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ORIGINAL RESEARCH

EFFECT OF ANKLE BRACES ON LOWER EXTREMITY MUSCLE ACTIVATION DURING FUNCTIONAL EXERCISES IN PARTICIPANTS WITH CHRONIC ANKLE INSTABILITY

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ABSTRACT

Background: Ankle bracing and rehabilitation are common methods to reduce the rate of recurrent ankle sprain in participants with chronic ankle instability (CAI). CAI participants utilize less muscle activity when performing functional exercises compared to healthy controls. The effect of ankle braces on muscle activity during functional exercises in participants with CAI has not been previously studied.

Purpose: To determine the effect of bracing on motor output as demonstrated by surface EMG amplitudes in participants with CAI during single limb, eyes closed balance, star excursion balance, forward lunge, and lateral hop exercises.

Methods: A descriptive laboratory study was performed. Fifteen young adults with CAI performed functional exercises with and without ankle braces while surface EMG signals were recorded from the tibialis anterior, peroneus longus, lateral gastrocnemius, rectus femoris, biceps femoris, and gluteus medius. The main outcome measures were normalized surface EMG amplitudes (root mean square area) for each muscle, muscles of the shank (distal three muscles), muscles of the thigh (proximal three muscles), and total muscle activity (all six muscles) of the lower extremity. A paired t-test was performed for each dependent variable to compare conditions. The level of significance was set *a priori* at $p \leq 0.05$ for all analyses.

Results: During the forward lunge, bracing significantly reduced muscle activity pre-initial contact in the lateral gastrocnemius and post-initial contact in the peroneus longus. During the star excursion balance anterior reach the peroneus longus, lateral gastrocnemius, rectus femoris, and gluteus medius had significantly less muscle activity during braced trials. Bracing significantly reduced thigh and total muscle activity during the anterior reach and gluteus medius activity during the posterolateral reach. There were no differences between braced and unbraced conditions during the single limb eyes closed balance, star excursion balance posteromedial reach, or during lateral hop exercises.

Conclusions: Clinicians should be aware of the decreased muscle activity that occurs during common rehabilitation exercises when patients with CAI complete those activities while wearing ankle braces.

Level of Evidence: Level III

Key Words: Ankle brace, ankle sprain, therapeutic exercise

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Conflicts of Interest: None

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INTRODUCTION

Ankle sprains are one of the most common musculoskeletal injuries.[1-3] Following an initial sprain, patients are more susceptible to future sprains,[4] and up to 70% may have residual ankle symptoms that affect their quality of life.[5,6] Patients that do not fully recover from the initial sprain develop a condition known as chronic ankle instability (CAI).[7-9] CAI is defined by repetitive bouts of the ankle 'giving way' and self-reported functional limitations following at least one significant ankle sprain.[9]

Self-reported functional deficits in patients with CAI have consistently been related to alterations in joint kinematics, kinetics, and motor control strategies just prior to and following ground contact during gait[10-15] and jump landing.[16-19] Patients with CAI have more ankle inversion prior to ground contact,[11,12] increased lateral loading,[20] and demonstrate task dependent alterations in muscle activity during walking,[14] functional exercise,[15] and drop jump maneuvers.[21] When performing lunges and lateral hopping exercises, participants with CAI demonstrate decreased preparatory and reflexive muscle activity, which may indicate muscle inhibition or an unconscious protective mechanism by which participants with CAI complete the exercises at lower intensities compared to healthy counterparts.[15] Currently, neuromuscular re-education and the application of ankle braces are two of the commonly utilized methods for improving outcomes in patients with CAI.[22]

Neuromuscular re-education is thought to be effective by improving balance and postural control.[22,23] Rehabilitation protocols for patients with CAI have been able to improve self-reported functional limitations following the intervention.[24-26] A recent randomized control trial compared neuromuscular training, prophylactic ankle bracing, and a combination of neuromuscular training and ankle bracing.[27] The risk of recurrent sprain over a 12-month period was 50% less in patients that wore ankle braces for 12 months when compared to patients that underwent 8 weeks of home-based neuromuscular training.[27] In this study, the combination group performed 8 weeks of unsupervised home-based neuromuscular training with 8 weeks of concurrent brace wear.[27] The authors suggested that the effects of neuromuscular training would take full effect by eight weeks and that further brace wear would not be required.[27] However, concurrent use of prophylactic ankle braces and eight weeks of un-supervised neuromuscular training, did not significantly reduce the risk of ankle sprain reoccurrence when compared to the neuromuscular training group alone or compared to 12 months of prophylactic bracing.[27]

The exact mechanism by which ankle braces reduce the rate of ankle sprain has yet to be elucidated. Two broad theories for the mechanism are via passive mechanical support and/or improving sensorimotor function.[28] A meta-analysis by Cordova et al.[29] illustrates the effectiveness of ankle braces at mechanically restricting range of motion. Ankle braces have also been shown to improve static[30] and dynamic[31] balance in participants with ankle instability during single limb stance and the star excursion balance test (SEBT), respectively. However, braces either impair[30,32] or have no effect[33] on balance in healthy participants. Hadadi et al[30] speculated that the ability of braces to improve balance in CAI subjects, while decreasing balance in healthy individuals may be related to how each group's proprioception and/or motor output is altered with the application of braces.

