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Alterations in stride-to-stride variability during walking in individuals with chronic ankle instability

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A B S T R A C T

The aim of this study was to evaluate stride-to-stride variability of the lower extremity during walking in individuals with and without chronic ankle instability (CAI) using a nonlinear analysis. Twenty-five participants with self-reported CAI and 27 healthy control participants volunteered for this study. Participants walked on a motor-driven treadmill for 3 min at their selected speed. Lower extremity kinematics in the sagittal and frontal planes were recorded using a passive retroreflective marker motion capture system. The temporal structure of walking variability was analyzed with sample entropy (SampEn). The CAI group produced lower SampEn values in frontal-plane ankle kinematics compared to the control group ($P = .04$). No significant group differences were observed for SampEn values of other kinematics ($P > .05$). Participants with CAI demonstrated less stride-to-stride variability of the frontal plane ankle kinematics compared to healthy controls. Decreased variability of walking patterns demonstrated by participants with CAI indicates that the presence of CAI may be associated with a less adaptable sensorimotor system to environmental changes. The altered sensorimotor function associated with CAI

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may be targets for clinical interventions, and it is critical to explore how interventions protocols affect sensorimotor system function.

1. Introduction

The ankle is the most common site for initial and recurrent injuries related to sport (Fernandez, Yard, & Comstock, 2007; Swenson, Yard, Fields, & Comstock, 2009). Many physically active individuals suffer from ankle sprains (Hootman, Dick, & Agel, 2007; Waterman, Owens, Davey, Zacchilli, & Belmont, 2010), and it has been estimated that up to 73.6% of those with a history of ankle sprain will go on to experience recurrent ankle sprains and repeated bouts of perceived feeling of giving-way (Anandacoomarasamy & Barnsley, 2005; Gerber, Williams, Scoville, Arciero, & Taylor, 1998; Konradsen, Bech, Ehrenbjerg, & Nickelsen, 2002). Chronic ankle instability (CAI) is a significant orthopedic concern in physically active populations and characterized by a recurrent perception of the ankle giving away (Hertel, 2002). People with CAI demonstrate decreased physical activity levels (Hiller et al., 2012; Verhagen, van Mechelen, & de Vente, 2000) and quality of life (Arnold, Wright, & Ross, 2011), as well as a higher risk of developing posttraumatic ankle osteoarthritis (Hirose, Murakami, Minowa, Kura, & Yamashita, 2004; Valderrabano, Hintermann, Horisberger, & Fung, 2006). Elucidating the underlying mechanism of CAI is critically important to improve current care for CAI.

It has been suggested that inappropriate alterations in sensorimotor control play a significant role in perpetuating the recurrent perception of ankle instability (Hertel, 2008; Wikstrom, Hubbard-Turner, & McKeon, 2013). Movement patterns during gait have been examined with biomechanical measures to estimate sensorimotor function in individuals with CAI, with altered lower extremity kinematics and kinetics observed in those with CAI. (Brown, 2011; Drewes, McKeon, Kerrigan, & Hertel, 2009; Drewes et al., 2009; Hass, Bishop, Doidge, & Wikstrom, 2010; Herb et al., 2014; Wikstrom, Bishop, Inamdar, & Hass, 2010). Individuals with CAI have demonstrated less joint coupling variability compared to healthy controls during gait (Herb et al., 2014). Applying dynamical system theory of motor control, a healthy sensorimotor system self-organizes in multiple ways by adapting organismic, environmental, and task constraints to find the most stable solutions to achieve movement goals (Davids, Glazier, Araujo, & Bartlett, 2003; Hoch & McKeon, 2010). As constraints on the sensorimotor system increase, the sensorimotor system becomes unstable and switches to use a new, more stable movement strategies (Davids et al., 2003). The presence of CAI may increase organismic constraints on the sensorimotor system and diminish its ability to reorganize movement strategies and adjust changes in task demands or environmental conditions, thereby producing rigid and inflexible movement patterns (Herb et al., 2014; McKeon, 2012; Wikstrom et al., 2013).

Stergiou and Decker (2011) suggested that ideal variability of healthy motor control has chaotic characteristics that are not random but have a deterministic pattern. In a healthy state, the sensorimotor system is flexible and adaptable to stresses placed on the human body and changes in tasks demands or environmental conditions (Stergiou, Harbourne, & Cavanaugh, 2006). Herb et al. (2014) has calculated an intersegmental variability coefficient to assess the magnitude of the stride-to-stride variability in shank-rearfoot coupling in patients with CAI. During this variability analysis, kinematic data from a few strides are averaged to generate a mean ensemble curve and accompanied by time normalization (Buzzi, Stergiou, Kurz, Hageman, & Heidel, 2003). However, the time normalization masks the temporal variations of the gait pattern since it stretches or pulls the original data (Buzzi et al., 2003). Alternatively, a chaotic gait pattern can be determined using a nonlinear mathematical approach that quantifies the temporal structure of stride-to-stride variability (Buzzi et al., 2003; Stergiou & Decker, 2011). The nonlinear variability analysis focuses on understanding how a movement pattern changes over multiple gait cycles and determines whether a chaotic structure and complexity are present in movement (Buzzi et al., 2003; Stergiou & Decker, 2011).