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Surface electromyography and plantar pressure changes with novel gait training device in participants with chronic ankle instability

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ABSTRACT

Background: Rehabilitation is ineffective at restoring normal gait in chronic ankle instability patients. Our purpose was to determine if a novel gait-training device could decrease plantar pressure on the lateral column of the foot in chronic ankle instability patients.

Methods: Ten chronic ankle instability patients completed 30 s trials of baseline and gait-training walking at a self-selected pace while in-shoe plantar pressure and surface electromyography were recorded from their anterior tibialis, peroneus longus, medial gastrocnemius, and gluteus medius. The gait-training device applied a medially-directed force to the lower leg *via* elastic bands during the entire gait cycle. Plantar pressure measures of the entire foot and 9 specific regions of the foot as well as surface electromyography root mean square areas were compared between the baseline and gait-training conditions using paired *t*-tests with *a priori* level of significance of $p \leq 0.05$.

Findings: The gait-training device decreased pressure time integrals and peak pressures in the lateral midfoot ($p = 0.003$ and $p = 0.003$) and lateral forefoot ($p = 0.023$ and $p = 0.005$), and increased pressure time integrals and peak pressures for the total foot ($p = 0.030$ and $p = 0.017$) and hallux ($p = 0.005$ and $p = 0.002$). The center of pressure was shifted medially during the entire stance phase ($p < 0.003$ for all comparisons) due to increased peroneus longus activity prior to ($p = 0.002$) and following initial contact ($p = 0.002$).

Interpretation: The gait-training device decreased pressure on the lateral column of the foot and increased peroneus longus muscle activity. Future research should analyze the efficacy of the gait-training device during gait retraining for chronic ankle instability.

1. Introduction

Chronic ankle instability (CAI) may develop in approximately one-third of individuals who incur lateral ankle sprains (Gerber et al., 1998; Waterman et al., 2010). CAI patients have decreased self-reported function due to residual ankle symptoms (van Rijn et al., 2008) and are less physically active over their lifespan compared to healthy counterparts (Verhagen et al., 1995). There is a wide spectrum of pathological characteristics that depict this heterogeneous condition (Gribble et al., 2013; Hertel, 2008; Hiller et al., 2011). These characteristics range from structural deficits such as joint laxity to functional impairments in gait, landing and cutting mechanics (Hertel, 2008). Due to the wide range of potential deficits seen in CAI patients, Donovan and Hertel (2012) developed a treatment algorithm that encourages clinicians to assess for and treat specific CAI impairments with targeted therapeutic interventions.

The treatment algorithm highlights four impairment domains of range of motion, strength, balance, and functional activities (Donovan and Hertel, 2012). Authors (Hoch and McKeon, 2011; Terada et al., 2013; Vicenzino et al., 2006) have demonstrated that deficits in ankle dorsiflexion range of motion can be improved with joint mobilizations or calf stretching to address arthro- and osteokinematic restrictions. Similarly, deficits in invertor and evertor strength (Arnold et al., 2009; Holmes and Delahunt, 2009) can effectively be addressed with strength training interventions (Docherty et al., 1998; Sekir et al., 2007). Mckeon et al. (2008) found that 4-weeks of supervised single limb balance training can improve postural control and self-reported function. However, evidence-based treatments for functional impairments during gait have yet to be established in this population.

Donovan and Hertel (2012) included walking, running, jumping, and cutting activities into the functional activity domain of the aforementioned algorithm. An important first step following lateral ankle sprains is restoring a normal gait pattern before a further functional progression should occur. Similarly, when addressing functional limitations in CAI patients, it may be advantageous to address walking pathomechanics before progressing to running, jumping, or cutting.

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Characteristic pathomechanics of gait associated with CAI have been identified during different phases of the gait cycle. CAI patients have a more inverted foot position prior to initial contact during gait (Delahunt et al., 2006; Drewes et al., 2009). This improper foot positioning with CAI may provide a stimulus that results in pre-activation of the peroneus longus during the swing phase, whereas healthy subjects do not activate their peroneus longus until midstance (Feger et al., 2015). However, the earlier peroneus longus muscle activation (Feger et al., 2015) does not appear to be effective at restoring normal frontal plane alignment as CAI patients maintain the more inverted foot position at and following ground contact as well (Delahunt et al., 2006). It has been speculated that the inverted foot position and altered timing of peroneus longus activation contribute to the increased plantar pressure on the lateral column of the foot exhibited by CAI subjects during mid-stance when compared to healthy controls (Morrison et al., 2010; Nawata, 2005; Schmidt et al., 2011; Ty Hopkins et al., 2012). Koldenhoven et al. (2016)) recently demonstrated that CAI patients exhibit increased loading of the lateral forefoot and a more lateral center of pressure throughout the entire stance phase and the resultant inversion torque may contribute to episodes of giving way.