A recent systematic review illustrated that ankle bracing or taping has no significant effect on proprioceptive acuity as measured by joint position sense or threshold to movement detection.[34] In terms of motor output, lace-up braces increase the peroneus longus stretch reflex amplitude immediately after application and semi-rigid braces increase the peroneus longus amplitude after eight weeks of prolonged use in healthy subjects.[35] However, the application of ankle braces does not appear to influence the motor neuron pool excitability of the peroneus longus in healthy subjects during an inversion perturbation.[36] During walking, Barlow et al[37] identified that the application of ankle braces decreases the peroneus longus pre-contact muscle activity and decreases the duration of muscle activation in the peroneus longus and rectus femoris in CAI subjects.

Despite the widespread use and acceptance of ankle braces in patients with a history of ankle sprain, there is limited research investigating the effect of ankle braces on motor output in participants with CAI during functional exercises. Understanding how ankle braces influence motor output may provide insight into not only how ankle braces reduce the rate of recurrent ankle sprain but also the influence braces have on muscle activity when worn during functional rehabilitation following an ankle sprain or during neuromuscular training for prophylactic injury prevention. Therefore, the purpose of this study was to investigate the effect of ankle braces on motor output during single-limb eyes closed balance, star excursion balance, forward lunges, and lateral hopping exercises in participants with CAI.

METHODS

Design

A descriptive laboratory study was performed in which the independent variable was condition (brace, no brace) and the dependent variables were normalized surface electromyography (sEMG) root mean square (RMS) amplitudes for the tibialis anterior, peroneus longus, lateral gastrocnemius, rectus femoris, biceps femoris, and gluteus medius during single limb eyes closed balance, star excursion balance reach directions (anterior, posteromedial, and posterolateral), forward lunges, and lateral hops. To gain a more comprehensive understanding of lower extremity muscle activation normalized sEMG amplitudes for individual muscles were summed for the distal musculature (tibialis anterior, peroneus longus, lateral gastrocnemius), proximal musculature (rectus femoris, biceps femoris, and gluteus medius), and total lower extremity musculature (all six muscles) between conditions.

Subjects

Fifteen young adults with CAI participated. (Table 1) This study was part of a larger study and the same cohort has been previously reported in another manuscript investigating differences in normalized sEMG between CAI and healthy controls during the same functional exercises.[15] Briefly, CAI participants had a history of more than one ankle sprain with the initial sprain occurring greater than one year prior to study onset and current self reported functional deficits due to ankle symptoms that were qualified by a score of <85% on the Foot and Ankle Ability Measure (FAAM) sport scale. Participants were excluded if they had an ankle sprain within the six weeks prior to study onset, history of lower extremity injury or surgery, balance disorders, neuropathies, diabetes, or other conditions known to affect balance. Subjects provided informed consent and the study was approved by the University of Virginia's institutional review board.

Instruments

Surface EMG signals were collected from disposable, pre-gelled 10 mm round Ag-AgCl electrodes (EL 503 Biopac Systems, Inc., Goleta, CA) and amplified with a high-gain, differential-input biopotential amplifier with a gain of 1000 and digitized with a 16-bit data acquisition system (MP 150, Biopac Systems) at 2000 Hz with a common-mode rejection ratio of 110 dB, an input impedance of 1.0 MΩ, and a noise voltage of 0.2 mV. Acqknowledge software (v.4.0, Cambridge, England) was used for data collection and processing of EMG signals. The EMG data was collected using real time processing with a 10-500 Hz band pass filter and a 10 sample moving average RMS algorithm. A foot switch (BN-STRIKE-XDCR, Biopac Systems) was used to identify ground contact during the star excursion balance, forward lunge, and lateral hop-

Table 1. *Subject Demographics*

	Mean (Standard Deviation)
Age (years)	23 (4.2)
Height (centimeters)	173 (10.8)
Mass (kilograms)	72.4 (14)
Gender	Male:5, Female:10
# of previous sprains	4.5 (3.2)
Time since last sprain (months)	15.2 (9.3)
Godin Score	94 (47)
FAAM ADL	87.2 (7.1)
FAAM Sport	68.5 (5.7)

Godin Score= Godin Leisure-Time Exercise Questionnaire score
FAAM ADL= Foot and Ankle Ability Measure Activities of Daily Living scale score
FAAM Sport =Foot and Ankle Ability Measure Sport sub-scale score

ping exercises. All subjects wore standard athletic shoes for all exercises (New Balance, Brighton, MA, X755WB). During the braced condition, all subjects used the same lace-up ankle brace (McDavid Ultralight 195, McDavid Inc., Woodridge, IL).

Testing Procedures

Using previously described methods[15] and ISEK recommendations,[38] surface electrodes were placed 2 cm apart on all 6 muscles parallel to muscle fiber orientation. Electrodes were placed over the middle of the muscle belly as determined by palpation during a voluntary contraction against manual resistance. All participants performed a warm up by walking at a self-selected pace for 5 minutes. Maximal voluntary isometric contractions against manual resistance were recorded for each muscle for normalization of sEMG amplitudes during testing trials. The order of conditions (brace and no brace) was randomized for each participant. The research team applied the support straps and inspected the brace for an appropriate fit prior to testing. Participants were allowed to tighten the ankle braces prior to testing, based on their level of comfort, and throughout testing if required. Brace tightness was not monitored throughout testing. The research team and participants were not blinded for any part of this study and participants were given as much time between conditions as needed, however, no participant required more than five minutes of rest.

Exercises

Standardized exercises were performed as described previously.[15] Briefly, participants performed at least three but no more than five practice trials for each exercise. For all exercises, failed trials[15] were repeated until the desired number of repetitions was achieved. The order of brace condition was randomized. Randomization was predetermined to ensure a balanced study design, but the order of the exercises performed within each condition was done in the same order for each participant. Due to the low volume of exercises performed, there was not a predetermined rest period between exercises. The exercises were completed in the order of which they are described below. Only the involved limb was tested for each exercise, however, braces were worn bilaterally.

