support/balance. Also, you may feel tired/fatigued or bored due to multiple testing procedures. There are no political, social or economical risks to you for participating in the study. There is also a minimal risk of breach of confidentiality. There might be a risk of embarrassment that will be minimized by private screen area of curtains.

6. WILL THERE BE ANY BENEFIT TO ME OR OTHERS?

Although you will not benefit from this study, the scientific information we learn from the study may benefit individuals in the future by determining the association between hip muscles weakness and the increased recurrence rates of ankle sprains in subjects with chronic ankle instability (CAI). This will help in the clinical decision-making and will benefit other subjects with similar conditions in the future, and will advance the research in this particular area.

7. WHAT ARE MY RIGHTS AS A SUBJECT?

Participation in this study is voluntary. Your decision whether or not to participate or withdraw at any time from the study will not affect your ongoing relationship with Loma Linda Health and will not involve any penalty or loss of benefits to which you are otherwise entitled. You do not give up any legal rights by participating in this study.

8. WHAT HAPPENS IF I WANT TO STOP TAKING PART IN THIS STUDY?

You are free to withdraw from this study at any time. If you decide to withdraw from this study you should notify the research team immediately. The research team may also end your participation in this study if you do not follow instructions, or if your safety and welfare are at risk.

9. HOW WILL INFORMATION ABOUT ME BE KEPT CONFIDENTIAL?

Efforts will be made to keep your personal information confidential. Your information will be kept on a safe external computer hard drive in a locked file cabinet. Access to the hard drive will require a coded password. You will not be identified by name in any publications describing the results of this study.

10. WILL I BE PAID TO PARTICIPATE IN THIS STUDY?

In appreciation for you participation in this study, you will receive $25 gift card for completing this study. You will receive this upon completion of your data collection.

11. WHAT COSTS ARE INVLOVED?

There is no cost to you for your participation in this study. If you agree to participate in this study, you will be responsible for your own travel to and from the research lab.

12. WHO DO I CALL IF I AM INJURIED AS A RESULT OF BEING IN THIS STUDY?

If you feel you have been injured by taking part in this study, consult with a physician or call 911 if the situation is a medical emergency. No funds have been set aside nor any plans made to compensate you for time lost for work, disability, pain or other discomforts resulting from your participation in this research.

13. WHO DO I CALL IF I HAVE QUESTIONS?

If you have any concerns or questions regarding this research, please contact Everett Lohman DSc at elohman@llu.edu or 909-558-4632 Ext 83171. If you wish to contact an impartial third party not associated with this study regarding any questions about your rights or to report a complaint you may have about the study, you may contact the office of Patient Relations, Loma Linda University Medical Center, Loma Linda, CA 92354, phone (909) 558-4647, e-mail: patientrelation@llu.edu for information and assistance.

14. SUBJECT'S STATEMENT OF CONSENT

I have read the contents of the consent form and have listened to the verbal explanation given by the investigator. My questions concerning this study have been answered to my satisfaction. Signing this consent document does not waive my rights nor does it release the investigators, institution or sponsors from their responsibilities. I hereby give voluntary consent to participate in this study.

I understand I will be given a copy of this consent form after signing it.

______________________________ ______________________________

Signature of Subject Printed Name of Subject

____

Date

15. INVESTIGATOR'S STATEMENT

I attest that the requirements for informed consent for the medical research project described in this form have been satisfied – that the subject has been provided with a copy of the California Experimental Subject's Bill of Rights, that I have discussed the research project with the subject, and that I have explained to him or her in non-technical terms all of the information contained in this informed consent form, including any risks and adverse reactions that may reasonably be expected to occur. I further certify that I encouraged the subject to ask questions and that all questions asked were answered.

