Journal of Electromyography and Kinesiology 38 (2018) 155–161

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Variability in center of pressure position and muscle activation during walking with chronic ankle instability

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ARTICLE INFO

Keywords:
Ankle sprain
Plantar pressure
Electromyography
Gait

ABSTRACT

Chronic ankle instability (CAI) patients exhibit altered gait mechanics. The objective was to identify differences in stride-to-stride variability in the position of the center of pressure (COP) and muscle activity during walking between individuals with and without CAI. Participants (17 CAI;17 Healthy) walked on a treadmill at 1.3 m/s while surface electromyography (sEMG) of the fibularis longus (FL) and plantar pressure were recorded. The medial-lateral COP position was averaged for each 10% interval of stance and group standard deviations (SD), coefficient of variation (COV), and range for the COP position were compared between groups via independent t-tests. Ensemble curves for sEMG amplitude SD were graphed for the entire stride cycle to determine significant differences. The CAI group had increased COP position variability (SD (CAI = 0.79 ± 0.47 mm, Control = 0.48 ± 0.17 mm), COV (CAI = 1.47 ± 0.87 mm, Control = 0.93 ± 0.33 mm), range (CAI = 2.97 ± 2.07 mm, Control = 1.72 ± 0.33 mm, $P < .05$ for all analyses)) during the first 10% of stance. The CAI group had lower FL sEMG amplitude variability from 1 to 10% (mean difference = 0.014 ± 0.006), 32–38% (mean difference = 0.013 ± 0.004) and 56–100% (mean difference = 0.026 ± 0.01) of the gait cycle. Increased COP variability at initial contact may increase risk of lateral ankle sprains in CAI patients. Decreased sEMG amplitude variability may indicate a constrained sensorimotor system contributing to an inability to adapt to changing environmental demands.

1. Introduction

Ankle sprains are extremely common musculoskeletal injuries in active populations (Waterman et al., (2010)). Unfortunately, many patients who sustain a lateral ankle sprain (LAS) do not seek appropriate medical attention (Doherty et al., 2016; McKay et al., 2001). One year following an initial LAS, 40% of individuals develop chronic ankle instability (CAI) (Doherty et al., 2016). This condition is commonly described as patients having decreased self-reported function, subsequent bouts of instability or feelings of "giving way," and persistent symptoms for at least 12 months following an initial LAS (Gribble et al., 2014). A history of a previous ankle sprain (Beynnon et al., 2002) impaired postural control (McKeon and Hertel, 2008), an inverted foot position prior to initial contact (IC) (Delahunt et al., 2006; Monaghan et al., 2006), or increased lateral pressure during the stance phase of gait (Koldenhoven et al., 2016), may contribute to episodes of giving way or increase the risk of recurrent sprain.

During walking, CAI individuals demonstrate a more lateral center of pressure (COP) trajectory following IC (Hopkins et al., 2012) which may lead to a laterally deviated COP under each foot throughout the entire stance phase (Koldenhoven et al., 2016). We have previously demonstrated that the CAI participants had a medial-lateral location of COP that was 2.9 mm more lateral during the first 10% of stance and 7.5 mm more lateral during 50–60% of stance when compared to healthy participants (Koldenhoven et al., 2016). Laterally deviated pressures under each foot throughout stance could increase the risk for a subsequent LAS as the patient is walking on the lateral column of their foot, closer to the edge of their base of support. The fibularis longus muscle is uniquely suited to correct the aforementioned alterations in gait mechanics due to its role in producing eversion of the foot prior to IC and pronation of the foot during the stance phase of gait. Individuals with CAI have demonstrated earlier onset and increased activation of the fibularis longus muscle prior to (Feger et al., 2015; Koldenhoven et al., 2016), and following IC (Hopkins et al., 2012).

Alterations in muscle activity and plantar pressure profiles have been well established in CAI patients with respect to differences in the group means, but it may also be beneficial to understand how CAI and healthy individuals differ on a step-to-step basis. Variability is commonly defined as the amount of change observed after multiple repetitions of the same task. It has been theorized that an optimal range of

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https://doi.org/10.1016/j.jelekin.2017.12.003
Received 21 July 2017; Received in revised form 15 November 2017; Accepted 14 December 2017
1050-6411/

movement variability would allow the body to adapt to various situations and potentially reduce overuse of specific structures (Harbourne and Stergiou, 2009). As movements commonly fall within a certain range during gait, too little variability may be the result of an overly constrained system while too much variability may suggest an uncoordinated system (Harbourne and Stergiou, 2009).

Variability can be measured using many different techniques that employ linear or non-linear mathematics. Many different variability analyses have been reported in the assessment of gait mechanics in CAI patients with no single technique being identified as the optimal method. Sample entropy is a form of nonlinear variability that measures the uncertainty or unpredictability during a kinematic time series (Yentes et al., 2013). Terada et al. (2015) found decreased frontal plane ankle kinematic sample entropy during walking in individuals with CAI which may indicate constrained mechanics. Studies have also measured variability in intersegmental coupling in individuals with CAI (Drewes et al., 2009; Herb et al., 2014; Herb and Hertel, 2015; Lilley et al., 2017). Shank-rearfoot coupling assesses the continuous relationship of angles between the two segments about the ankle (Drewes et al., 2009; Herb et al., 2014). Using vector coding methods, Herb et al. found decreased shank-rearfoot joint coupling variability during late stance, toe off, and early swing for individuals with CAI during walking (Herb et al., 2014). In a follow-up cross-correlation analysis, the CAI group had more asynchronous shank-rearfoot coupling during both walking and jogging indicating less functional variability (Herb and Hertel, 2015). Decreases in stride-to-stride variability measures in individuals with CAI may indicate having a more constrained and less adaptable sensorimotor systems system during gait (Herb et al., 2014; Herb and Hertel, 2015; Terada et al., 2015). On the contrary, one study using continuous relative phase methods to measure shank-rearfoot coupling, found that individuals with CAI had altered shank-rearfoot coupling resulting in a more "out of phase" relationship during the terminal swing phase (94–97%) of walking than their healthy counterparts (Drewes et al., 2009). The authors speculated that increased variability during terminal swing in individuals with CAI may indicate less coordinated movement patterns prior to IC (Drewes et al., 2009).