Five consecutive forward lunges[15] were performed and the lead leg was the test limb. Single limb eyes closed balance[15] was performed on a stable surface for 15 seconds with the stance limb as the test limb. Star excursion balance[15] was performed three times each in the anterior, posteromedial, and posterolateral reach directions with the stance limb as the test limb. Reach distance was not standardized as subjects were instructed to reach as far as possible during each repetition. Lateral hops were performed over a 1.5-inch line at a rate of 110 hops per minute for 20 seconds. Lateral hopping rate was standardized to the beat of a metronome.

Data Processing

Forward Lunges

The middle three lunges of the five consecutive lunge trials were analyzed. A 50 ms epoch immediately prior to initial contact was used to calculate the pre-initial contact area under the RMS curve. A 100 ms epoch immediately following initial contact was used to calculate the post-initial contact area under the RMS curve. Lunge amplitudes were normalized to respective MVIC epochs.

Single Limb Eyes Closed Balance

A three second epoch during the middle of the single limb eyes closed balance trial was analyzed. The area under the RMS curve was calculated and normalized to a three second MVIC epoch for each muscle.

Star Excursion Balance Test

A 500 ms epoch just prior to maximum excursion was averaged over three trials for each of the three reach directions. Maximum excursion was defined as the time at which the contralateral limb's toe touched down for a reach distance to be recorded. The average area under the RMS curve over the three trials was normalized to a 500 ms MVIC epoch for each muscle.

Lateral Hops

Six total consecutive hops (3 in each direction) were selected from the middle of the lateral hopping trial. A 50 ms epoch immediately prior to initial contact was used to calculate the pre-initial contact area under the RMS curve. A 100 ms epoch immediately following initial contact was used to calculate the post-initial contact area under the RMS curve. Lateral hopping amplitudes were normalized to respective MVIC epochs.

Distal, Proximal, and Total Muscle Activity

To gain a more comprehensive understanding of the sEMG activity of the entire lower extremity during each exercise the normalized muscle activity of the distal, proximal, and entire lower extremity were summed and analyzed as separate dependent variables for each exercise as described below.

Statistical analysis

The independent variable was condition (brace and no brace) and the main outcome measures were sEMG RMS areas for a predetermined epoch for each exercise. Each individual muscle, the sum of the three distal muscles, the sum of the three proximal muscles, and the sum of all six muscles were treated as separate dependent variables. A paired t-test was performed for each dependent variable to compare conditions. The level of significance was set *a priori* at $p \leq 0.05$ for all analyses. Per contemporary statistical recommendations,[39] the p-level was not adjusted for multiple comparisons. Instead, in addition to inferential statistical comparisons, Cohen's *d* effect sizes and associated 95% confidence intervals were calculated to estimate the magnitude and precision of condition differences for each measure. Effect sizes were interpreted as ≥ 0.80 was large, 0.50-0.79 was moderate, 0.20-0.49 was small, and < 0.20 was trivial.[40] Negative effect sizes indicated decreased muscle activation in the braced condition. Positive effect sizes indicated increased muscle activation in the braced condition. Data were analyzed using Statistical Package for Social Sciences (SPSS) Version 20.0 (SPSS, Inc, Chicago, IL).

RESULTS

Participants with CAI had significantly less muscle activity during braced trials pre-initial contact in the lateral gastrocnemius and post-initial contact in the peroneus longus during the forward lunge. (Table 2) No other differences were identified in individual muscles or for groups of muscles during lunge trials. During single limb eyes closed balance trials, no differences were identified between brace and no brace conditions. (Table 3) For the star excursion balance anterior reach the peroneus longus, lateral gastrocnemius, rectus femoris, and gluteus medius had sig-

Table 2. *Effect of Ankle Braces on Muscle Activation Patterns during the Forward Lunge Exercise*

		Isolated Muscle Activation				Distal/Proximal Muscle Activation				Total Muscle Activation		
Muscles		No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)		No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)		No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)
Anterior Tibialis	Pre-IC	0.57±0.46	0.58±0.46	.87 0.01 (-0.70, 0.73)								
	Post-IC	0.59±0.60	0.60±0.36	.99 0.00 (-0.71, 0.72)								
Peroneus Longus	Pre-IC	0.24±0.14	0.22±0.13	.19 -0.19 (-0.91, 0.53)	Pre-IC	1.21±0.73	1.10±0.70	.12 -0.14 (-0.86, 0.57)				
	Post-IC	0.35±0.17	0.30±0.15	.03* -0.32 (-1.04, 0.40)	Post-IC	1.29±0.75	1.20±0.52	.39 -0.15 (-0.86, 0.57)				
Lateral Gastrocnemius	Pre-IC	0.39±0.35	0.31±0.37	.03* -0.23 (-0.95, 0.49)								
	Post-IC	0.35±0.22	0.30±0.22	.23 -0.20 (-0.92, 0.52)					Pre-IC	1.58±0.76	1.47±0.70	.15 -0.15 (-0.87, 0.57)
Rectus Femoris	Pre-IC	0.14±0.09	0.13±0.09	.98 0.00 (-0.72, 0.71)					Post-IC	1.82±0.87	1.77±0.67	.60 -0.06 (-0.78, 0.65)
	Post-IC	0.24±0.17	0.25±0.14	.39 0.09 (-0.63, 0.81)								
Biceps Femoris	Pre-IC	0.14±0.07	0.12±0.06	.23 -0.25 (-0.97, 0.47)	Pre-IC	0.37±0.16	0.36±0.14	.68 -0.05 (-0.77, 0.67)				
	Post-IC	0.13±0.05	0.13±0.05	.58 0.08 (-0.64, 0.80)	Post-IC	0.53±0.25	0.57±0.26	.16 0.16 (-0.56, 0.88)				
Gluteus Medius	Pre-IC	0.10±0.06	0.11±0.06	.41 0.14 (-0.58, 0.85)								
	Post-IC	0.17±0.10	0.20±0.13	.28 0.22 (-0.50, 0.93)								