______________________________ ______________________________

Signature of Investigator Printed Name of Investigator

____

Date

APPENDIX B

PROTECTED HEALTH INFORMATION

INSTITUTIONAL REVIEW BOARD

Authorization for Use of Protected Health Information (PHI)

Per 45 CFR §164.508(b)

RESEARCH PROTECTION PROGRAMS

LOMA LINDA UNIVERSITY | Office of the Vice President of Research Affairs
24887 Taylor Street, Suite 202 Loma Linda, CA 92350
(909) 558-4531 (voice) / (909) 558-0131 (fax)/e-mail: irb@llu.edu

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TITLE OF STUDY: “DIFFERENCES IN HIPAND ANKLE MUSCLE STRENGTH AND ACTIVATION PATTERNS BETWEEN SUBJECTS WITH AND WITHOUT CHRONIC ANKLE INSTABILTY”

PRINCIPAL INVESTIGATOR: Everett B. Lohman III, DSc, PT, OCS.

Others who will use, collect, or share PHI: Hatem Jaber, PT, MPT, DSc-c

The study named above may be performed only by using personal information relating to your health. National and international data protection regulations give you the right to control the use of your medical information. Therefore, by signing this form, you specifically authorize your medical information to be used or shared as described below.

The following personal information, considered “Protected Health Information” (PHI) is needed to conduct this study and may include, but is not limited to: Name, gender, address, diagnosis of chronic ankle instability, telephone number, and date of birth. This information will be obtained with your permission from your physician.

The individual(s) listed above will use or share this PHI in the course of this study with the Institutional Review Board (IRB) and the Office of Research Affairs of Loma Linda University.

The main reason for sharing this information is to be able to conduct the study as described earlier in the consent form. In addition, it is shared to ensure that the study meets legal, institutional, and accreditation standards. Information may also be shared to report adverse events or situations that may help prevent placing other individuals at risk.

All reasonable efforts will be used to protect the confidentiality of your PHI, which may be shared with others to support this study, to carry out their responsibilities, to conduct public health reporting and to comply with the law as applicable. Those who receive the PHI may share with others if they are required by law, and they may share it with others who may not be required to follow national and international "protected health information" (PHI) regulations such as the federal privacy rule.

Subject to any legal limitations, you have the right to access any protected health information created during this study. You may request this information from the Principal Investigator named above but it will only become available after the study analyses are complete.

- This authorization does not expire, and will continue indefinitely unless you notify the researchers that you wish to revoke it.

You may change your mind about this authorization at any time. If this happens, you must withdraw your permission in writing. Beginning on the date you withdraw your permission, no new personal health information will be used for this study. However, study personnel may continue to use the health information that was provided before you withdrew your permission. If you sign this form and enter the study, but later change your mind and withdraw your permission, you will be removed from the study at that time. To withdraw your permission, please contact the Principal Investigator or study personnel at 215-430-2931.

You may refuse to sign this authorization. Refusing to sign will not affect the present or future care you receive at this institution and will not cause any penalty or loss of benefits to which you are entitled. However, if you do not sign this authorization form, you will not be able to take part in the study for which you are being considered. You will receive a copy of this signed and dated authorization prior to your participation in this study.

I agree that my personal health information may be used for the study purposes described in this form.

____________________	____________________
Signature of Patient *or* Patient's Legal Representative	Date

____

Printed Name of Legal Representative (if any)	Representative's Authority to Act for Patient
Signature of Investigator Obtaining Authorization	Date

APPENDIX C

CALIFORNIA EXPERIMENTAL SUBJECT'S BILL OF RIGHTS

You have been asked to participate as a subject in an experimental clinical procedure. Before you decide whether you want to participate in the experimental procedure, you have a right to:

1. Be informed of the nature and purpose of the experiment.

2. Be given an explanation of the procedures to be followed in the medical experiment, and any drug or device to be utilized.

3. Be given a description of any attendant discomforts and risks reasonably to be expected from the experiment.

4. Be given an explanation of any benefits to the subject reasonably to be expected from the experiment, if applicable.

5. Be given a disclosure of any appropriate alternative procedures, drugs or devices that might be advantageous to the subject, and their relative risks and benefits.

6. Be informed of the avenues of medical treatment, if any available to the subject after the experiment if complications should arise.

7. Be given an opportunity to ask any questions concerning the experiment or the procedure involved.

8. Be instructed that consent to participate in the medical experiment may be withdrawn at any time and the subject may discontinue participation in the medical experiment without prejudice.

