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Effects of an auditory biofeedback device on plantar pressure in patients with chronic ankle instability

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ABSTRACT

Chronic ankle instability (CAI) patients have been shown to have increased lateral column plantar pressure throughout the stance phase of gait. To date, traditional CAI rehabilitation programs have been unable to alter gait. We developed an auditory biofeedback device that can be worn in shoes that elicits an audible cue when an excessive amount of pressure is applied to a sensor. This study determined whether using this device can decrease lateral plantar pressure in participants with CAI and alter surface electromyography (sEMG) amplitudes (anterior tibialis, peroneus longus, medial gastrocnemius, and gluteus medius). Ten CAI patients completed baseline treadmill walking while in-shoe plantar pressures and sEMG were measured (baseline condition). Next, the device was placed into the shoe and set to a threshold that would elicit an audible cue during each step of the participant's normal gait. Then, participants were instructed to walk in a manner that would not trigger the audible cue, while plantar pressure and sEMG measures were recorded (auditory feedback (AUD FB) condition). Compared to baseline, there was a statistically significant reduction in peak pressure in the lateral midfoot–forefoot and central forefoot during the AUD FB condition. In addition, there were increases in peroneus longus and medial gastrocnemius sEMG amplitudes 200 ms post-initial contact during the AUD FB condition. The use of this auditory biofeedback device resulted in decreased plantar pressure in the lateral column of the foot during treadmill walking in CAI patients and may have been caused by the increase in sEMG activation of the peroneus longus.

1. Introduction

Lateral ankle sprains are a common musculoskeletal injury during sports [1,2] and recreational activities [3]. Approximately 30% of lateral ankle sprain patients will develop persistent instability and dysfunction for greater than 1 year [4]. Patients with residual symptoms of "giving way" and "feelings of instability" have been termed to have chronic ankle instability (CAI) [5]. CAI encompasses a wide variety of functional impairments, which can include altered gait kinetics and kinematics [6–12].

Pressure insoles and mats are commonly used to assess gait pathomechanics following injury. These tools can quantify the amount and timing of pressure application over various regions of the foot. CAI patients have demonstrated increased lateral loading and increased contact time of the lateral aspect of their foot when compared to healthy individuals [8,11,13]. This altered gait pattern is hypothesized to contribute to the high recurrence of sprain and residual instability.

In addition to altered gait mechanics, CAI patients demonstrate an increase in percent activation time for the peroneus longus across the gait cycle when compared to healthy controls [14]. Furthermore, the peroneus longus activates prior to initial contact in CAI patients, as opposed to mid-stance in healthy individuals [14]. Altered peroneus longus activation may be in response to the supinated foot to either pull the foot out of its current position or to provide more stability.

We believe incorporating gait training, in addition to traditional range of motion and sensorimotor training interventions, may cause a reduction in recurrent ankle sprains [15]. Gait training interventions for the knee and hip often utilize verbal or visual feedback (mirrors or cameras) to help patients correct abnormal

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motions [16], however, due to the complex motions that quickly occur at the ankle during walking as well as difficulties in visualizing the ankle with a mirror or anteriorly placed camera throughout the gait cycle, these techniques may be implausible to use to correct faulty ankle mechanics. Therefore, we developed a custom auditory biofeedback device that can be worn without altering shoewear.

The device has the capability to elicit a noise when pressure exceeds a set threshold of a sensor. We believe we can alter plantar pressure by placing the device's sensor beneath the head of the 5th metatarsal, which is a common place for CAI patients to have increased plantar pressure. If the device elicits a noise during walking, this will signify an increased lateral pressure and allow the individual to correct their next step by placing their foot in a more neutral or pronated position prior to heel contact and by shifting their center of pressure (COP) more medially after heel contact. The medial shift in COP can be completed by increased muscle activity of lateral ankle dynamic stabilizers, such as the peroneus longus. However, before incorporating this device into rehabilitation programs, its effectiveness of altering plantar pressure during walking must be evaluated. Therefore, our purpose was to determine if using an in shoe auditory biofeedback device can alter plantar pressure measures in CAI patients during a single intervention session and increase lower extremity muscle activity measured by sEMG. We hypothesize that CAI patients will be able to decrease their lateral foot pressure during walking in response to the auditory biofeedback and have an increase in peroneus longus and gluteus medius muscle activation prior to initial contact and throughout the stance phases of gait.