p-values are for paired t-Test Statistical Results – Level of significance set *a priori* at p≤0.05, * denotes significant difference between brace and no brace conditions.
ES= Cohen's d Effect Sizes and CI= 95% Confidence Intervals Note: Negative ES indicates decreased muscle activity in braced condition
Positive ES indicates increased muscle activity in braced condition
SD – Standard Deviation
Pre-IC= Pre-Initial Contact Root Mean Square area 50ms
Post-IC= Post-Initial Contact Root Mean Square area 100ms

Table 3. *Effect of Ankle Braces on Muscle Activation Patterns during Single Limb, Eyes Closed Balance Exercise*

	Isolated Muscle Activation			Distal/Proximal Muscle Activation			Total Muscle Activation		
Muscles	No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)	No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)	No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)
Anterior Tibialis	0.43±0.37	0.49±0.41	.16 0.15 (-0.56, 0.87)						
Peroneus Longus	0.46±0.21	0.41±0.20	.47 -0.21 (-0.93, 0.50)	1.14±0.48	1.16±0.57	.82 0.04 (-0.67, 0.76)			
Lateral Gastrocnemius	0.25±0.11	0.26±0.14	.78 0.05 (-0.66, 0.77)				1.46±0.53	1.47±0.65	.92 0.02 (-0.69, 0.74)
Rectus Femoris	0.10±0.09	0.09±0.07	.52 -0.11 (-0.82, 0.61)						
Biceps Femoris	0.06±0.07	0.07±0.04	.47 0.16 (-0.56, 0.88)	0.32±0.16	0.31±0.13	.79 -0.07 (-0.78, 0.65)			
Gluteus Medius	0.16±0.11	0.15±0.09	.66 -0.10 (-0.82, 0.62)						

p-values are for paired T-Test Statistical Results – Level of significance set *a priori* at p≤0.05
Cohen's d Effect Sizes (ES) and 95% Confidence Intervals (CI)
SD – Standard Deviation
Negative ES indicates decreased muscle activity in braced condition
Positive ES indicates increased muscle activity in braced condition

nificantly less muscle activity during braced trials. There was also significantly less muscle activity in the brace condition for the thigh and total muscle activity during the star excursion balance anterior reach. (Table 4) Gluteus medius muscle activity during braced trials was significantly reduced during the star excursion balance posterolateral reach. (Table 4) There were no significant differences between braced and no brace conditions during the star excursion balance posteromedial reach (Table 4) or the lateral hop exercises. (Table 5)

DISCUSSION

Decreases in muscle activity were identified during common rehabilitation exercises in participants with CAI while wearing lace-up ankle braces. Deficits in muscle activity had effect sizes that ranged from trivial to moderate. Ankle braces caused moderate decreases in muscle activity during dynamic balance as well as small decreases in muscle activity pre and post-initial contact during forward lunges. There were no differences in muscle activity during single limb eyes closed balance or during lateral hopping exercises.

Previous authors have indicated that ankle braces undoubtedly restrict ankle ROM[29,41,42] and do not appear to influence measures of proprioception.[34] Furthermore, ankle braces have been shown to increase the peroneus longus Hoffman reflex while seated with a neutral foot position,[43] but have no effect on the Hoffman reflex when analyzed during an inversion perturbation.[36] However, this is the first study to analyze the effect ankle braces have on motor output during functional exercises in CAI participants. These findings are relevant to clinicians who prescribe rehabilitation exercises to patients with a history of recurrent ankle sprain or healthcare professionals who promote neuromuscular training for prophylactic ankle sprain injury prevention. Furthermore, these results can help clinicians decide whether it is appropriate for patients with CAI to wear ankle braces when performing functional exercises.

Previous authors have analyzed the effect of ankle braces on static and dynamic balance performance in subjects with ankle instability.[30,31] CAI subjects have consistently demonstrated deficits in single limb static balance trials as well as during dynamic balance as measured by the SEBT.[44,45] When performing these tasks while wearing ankle braces, CAI subjects demonstrate improvements in postural control.[30,31] Even though balance performance was not an outcome analyzed in the current study, reach distances were recorded during star excursion balance, and there were no significant differences in the distance reached between conditions. However, the current results suggest that wearing ankle braces does not enhance motor output while performing these balance tasks.

During the forward lunge, small decreases in lateral gastrocnemius activity were identified prior to ground contact and small decreases in peroneus longus activity following ground contact. At the ankle, dur-

Table 4. *Effect of Ankle Braces on Muscle Activation Patterns during Star Excursion Balance Reaching Exercise*