9. Be given a copy of any signed and dated written consent form used in relation to the experiment.

10. Be given the opportunity to decide to consent or not to consent to a medical experiment without the intervention of any element of force, fraud, deceit, duress, coercion or undue influence on the subject's decision.

I have carefully read the information contained above in the "California Experimental Subject's Bill of Rights" and I understand fully my rights as a potential subject in a medical experiment involving people as subjects.

________________________ ________________________________

Date Patient

APPENDIX D

PATIENT'S INFORMATION FORM

Subject's Initials: …………………………………………………

Diagnosis: ………………………………………

Gender: ……………

Phone numbers: …………………….

Date of birth (MM/DD/YYYY): …………………………

Weight: …………………….

Height: ………………………

Sport participation hours: Per day …………………..…Or, Per week …………………………….

History of ankle sprain:	Yes	No
Frequency of sprains:	≤2	≥3
Received Rehab following the sprain:	Yes	No

APPENDIX E

INCLUSION/EXCLUSION CRITERIA FORM

Subject #____________

A. Criteria for inclusion of subjects:

- **Chronic ankle instability group:**
  - 18 to 35 years of age
  - Have a history of at least 1 significant unilateral ankle sprain that resulted in swelling, pain, and loss of function of more than a day. ( )
  - Have no trauma to the lower limbs for at least 3 months prior to the study. ( )
  - Have a history of at least 2 repeated episodes of "giving way" in the past 6 months. ( )
  - Have a chronic ankle weakness, pain, or feeling of ankle instability. ( )
  - Physically active. ( )
- **Healthy matched control group:**
  - 18 to 35 years of age. ( )
  - No history of ankle sprain or fracture to either leg. ( )
  - No reported episodes of ankle giving way during activity. ( )
  - Physically active

B. Criteria for exclusion of subjects (other than those opposite the inclusion criteria):

- Pregnant (self reported). ( )
- Have a history of neurological or vestibular illness. ( )
- Have a history of fracture to the lower extremity. ( )
- Previous surgeries to either limb of the lower extremity. ( )
- Have any red flags (e.g. DVT) noted during the patient's medical screening. ( )
- Consumed drugs or alcohol within 24 hours prior to testing ( )
- Cannot perform requested procedures of the study according to protocol. ( )

APPENDIX F

PROCEDURE CHECK LIST

- Subject Number …………………
- Informed consent ( )
- Hipaa Model ( )
- Subject's Bill of rights ( )
- Patient's information ( )
- Cumberland Ankle Instability Tool ( )
- Ankle Instability Instrument ( )
- Leg Length ( )
- Muscle testing ( )
- MVC ( )
- Treadmill SEBT (Reach distance/EMG) ( )
- Balance Master SEBT (Reach distance/EMG) ( )

Group: Control Copers CAI

Assessor………………………………………..

APPENDIX G

SELF-REPORT QUESTIONNAIRE

[CUMBERLAND ANKLE INSTABILITY TOOL]

The Cumberland Ankle Instability Tool

Please tick the ONE statement in EACH question that BEST describes your ankles.

	LEFT	RIGHT	SCORE
1. I have pain in my ankle			
Never	☐	☐	5
During sport	☐	☐	4
Running on uneven surfaces	☐	☐	3
Running on level surfaces	☐	☐	2
Walking on uneven surfaces	☐	☐	1
Walking on level surfaces	☐	☐	0
2. My ankle feels UNSTABLE			
Never	☐	☐	4
Sometimes during sport (not every time)	☐	☐	3
Frequently during sport (every time)	☐	☐	2
Sometimes during daily activity	☐	☐	1
Frequently during daily activity	☐	☐	0
3. When I make SHARP turns, my ankle feels UNSTABLE			
Never	☐	☐	3
Sometimes when running	☐	☐	2
Often when running	☐	☐	1
When walking	☐	☐	0
4. When going down the stairs, my ankle feels UNSTABLE			
Never	☐	☐	3
If I go fast	☐	☐	2
Occasionally	☐	☐	1
Always	☐	☐	0
5. My ankle feels UNSTBLE when standing on ONE leg			
Never	☐	☐	2
On the ball of my foot	☐	☐	1
With my foot flat	☐	☐	0
6. My ankle feels UNSTABLE when			
Never	☐	☐	3
I hop from side to side	☐	☐	2
I hop on the spot	☐	☐	1
When I jump	☐	☐	0
7. My ankle feels UNSTABLE when			