The kinematic, kinetic, and muscle activity CAI patients exhibit during gait are not only different than healthy counterparts, but this coping strategy may have negative consequences for ankle sprain prevention (Feger et al., 2015). However, there is currently no evidence in regard to the ability of gait retraining at restoring a normal gait pattern in CAI patients. We recently demonstrated that 4 weeks of comprehensive rehabilitation for CAI was successful at improving self-reported function, range of motion (ROM), strength, and balance but had no meaningful effect on frontal plane gait mechanics (Donovan et al., 2016a; Donovan et al., 2016b). In an attempt to specifically target gait impairments with CAI, we developed a novel gait training device. The device was designed for use with a treadmill and was developed to target activation of the hip abductors and lateral ankle musculature prior to and following ground contact in an effort to decrease plantar pressure on the lateral column of the foot during the stance phase of gait. Prior to implementing this device in a gait training rehabilitation program, its ability to alter plantar pressure and muscle activity in CAI patients must be evaluated. Our purpose was to determine if the gait training device could decrease plantar pressure on the lateral column of the foot and alter muscle activity during treadmill walking in CAI patients. We hypothesized that the gait training device would decrease plantar pressure on the lateral column of the foot and increase peroneus longus and gluteus medius muscle activity as measured by surface electromyography (sEMG) prior to and following ground contact.

2. Methods

2.1. Participants

A descriptive laboratory study was performed to compare measures of plantar pressure and sEMG during treadmill walking with and without a gait training device in ten young adults with CAI. The inclusion criteria for CAI was a history of more than one ankle sprain with the initial sprain occurring greater than one year prior to study onset and no history of ankle sprain within 6 weeks of data collection. Subjects also had to have current self-reported functional deficits due to ankle symptoms that was quantified by a score of <85% on the Foot and Ankle Ability (FAAM) Sport scale and a score ≥10 on the Identification of Functional Instability scale (IdFAI) Table 1. All participants were physically active (at least 20 min of exercise per day at least 3 days per week) and have no other lower extremity injuries or pathologies that would affect outcome measures. Only the subject's involved limb was utilized for data collection and analysis and in the case of bilateral CAI the subject's perceived worse limb was analyzed as the involved limb. This study was approved by the Institutional Review Board for Health Sciences Research and all subjects provided informed consent prior to participation.

Table 1
Subject demographics (n = 10).

	Mean (SD)
Age (years)	21.5 (3.1)
Sex	Male: 3, female: 7
Height (centimeters)	166.0 (6.3)
Mass (kilograms)	65.6 (10.4)
Godin Leisure-Time Exercise Questionnaire Score	73.9 (24.5)
FAAM ADL %	86.3 (7.8)
FAAM sport %	68.1 (15.0)
idFAI	22.92 (1.71)
Number of ankle sprains	4.8 (3.2)
Time since last sprain (months)	11.5 (9.3)

FAAM = Foot and Ankle Ability Measure; ADL = Activities of Daily Living; IdFAI = Identification of Functional Ankle Instability.

2.2. Instruments

2.2.1. Plantar pressure

Plantar pressure was measured using the Pedar-x plantar pressure system (Novel Inc., St Paul MN, USA) with in-shoe insoles that had a sampling rate of 100 Hz. Participants used a standard athletic shoe for both conditions (Brooks Defyance 3, Brooks Sports Inc., Seattle, WA, USA). All trials were completed on a standard laboratory treadmill (Gait Trainer™ 3, Biodex, Shirley, NY, USA).

2.2.2. Surface electromyography

Surface EMG was collected using 2 parallel bar rectangular sensors. Each bar was 1 mm wide and 1 cm long and inter-electrode distance was 1 cm. The sensors were DE 2.1 differential EMG sensors (Delsys, Boston, MA, USA). The signal was amplified with a gain of 1000 and digitized with a 4 channel acquisition system (Bagnoli EMG system, Delsys, Boston, MA, USA) at 1000 Hz. Input impedance was >10 Ω/0.2 pF with a signal to noise ratio of 1.2 uV. Data were collected with Motion Monitor software (Innovative Sports Training, Inc., Chicago, Illinois) and processed with EMGworks software (version 4.1.1, Delsys, Boston, MA, USA). Data were filtered using a 10–500 Hz band-pass filter and smoothed using a 50-sample moving window root mean square (RMS) algorithm. Initial contact was identified with a foot switch that was placed beneath the heel of the subject's involved limb (Delysys, Boston, MA, USA).

2.3. Procedures

Participants provided informed consent and completed a general health history questionnaire (Godin et al., 1986), FAAM Activity of Daily Living and Sport scale (Carcia et al., 2008; Martin et al., 2003), and IdFAI questionnaire (Donahue et al., 2013). Next, surface electrodes were placed over the midline of each muscle belly that was determined *via* manual palpation during a voluntary contraction. To minimize skin impedance, the skin was shaved, abraded, and then cleansed with isopropyl alcohol. Proper sensor placement was visually inspected for crosstalk by having subjects perform voluntary contractions against manual resistance. Participants were then fitted with standard lab shoes and in-shoe pressure insoles.

Participants walked on the treadmill at their self-selected walking pace. Data were not collected until subjects reported they had achieved their self-perceived normal gait pattern. At this point, the tester collected 30 s of baseline gait. After completing baseline data collection, the subject was set-up with the gait training device. Since this was a preliminary investigation, we did not know if the gait training device would alter plantar pressure or sEMG immediately after use, thus the