	Isolated Muscle Activation				Distal/Proximal Muscle Activation				Total Muscle Activation			
Muscles	Reach Direction	No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)	Reach Direction	No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)	Reach Direction	No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)
Anterior Tibialis	Anterior	0.58±0.73	0.43±0.26	.33 -0.27 (-0.99, 0.45)								
	Posteromedial	0.63±0.59	0.54±0.35	.29 -0.19 (-0.90, 0.53)								
	Posterolateral	0.99±0.98	0.94±0.76	.56 -0.06 (-0.78, 0.66)								
Peroneus Longus	Anterior	0.49±0.20	0.36±0.19	.001* -0.65 (-1.38, 0.08)	Anterior	1.46±0.87	1.14±0.37	.07 -0.48 (-1.20, 0.25)				
	Posteromedial	0.36±0.13	0.32±0.09	.08 -0.38 (-1.10, 0.34)	Posteromedial	1.18±0.69	1.04±0.38	.16 -0.27 (-0.99, 0.45)				
	Posterolateral	0.38±0.17	0.38±0.17	.87 -0.04 (-0.76, 0.67)	Posterolateral	1.60±1.15	1.52±0.91	.51 -0.08 (-0.79, 0.64)				
Lateral Gastrocnemius	Anterior	0.39±0.27	0.35±0.25	.01* -0.18 (-0.90, 0.54)								
	Posteromedial	0.19±0.11	0.17±0.10	.38 -0.16 (-0.88, 0.56)								
	Posterolateral	0.23±0.10	0.21±0.12	.32 -0.16 (-0.88, 0.55)					Anterior	2.22±0.96	1.77±0.50	.02* -0.59 (-1.32, 0.14)
Rectus Femoris	Anterior	0.42±0.22	0.35±0.22	.01* -0.35 (-1.07, 0.37)					Posteromedial	2.09±0.82	1.91±0.53	.15 -0.27 (-0.99, 0.45)
	Posteromedial	0.53±0.27	0.53±0.26	.98 0.00 (-0.72, 0.71)					Posterolateral	2.52±1.17	2.37±0.90	.32 -0.15 (-0.87, 0.56)
	Posterolateral	0.54±0.30	0.49±0.20	.44 -0.18 (-0.89, 0.54)								
Biceps Femoris	Anterior	0.17±0.07	0.15±0.07	.06 -0.24 (-0.95, 0.48)	Anterior	0.76±0.36	0.63±0.33	<.001* -0.37 (-1.09, 0.35)				
	Posteromedial	0.11±0.06	0.11±0.04	.30 -0.12 (-0.84, 0.59)	Posteromedial	0.91±0.36	0.87±0.34	.44 -0.12 (-0.83, 0.60)				
	Posterolateral	0.16±0.08	0.16±0.07	.44 0.11 (-0.60, 0.83)	Posterolateral	0.92±0.44	0.84±0.26	.25 -0.23 (-0.95, 0.49)				
Gluteus Medius	Anterior	0.17±0.12	0.13±0.08	.04* -0.35 (-1.07, 0.37)								
	Posteromedial	0.26±0.13	0.23±0.12	.11 -0.26 (-0.98, 0.46)								
	Posterolateral	0.23±0.15	0.19±0.01	.04* -0.53 (-1.08, 0.37)								

p-values are for paired T-Test Statistical Results – Level of significance set *a priori* at $p \leq 0.05$, * denotes significant difference between brace and no brace
ES= Cohen's d Effect Sizes and CI= 95% Confidence Intervals Note: Negative ES indicates decreased muscle activity in braced condition
Positive ES indicates increased muscle activity in braced condition
SD – Standard Deviation

Table 5. *Effect of Ankle Braces on Muscle Activation Patterns during performance of the Lateral Hop Exercise*

		Isolated Muscle Activation			Distal/Proximal Muscle Activation				Total Muscle Activation			
Muscles		No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)		No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)		No Brace Mean±SD	Brace Mean±SD	p-value ES (95% CI)
Anterior Tibialis	Pre-IC	0.29±0.23	0.38±0.46	.21 0.25 (-0.46, 0.97)								
	Post-IC	0.45±0.44	0.57±0.79	.30 0.20 (-0.52, 0.91)								
Peroneus Longus	Pre-IC	0.50±0.17	0.52±0.23	.67 0.07 (-0.64, 0.79)	Pre-IC	1.62±0.68	1.87±0.98	.09 0.29 (-0.43, 1.01)				
	Post-IC	0.73±0.29	0.68±0.44	.40 -0.13 (-0.84, 0.59)	Post-IC	2.38±1.39	2.36±1.49	.94 -0.01 (-0.73, 0.70)				
Lateral Gastrocnemius	Pre-IC	0.83±0.53	0.97±0.73	.17 0.22 (-0.50, 0.94)								
	Post-IC	1.21±1.18	1.11±0.84	.43 -0.09 (-0.81, 0.62)					Pre-IC	2.62±0.97	2.90±1.07	.13 0.27 (-0.45, 0.99)
Rectus Femoris	Pre-IC	0.27±0.37	0.26±0.19	.86 -0.05 (-0.76, 0.67)					Post-IC	3.94±1.69	3.94±1.91	.99 0.00 (-0.71, 0.72)
	Post-IC	0.64±0.46	0.63±0.36	.92 -0.01 (-0.73, 0.70)								
Biceps Femoris	Pre-IC	0.37±0.19	0.41±0.24	.20 0.20 (-0.52, 0.91)	Pre-IC	1.00±0.49	1.03±0.39	.79 0.06 (-0.65, 0.78)				
	Post-IC	0.31±0.25	0.30±0.19	.83 -0.03 (-0.75, 0.69)	Post-IC	1.56±0.76	1.58±0.72	.85 0.03 (-0.69, 0.74)				
Gluteus Medius	Pre-IC	0.36±0.20	0.36±0.15	.97 -0.01 (-0.73, 0.71)								
	Post-IC	0.61±0.25	0.65±0.35	.64 0.11 (-0.60, 0.83)								