Never	☐	☐	4
I run on uneven surfaces	☐	☐	3
I jog on uneven surfaces	☐	☐	2
I walk on uneven surfaces	☐	☐	1
I walk on a flat surface	☐	☐	0
8. TYPICALLY, when I start to roll over (or twist) on my ankle, I can stop			
Immediately	☐	☐	4
Often	☐	☐	3
Sometimes	☐	☐	2
Never	☐	☐	1
I have never rolled over on my ankle	☐	☐	0
9. After a TYPICAL incident of my ankle rolling over, my ankle returns to "normal "			
Almost immediately	☐	☐	4
Less than one day	☐	☐	3
1-2 days	☐	☐	2
More than 2 days	☐	☐	1
I have never rolled over on my ankle	☐	☐	0

[ANKLE INSTABILITY INSTRUMENT]

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 participate.

1. Have you ever sprained your ankle?	☐ Yes	☐ No
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 the ankle "gave way"? ☐ <1 months ☐ 1-6 months ago ☐ 6-12 months ago ☐ 1-2 years ago ☐ >2 years		
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 recreational or sport activity?	☐ 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

APPENDIX H

DATA COLLECTION SHEET

MUSCLE TESTING SCORING SHEET

Manual Muscle Testing Scoring Sheet
Subject's number ___________________________________
Assessor ___________________________________
Date of assessment (mm/dd/yy) ___________________________________

Right Side Muscles	**Test Position**	**Score 1**	**Score 2**	**Score 3**
Gluteus Medius	Sidelying			
Gluteus Maximus	Pronelying			
Tibialis Anterior	Long sitting/Supine			
Peroneus Longus	Long sitting/Supine			

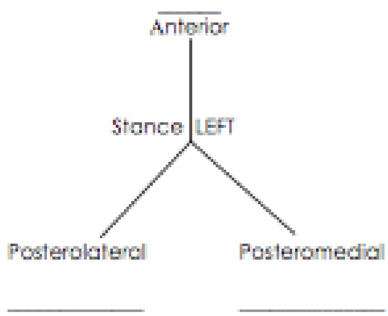
Left Side Muscles	**Test Position**	**Score 1**	**Score 2**	**Score 3**
Gluteus Medius	Sidelying			
Gluteus Maximus	Pronelying			
Tibialis Anterior	Long sitting/Supine			
Peroneus Longus	Long sitting/Supine			

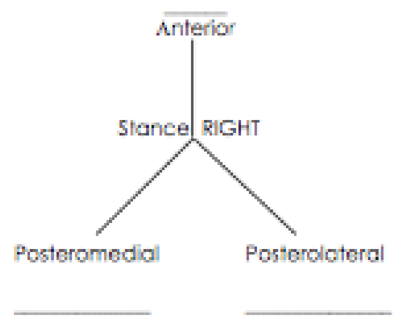
Score Sheet for Y Balance Test™ & Limb Length

Treadmill

Athlete Name: ______________________________ Date: ______________________

RIGHT Limb Length: ____________________





	Left			Right			Difference
Anterior							
Posteromedial							
Posterolateral							

*** Difference should be less than 4 cm. for return to sport and preparticipation screening ***

$$\text{Composite Score} = \frac{(\text{Anterior} + \text{Posteriomedial} + \text{Posterolateral})}{(3 \times \text{Limb Length})} \times 100$$

Composite	
Right	
Left	

APPENDIX I

FLYER FOR RECRUITING PARTICIPANTS

LOMA LINDA UNIVERSITY

School of Allied Health Professions

Research Opportunity

DIFFERENCES IN HIP AND ANKLE MUSCLE STRENGTH AND ACTIVATION PATTERNS BETWEEN SUBJECTS WITH AND WITHOUT CHRONIC ANKLE INSTABILITY

The Department of Physical Therapy of the School of Allied Health Profession, Loma Linda University is conducting a graduate student research study.