2. Methods

2.1. Study design

We performed a descriptive laboratory study comparing treadmill gait using standard athletic shoes and shoes with an auditory biofeedback device on measures of plantar pressure and sEMG during walking in adults with CAI. Our independent variables were condition at two levels: (1) shod with no auditory biofeedback device (Baseline) and (2) shod with the auditory biofeedback device (AUD FB). The primary dependent variables were measures of plantar pressure (peak pressure, pressure time integral, time to peak pressure, contact area and contact time) at nine regions of the foot (medial heel, lateral heel, medial midfoot, lateral midfoot, medial forefoot, central forefoot, lateral forefoot, hallux, and toes 2–5) and measures of sEMG amplitudes pre and post initial contact for four lower extremity muscles (anterior tibialis, peroneus longus, medial gastrocnemius, and gluteus medius).

2.2. Participants

Ten adults with CAI (Table 1) were recruited from a University and surrounding community to participate in this study. The inclusion criteria for the CAI group was a history of more than one ankle sprain with the initial sprain occurring greater than 1 year ago, no sprain within the past 6 weeks and current self-reported functional deficits due to ankle symptoms that was qualified by a score of $<$85% on the FAAM Sport scale and a $\geq$11 on the Identification of Functional Instability scale (IdFAI) [17]. All participants were physically active (at least 20 min of exercise a day at least 3 days a week) and had no other known lower extremity injuries or pathologies. In the event of a participant having bilateral CAI, the perceived worse limb was used for testing. The study was approved by the University's Institutional Review Board and all patients provided informed consent prior to study participation.

Table 1
Participant demographics (n = 10).

Mean (SD)	
Age (years)	21.5 (3.1)
Sex	Male: 3, Female: 7
Height (cm)	166.0 (6.3)
Mass (kg)	65.6 (10.4)
Godin leisure-time exercise questionnaire	73.9 (24.5)
Foot and ankle ability measure ADL%	86.3 (7.8)
Foot and ankle ability measure sport %	68.1 (15.0)
Identification of functional ankle instability scale	23.6 (5.3)
Number of ankle sprains	4.8 (3.2)
Time since last sprain (months)	11.5 ± 9.3
Anterior drawer arthrometer (mm)	12.2 ± 5.2
Inversion arthrometer (degrees)	44.9 ± 9.7

SD – standard deviation; cm – centimeter; kg – kilogram.

2.3. Instruments

2.3.1. Plantar pressure

Plantar pressure was measured using the Pedar-x plantar pressure system (Novel Inc., St Paul, MN) with in-shoe insoles that had a sampling rate of 100 Hz. Participants used a standard athletic shoe properly fitted to foot size (Brooks Defyance 3, Brooks Sports Inc., Seattle, WA).

2.3.2. Auditory biofeedback device

The auditory biofeedback device was custom made using a force sensitive resistor (FlexiForce, Tekscan Inc., South Boston, MA), piezobuzzer (Intervox, International Components Corporation, Bohemia, NY), trimpot (Bourns Inc., Riverside, CA, and a 12 V (Fig. 1). The sensor was the only part of the device that was placed inside the shoe, which was done so through a small incision (Fig. 1). The sensor was a thin filament ($\approx$0.203 mm) that lied flat within the shoe, while the rest of the device was fixed to the top of the shoe. The device was designed to elicit an audible noise when a patient's vertically directed force exceeded the threshold of the force sensor by allowing the circuit between the battery and piezobuzzer to be completed. The force sensor threshold could be adjusted using the trimpot.

2.3.3. Surface electromyography

Surface EMG was collected using two parallel bar rectangular sensors. Each bar was 1 mm wide and 1 cm long and separated by 1 cm. The sensors were DE 2.1 differential EMG sensors (Delsys, Boston, MA). The signal was amplified with a gain of 1000 and digitized with a four channel acquisition system (Bagnoli EMG system, Delsys, Boston, MA) at 1000 Hz. Input impedance was $>10^{15}\ \Omega$//0.2 pF with a signal to noise ratio of 1.2 μV. Data was collected using Motion Monitor software (Innovative Sports Training, Inc., Chicago, IL) and processed by using EMGworks software (version 4.1.1, Delsys, Boston, MA). Using the Motion Monitor software, data was filtered using a 10–500 band-pass filter and smoothed using a 50-sample moving window root mean square (RMS) algorithm as recommended by Konrad [18]. Initial heel contact was identified using a foot switch placed beneath the heel of the involved limb (Delysis, Boston, MA).

2.3.4. Procedures

Participants completed the FAAM activity of daily living and sport scales, the IdFAI questionnaire, and mechanical laxity testing using an ankle arthrometer (Blue Bay Research Inc., Navarre, FL) (Table 1). Mechanical laxity was recorded for descriptive purposes only and not used as part of inclusion criteria or analysis. Next, patients were fitted for standard neutral shoes and performed walking trials. Patients were instructed to walk on the treadmill (Gait Trainer™ 3, Biodex, Shirley, NY) and increase the speed until