p-values are for paired t-Test Statistical Results – Level of significance set *a priori* at $p \leq 0.05$, * denotes significant difference between brace and no brace conditions.
ES= Cohen's d Effect Sizes and CI= 95% Confidence Intervals Note: Negative ES indicates decreased muscle activity in braced condition
Positive ES indicates increased muscle activity in braced condition
SD – Standard Deviation
Pre-IC= Pre-Initial Contact Root Mean Square area 50ms
Post-IC= Post-Initial Contact Root Mean Square area 100ms

ing the 50 ms prior to initial contact and the 100 ms following initial contact, the forward lunge is comparable to ground contact during gait where a heel to toe pattern is followed. In CAI subjects during gait, bracing elicits a similar decrease in peroneus longus muscle activity pre-initial contact.[37] CAI subjects have been shown to be more inverted just prior to and immediately following heel strike.[11,12] Activity of the peroneus longus prior to heel strike in CAI subjects has been speculated as a coping strategy to decrease the excessive inversion identified during this phase of gait.[14] While the timing of the bracing effect relative to initial contact (pre vs. post initial contact) is different in the lunge compared to gait, both instances of decreased peroneus longus activity indicate that the ankle brace is aiding in the role of the peroneus longus during heel to toe weight acceptance tasks. This decreased peroneus longus muscle activity suggests that the brace is aiding in the foot and ankle frontal plane alignment prior to initial contact or providing mechanical resistance to inversion at and following ground contact. This theory is supported by previous authors that analyzed the effect of ankle bracing on rearfoot motion during sudden inversion.[41] In this study,[41] lace-up ankle braces significantly limited rearfoot angular displacement and velocity, which without the ankle braces would be dependent upon lateral ankle ligaments and lateral shank musculature. However, if the goal of rehabilitation is to decrease the reliance of the peroneus longus on mechanical support for proper foot alignment and dynamic support of the lateral ankle, then the current results suggest wearing ankle braces during these controlled tasks is not indicated.

Due to the pronounced effect ankle braces have at reducing the rate of ankle sprain,[27,46,47] many patients with ankle instability wear ankle braces at all times during exercise, including during neuromuscular training tasks designed for prophylactic ankle sprain prevention and functional rehabilitation while progressing back to sport following initial or recurrent ankle sprain. This same cohort, when compared to healthy counterparts,[15] demonstrated moderate to large decreases in muscle activity during the same exercises analyzed in this study. These previous results indicated that clinicians should introduce various constraints during rehabilitation for patients with CAI to elicit increased muscle activity.[15] Therefore, the decreased muscle activity in participants with CAI while wearing braces may indicate that wearing ankle braces during neuromuscular training may be counterproductive to the goals associated with the prescribed exercises. Future research should analyze changes in muscle activity during functional exercises following a structured rehabilitation program for patients with CAI and after prolonged use of ankle braces.

While the authors' cannot speculate on the effect ankle braces may have on muscle activity in uncontrolled athletic environments, the results suggest that wearing ankle braces during neuromuscular training or rehabilitation exercises does not increase muscle activity. Pevious results[15] indicate patients with CAI have less muscle activity during functional exercises and the current results indicate ankle braces do not improve upon that deficit. Similar results were reported by Zinder et al,[48] who found ankle braces increased rotational ankle stiffness in participants with ankle instability, but the increased rotational stiffness was not due to increased pre-activation of ankle musculature. Similarly, in healthy subjects, the application of ankle braces does not improve peroneus longus motor output during lateral shuffling.[49] Cordova and Ingersoll[35] demonstrated that the peroneus longus stretch reflex amplitude is higher immediately following brace application in healthy subjects, but to the authors' knowledge these results have not been replicated in patients with CAI. However, authors have discussed the importance of foot position prior to ground contact as a very important factor that may contribute to ankle sprain prevention,[50] as the peroneus longus stretch reflex does not appear to be quick enough to prevent an ankle sprain from occurring.[51] Wright et al[52] indicated that increased plantar flexion prior to ground contact increases the susceptibility to ankle sprains. Others have demonstrated that external ankle support can decrease plantarflexion at and following initial contact.[53,54] Furthermore, Eils et al[50] compared various models of ankle braces and found that the braces that restricted inversion most effectively prior to ground contact exhibited less inversion and slower inversion velocities after contact. These previous studies did not concurrently analyze the effect of bracing or the effect of the altered joint position on muscle activity prior to or following ground contact. These results coupled with the current results, indicate that the more favorable alignment prior to initial contact,[50,54,55] decreased angular velocities,[41] and decreased ROM[29,41,42] seen with bracing are likely due to mechanical restraint and not improvements in muscle recruitment.

LIMITATIONS

Limitations of the current study include the short-term application of ankle braces on muscle activity and thus these results cannot be generalized to prolonged ankle brace use. Additionally, this study was part of a larger study that compared muscle activity between CAI and controls during gait. The *a priori* sample size estimate was performed to identify gait differences and the relatively small sample size in the current study increases the potential risk of type II error in comparisons where statistical significance was not found. Specifically, in regards to the star excursion balance and lateral hop analyses, there are five total comparisons with p-values $<.11$ but $>.05$, suggesting the potential for type II error exists for those comparisons. However, the effect size calculations for those comparisons range from trivial to small with confidence intervals that are centered around zero, which indicates no meaningful treatment effect due to brace application regardless of statistical significance. Lastly, the current analysis is limited to therapeutic exercises performed in a controlled laboratory setting and these results cannot be generalized to more dynamic uncontrolled athletic environments.

CONCLUSION

Participants with CAI exhibit decreased normalized EMG muscle activity during common rehabilitation exercises after the application of ankle braces. If the goal of rehabilitation is to increase motor unit recruitment, patients with CAI should not wear ankle braces while performing the prescribed rehabilitation exercises.