PARTICIPANTS ARE NEEDED

You may qualify to participate in this study if you are 18-35 years of age, physically active, and if:

- You have a history of at least 1 significant ankle sprains that resulted in swelling, pain, and temporary loss of function
- You have a chronic ankle weakness, pain, or feeling of ankle instability or giving way in the past 6 months
- Or a healthy subject with no history of ankle sprain or fracture to either leg and with no reported episodes of ankle giving way during activity

If you are eligible to participate, you will be screened for sources of ankle instability and then your ankle and hip muscle strength and muscle activity will be evaluated. Your participation will last for up to two hours during two visits. The study will take place at Nichol Hall room A620, Loma Linda University.

Neither you nor your health insurance provider will be charged for the cost of any evaluation provided for the purposes of this study. After completing the evaluation, you will receive a gift card as an expression of our thanks for your participation.

If you are interested to participate or would like to know more about the study, please contact graduate student **Hatem Jaber** at **215-430-2931** or email at **hjaber@llu.edu**

PARTICIPANTS NEEDED

The Department of Physical Therapy of the School of Allied Health Professions at Loma Linda University is currently conducting a graduate student research study to examine the differences in hip and ankle muscle strength and electromyographic activity in subjects with and without unilateral (one-sided) chronic ankle sprain.

You may qualify to participate in this study if:

- Your age is between 18-35 and are physically active
- You have a history of at least 1 significant ankle sprains that resulted in swelling, pain, and temporary loss of function
- You have a chronic ankle weakness, pain, or feeling of ankle instability or giving way in the past 6 months
- Or a healthy subject with no history of ankle sprain or fracture to either leg and with no reported episodes of ankle giving way during activity

Neither you nor your health insurance provider will be charged for the cost of any evaluation provided for the purposes of this study. The study will take place at Nichol Hall room A620, Loma Linda University. After completing the study, you will receive a gift card.

If you are interested to participate or would like to know more about the study, please contact graduate student **Hatem Jaber at 215-430-2931 or email at** hjaber@llu.edu

APPENDIX J

LETTER FOR PATIENT REFERRAL

Dr.__________________________________;

My name is Everett Lohman, DSC, PT, OCS. I am a faculty member in the Department of Physical Therapy School of Allied Health, Loma Linda University. My DSC graduate student, Hatem Jaber and I are conducting a research study on subjects with unilateral chronic ankle instability. The purpose of this study is to examine the differences in hip and ankle muscle strength and electromyographic activity in subjects with and without unilateral chronic ankle instability.

Our inclusion criteria include subjects diagnosed with unilateral chronic ankle instability with the following criteria:

- Ages between 18-35 years and are physically active
- Have a history of at least 1 significant unilateral ankle sprains to the same side with no injury to the opposite side
- Have no trauma to the lower limbs for at least 3 months prior to the study
- Have a history of at least 2 repeated episodes of "giving way" in the past 6 months
- Have a chronic ankle weakness, pain, or feeling of ankle instability

Our exclusion criteria will include:

- Pregnancy
- A history of neurological or vestibular illness
- A history of fracture to the lower extremity
- A history of previous surgeries to either limb of the lower extremity

If you have subjects who you feel would qualify for or may benefit from participation in our study, we would appreciate if you would inform them about our study and check if they are interested in learning more about it. If the patient expresses interest, we will contact them with details about the study. However, we need the patient's permission to do so. Thus, we would appreciate if you provide him/her with enclosed Authorization for Use of Protected Health Information (PHI) form to read and sign. This form will allow his or her name, diagnosis, phone number (home, cellular), date of birth, and gender to be forwarded to the study investigator. After the form is signed please contact graduate student Hatem Jaber, PT, MPT at (215) 430-2931 or email at hjaber@llu.edu to arrange for initial visit, to obtain the signed PHI form, and relevant patient information form.

Thank you for referring subjects for participation in our study.

Sincerely,

Everett Lohman, DSC, PT, OCS.

24951 North Circle Drive, Nichol Hall
Loma Linda, CA 92350
Phone: (909) 558 – 4632 Ext 83171
E- mail: elohman@llu.edu