Only one study has reported variability of muscle function during walking in individuals with CAI (Kautzky et al., 2015). The CAI group demonstrated increased variability of gluteus medius sEMG amplitude, as measured by coefficient of variation (COV), prior to IC compared to a healthy group (Kautzky et al., 2015). Additionally, increased time of activation variability for the biceps femoris relative to IC was identified in the CAI group (Kautzky et al., 2015). This increase in muscle variability may be a response to altered ankle mechanics or potentially a contributing factor for subsequent ankle sprains (Kautzky et al., 2015). While there is clear evidence of altered kinematic variability in CAI patients and some evidence regarding variability in muscle activation patterns (Kautzky et al., 2015), variability for plantar pressure measures with concurrent sEMG has not been previously reported. Therefore, the purpose of this study was to compare the stride-to-stride variability for the location of COP throughout the stance phase and the sEMG activation amplitude of the fibularis longus and tibialis anterior muscles throughout the stride cycle and the root mean square (RMS) area under the curve for the timing around IC during walking in individuals with and without CAI. We hypothesized that the individuals would have increased stride-to-stride variability for both plantar pressure and sEMG measures.

2. Methods

We performed a case–control laboratory study comparing measures of variability for plantar pressure and sEMG for CAI and healthy subjects during treadmill walking. Group mean differences in plantar pressure and sEMG measures have been previously reported utilizing the same participants (Koldenhoven et al., 2016). For this study, the independent variable was group (CAI, Healthy) and the dependent variables were variability measures for plantar pressure path location and sEMG amplitude of the fibularis longus and tibialis anterior muscles. The standard deviation (SD), coefficient of variation (COV), and range for the medial to lateral location of the center of pressure (COP) was analyzed at 10% intervals for the entire stance phase of gait. For temporal variables of sEMG, the SD for root mean square (RMS) amplitude across the entire gait cycle and the COV for the area under the RMS curve for the 100 ms pre-IC and 200 ms post-IC epochs were analyzed for the tibialis anterior and fibularis longus muscles.

Table 1
Participant demographics (n = 34).

	CAI (n = 17) Mean ± SD	Healthy (n = 17) Mean ± SD
Age (years)	20.0 ± 2.6	21.8 ± 4.3
Sex	Male: 6, Female: 11	Male: 6, Female: 11
Height (cm)	170.2 ± 11.4	167.0 ± 9.7
Mass (kg)	77.4 ± 5.1	75.9 ± 4.4
idFAI	21.3 ± 5.2	0.1 ± 0.5
FAAM ADL %	92.9 ± 3.6	100 ± 0
FAAM Sport %	75.0 ± 6.9	100 ± 0
Number of Ankle Sprains	5.0 ± 5.6	0
Time Since Last Sprain (months)	16.9 ± 18.4	N/A

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

3. Participants

Thirty-four young adults (CAI = 17, Healthy = 17) participated in this study Table 1). The participants were placed into their respective group based on the health status of their ankle. Healthy participants did not have a history of sprain in either ankle. Previously established inclusion criteria was used to identify participants with CAI (Gribble et al., 2014). CAI participants were included if they had a history of at least one significant ankle sprain that occurred at least 12 months prior to the study and self-reported functional deficits on the Foot and Ankle Ability Measure (FAAM) Sport subscale (< 85%) (Carcia et al., 2008; Martin et al., 2005) and the Identification of Functional Ankle Instability (idFAI) (≥10) (Donahue et al., 2013). For participants with bilateral history of ankle sprains (n = 6), the limb that had the greater perceived deficit was analyzed in this study. Healthy participant test limbs were matched to the CAI test limbs by side (right or left) for analysis. All participants were recreationally physically active (> 3 times per week at moderate intensity for > 20 min per day).

Participants were excluded if they had a history of lower extremity surgery or fracture, lower extremity musculoskeletal injury within 1 year of study participation, ankle sprain within 6 weeks (CAI group only) of study participation, any neurologic or vestibular conditions, were currently seeking rehabilitation care for CAI, or had any condition known to adversely affect muscle function or gait mechanics (muscular dystrophy, multiple sclerosis, diabetes mellitus, lumbosacral radiculopathy, etc.).

Participants were recruited from a large public university setting and provided written informed consent prior to participating in the study. The University's Institutional Review Board approved the methods of this study.

3.1. Instrumentation

3.1.1. Plantar pressure

Plantar pressure was measured using in-shoe plantar pressure insoles (Pedar-X, Novel Inc., St Paul, MN) at a sampling rate of 100 Hz. All subjects wore standardized laboratory shoes (New Balance cross-training shoe, Model WX755WB, Boston, MA) and all trials were