REFERENCES

1. Hootman JM, Dick R, Agel J. Epidemiology of collegiate injuries for 15 sports: Summary and recommendations for injury prevention initiatives. *J Athl Train*. 2007;42(2):311-319.
2. Nelson AJ, Collins CL, Yard EE, Fields SK, Comstock RD. Ankle injuries among united states high school sports athletes, 2005–2006. *J Athl Train*. 2007;42(3):381.
3. Waterman BR, Owens BD, Davey S, Zacchilli MA, Belmont PJ. The epidemiology of ankle sprains in the united states. *J Bone Joint Surg AM*. 2010;92-A(13):2279-2284.
4. McKay GD, Goldie PA, Payne WR, Oakes BW. Ankle injuries in basketball: Injury rate and risk factors. / lesions traumatiques de la cheville en basket-ball: Frequence des blessures et facteurs de risque. *Br J Sports Med*. 2001;35(2):103-108.
5. Anandacoomarasamy A, Barnsley L. Long term outcomes of inversion ankle injuries. *Br J Sports Med*. 2005;39(3):e14-e14.
6. Gerber JP, Williams GN, Scoville CR, Arciero RA, Taylor DC. Persistent disability associated with ankle sprains: A prospective examination of an athletic population. *Foot Ankle Int*. 1998;19(10):653-660.
7. Hertel J. Functional anatomy, pathomechanics, and pathophysiology of lateral ankle instability. *J Athl Train*. 2002;37(4):364-375.
8. Hiller CE, Kilbreath SL, Refshauge KM. Chronic ankle instability: Evolution of the model. *J Athl Train*. 2011;46(2):133-141.
9. Gribble PA, Delahunt E, Bleakley C, et al. Selection criteria for patients with chronic ankle instability in controlled research: A position statement of the international ankle consortium. *J Orthop Sports Phys Ther.* 2013;43(8):585-591.
10. Monaghan K, Delahunt E, Caulfield B. Ankle function during gait in patients with chronic ankle instability compared to controls. *Clin Biomech*. 2006;21(2):168-174.
11. Delahunt E, Monaghan K, Caulfield B. Altered neuromuscular control and ankle joint kinematics during walking in subjects with functional instability of the ankle joint. *Am J Sports Med*. 2006;34(12):1970-1976.
12. Drewes LK, McKeon PO, Paolini G, et al. Altered ankle kinematics and shank-rear-foot coupling in those with chronic ankle instability. *J Sport Rehab*. 2009;18(3):375-388.
13. Drewes LK, McKeon PO, Casey Kerrigan D, Hertel J. Dorsiflexion deficit during jogging with chronic ankle instability. *J Sci Med Sport*. 2009;12(6):685-687.
14. Feger M, Donovan L, Hart J, Hertel J. Lower extremity muscle activation in patients with and without chronic ankle instability. *J Athl Train*. IN PRESS.
15. Feger MA, Donovan L, Hart JM, Hertel J. Lower extremity muscle activation during functional exercises in patients with and without chronic ankle instability. *PM R*. 2014.

16. Delahunt E, Monaghan K, Caulfield B. Changes in lower limb kinematics, kinetics, and muscle activity in subjects with functional instability of the ankle joint during a single leg drop jump. *J Orthop Res*. 2006;24(10):1991-2000.
17. Brown C, Bowser B, Simpson KJ. Movement variability during single leg jump landings in individuals with and without chronic ankle instability. *Clin Biomech*. 2012;27(1):52-63.
18. Gribble PA, Robinson RH. Alterations in knee kinematics and dynamic stability associated with chronic ankle instability. *J Athl Train*. 2009;44(4):350.
19. Gribble P, Robinson R. Differences in spatiotemporal landing variables during a dynamic stability task in subjects with CAI. *Scand J Med Sci Sports*. 2010;20(1):1-9.
20. Schmidt H, Sauer LD, Sae YL, Saliba S, Hertel J. Increased in-shoe lateral plantar pressures with chronic ankle instability. *Foot Ankle Int*. 2011;32(11):1075-1080.
21. Delahunt E, Monaghan K, Caulfield B. Ankle function during hopping in subjects with functional instability of the ankle joint. *Scand J Med Sci Sports*. 2007;17(6):641-648.
22. Verhagen E, Bay K. Optimising ankle sprain prevention: A critical review and practical appraisal of the literature. *Br J Sports Med*. 2010;44(15):1082-1088.
23. Lin CC, Hiller CE, de Bie RA. Evidence-based treatment for ankle injuries: A clinical perspective. *J Man Manip Ther*. 2010;18(1):22-28.
24. Mckeon P, Ingersoll C, Kerrigan DC, Saliba E, Bennett B, Hertel J. Balance training improves function and postural control in those with chronic ankle instability. *Med Sci Sport Exerc.* 2008;40(10):1810.
25. McKeon PO, Hertel J. Systematic review of postural control and lateral ankle instability, part II: Is balance training clinically effective? *J Athl Train*. 2008;43(3):305-315.
26. Hale SA, Hertel J. Reliability and sensitivity of the foot and ankle disability index in subjects with chronic ankle instability. *J Athl Train*. 2005;40(1):35-40.
27. Janssen KW, van Mechelen W, Verhagen EA. Bracing superior to neuromuscular training for the prevention of self-reported recurrent ankle sprains: A three-arm randomised controlled trial. *Br J Sports Med*. 2014.
28. Osborne MD, Rizzo Jr TD. Prevention and treatment of ankle sprain in athletes. *Sports Med*. 2003;33(15):1145-1150.
29. Cordova ML, Ingersoll CD, LeBlanc MJ. Influence of ankle support on joint range of motion before and after exercise: A meta-analysis. *J Orthop Sports Phys Ther*. 2000;30(4):170-7; discussion 178-82.
30. Hadadi M, Mazaheri M, Mousavi ME, Maroufi N, Bahramizadeh M, Fardipour S. Effects of soft and semi-rigid ankle orthoses on postural sway in people with and without functional ankle instability. *J Sci Med Sport*. 2011;14(5):370-375.
31. Hadadi M, Mousavi ME, Fardipour S, Vameghi R, Mazaheri M. Effect of soft and semirigid ankle orthoses on star excursion balance test performance in patients with functional ankle instability. *J Sci Med Sport*. 2013.
32. Bennell KL, Goldie PA. The differential effects of external ankle support on postural control. *J Orthop Sports Phys Ther.* 1994;20(6):287-295.
33. Hardy L, Huxel K, Brucker J, Nesser T. Prophylactic ankle braces and star excursion balance measures in healthy volunteers. *J Athl Train*. 2008;43(4): 347-351.
34. Raymond J, Nicholson LL, Hiller CE, Refshauge KM. The effect of ankle taping or bracing on proprioception in functional ankle instability: A systematic review and meta-analysis. *J Sci Med Sport*. 2012;15(5):386-392.
35. Cordova M, Ingersoll C. Peroneus longus stretch reflex amplitude increases after ankle brace application. *Br J Sports Med*. 2003;37(3): 258-262.
36. Sefton J, Hicks-Little C, Koceja D, Cordova M. Effect of inversion and ankle bracing on peroneus longus hoffmann reflex. *Scand J Med Sci Sports*. 2007;17(5):539-546.
37. Barlow G, Donovan L, Hart J, Hertel J. Effect of lace-up ankle braces on electormyography measures during walking in subjects with chronic ankle instability. *Phys Ther Sport*. (In Press).
38. Merletti R, Di Torino P. Standards for reporting EMG data. *J Electromyogr Kinesiol*. 1999;9(1):3-4.
39. Hopkins W, Marshall S, Batterham A, Hanin J. Progressive statistics for studies in sports medicine and exercise science. *Med Sci Sport Exerc*. 2009;41(1):3-13.
40. Cohen J. *Statistical power analysis for the behavioral sciencies.* Routledge; 1988.
41. Cordova M, Dorrough J, Kious K, Ingersoll C, Merrick M. Prophylactic ankle bracing reduces rearfoot motion during sudden inversion. *Scand J Med Sci Sports*. 2007;17(3):216-222.
42. Cordova ML, Ingersoll CD, Palmieri RM. Efficacy of prophylactic ankle support: An experimental perspective. *J Athl Train*. 2002;37(4):446-457.

43. Nishikawa T, Grabiner MD. Peroneal motoneuron excitability increases immediately following application of a semirigid ankle brace. *J Orthop Sports Phys Ther.* 1999;29(3):168-176.

44. McKeon PO, Hertel J. Systematic review of postural control and lateral ankle instability, part I: Can deficits be detected with instrumented testing? *J Athl Train*. 2008;43(3):293-304.

45. Olmsted LC, Carcia CR, Hertel J, Shultz SJ. Efficacy of the star excursion in balance tests in detecting reach deficits in subjects with chronic ankle instability. *J Athl Train*. 2002;37(4):501-506.

46. McGuine TA, Hetzel S, Wilson J, Brooks A. The effect of lace-up ankle braces on injury rates in high school football players. *Am J Sports Med*. 2012;40(1):49-57.

47. McGuine TA, Brooks A, Hetzel S. The effect of lace-up ankle braces on injury rates in high school basketball players. *Am J Sports Med*. 2011;39(9):1840-1848.

48. Zinder SM, Granata KP, Shultz SJ, Gansneder BM. Ankle bracing and the neuromuscular factors influencing joint stiffness. *J Athl Train*. 2009;44(4):363-369.

49. Gribble PA, Radel S, Armstrong CW. The effects of ankle bracing on the activation of the peroneal muscles during a lateral shuffling movement. *Phys Ther Sport*. 2006;7(1):14-21.

50. Eils E, Demming C, Kollmeier G, Thorwesten L, Völker K, Rosenbaum D. Comprehensive testing of 10 different ankle braces: Evaluation of passive and rapidly induced stability in subjects with chronic ankle instability. *Clin Biomech*. 2002;17(7):526-535.

51. Konradsen L, Voigt M, Hojsgaard C. Ankle inversion injuries: The role of the dynamic defense mechanism. *Am J Sports Med*. 1997;25(1):54-58.

52. Wright I, Neptune R, Van Den Bogert A, Nigg B. The influence of foot positioning on ankle sprains. *J Biomech*. 2000;33(5):513-519.

53. Delahunt E, O'Driscoll J, Moran K. Effects of taping and exercise on ankle joint movement in subjects with chronic ankle instability: A preliminary investigation. *Arch Phys Med Rehabil*. 2009;90(8):1418-1422.

54. DiStefano LJ, Padua DA, Brown CN, Guskiewicz KM. Lower extremity kinematics and ground reaction forces after prophylactic lace-up ankle bracing. *J Athl Train*. 2008;43(3):234-241.

55. Delahunt E, O'Driscoll J, Moran K. Effects of taping and exercise on ankle joint movement in subjects with chronic ankle instability: A preliminary investigation. *Arch Phys Med Rehabil*. 2009;90(8):1418-1422.