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Full Length Article

Forward leaning alters gait initiation only at extreme anterior postural positions

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ABSTRACT

We investigated the impact of initial body position on the displacement and velocity of center of pressure adjustments made during gait initiation. Twenty-nine healthy adults (21 ± 1y) initiated forward gait following six seconds of sustained forward posture based on percentage of their forward maximum voluntary lean (0, 5, 10, 20, 50%). Final center of pressure positions for each trial were back-calculated, as a percentage of maximum voluntary lean, using average anteroposterior constant error to the target during the last second of feedback. Scores were aggregated into percentage bands for analysis: Band 1 = −2–4.99%; Band 2 = 5–8.99%; Band 3 = 9–17.99%; Band 4 = 18–29%; Band 5 = 44–54%. Center of pressure displacement and velocity were evaluated during the decoupling, weight shift, and step initiation phases of gait initiation. Subsequent stepping parameters were also compared. During the decoupling phase, greater posterior displacement was observed in band 5 trials compared to 1, 2, and 3, and greater posterior velocity was found for band 5 compared to 1 and 3. During the weight shift phase, greater resultant displacement was found for band 5 compared to 3 and greater resultant velocity for band 5 compared to 2, 3, and 4. During step initiation, participants produced greater anterior displacement and resultant velocity during band 1, 2, and 3 compared to 5. Participants demonstrated greater swing step length and stance step time during band 5 trials compared to 3. These results suggest that only anterior postural positions greater than 44% of a person's maximum voluntary lean systematically alter spatiotemporal and kinematic indices of forward gait initiation in healthy populations. We discuss the conceptual implications of this work with respect to previous behavioral interventions.

1. Introduction

Gait initiation (GI) is a dynamic period in which individuals transition from quiet comfortable stance to steady state (i.e. stable speed) walking (Brenière & Do, 1986; Elble, Moody, Leffler, & Sinha, 1994; Jian, Winter, Ishac, & Gilchrist, 1993). During quiet standing, the position of center of pressure (COP), or the point of application of the ground reaction force, is tightly coordinated with the position of the center of mass (COM) in the transverse plane in order to maintain balance and upright body position (Dalton, Bishop, Tillman, & Hass, 2011; Winter, Prince, Frank, Powell, & Zabjek, 1996). Prior to step execution, centrally mediated anticipatory postural adjustments (APA's) are generated to uncouple the COP and COM and contribute to the generation of forward momentum (Elble et al., 1994; Jian et al., 1993; Polcyn, Lipsitz, Kerrigan, & Collins, 1998; Santos, Kanekar, & Aruin, 2010). More

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specifically, bilateral deactivation of the triceps surae musculature, tightly coupled with activation of the tibialis anterior, hip abductor activation, and stance limb knee flexion (Honeine, Schieppati, Gagey, & Do, 2013; Mickelborough, van der Linden, Tallis, & Ennos, 2004), shifts the COP backward and laterally towards the swing/stepping limb. This COP shift contributes to the initial momentum necessary for taking a step before the COM moves forward of the base of support, thus resolving the inherent conflict of generating momentum and maintaining stability (Polcyn et al., 1998).

Gait initiation, as a functional task of daily living, has been used as an investigative tool to provide insight into postural control and changes in mobility that occur with advancing age (e.g., Hass, Waddell, Wolf, Juncos, & Gregor, 2008; Muir, Rietdyk, & Haddad, 2014; Patchay, Gahery, & Serratrice, 2002; Sparto, Jennings, Furman, & Redfern, 2014) and disability (e.g., Crenna, Frigo, Giovannini, & Piccolo, 1990; Halliday, Winter, Frank, Patla, & Francois, 1998; Hass, Waddell, Fleming, Juncos, & Gregor, 2005; Nocera, Roemmich, Elrod, Altmann, & Hass, 2013; Polcyn et al., 1998). Within this body of literature, APA's have been assessed by quantifying the magnitudes and velocities of the COP movements to provide insight into motor planning or control processes (Brunt et al., 1991; Brunt, Liu, Trimble, & Bauer, 1999; Eng, Winter, MacKinnon, & Patla, 1992; MacKinnon et al., 2007). For example, the influence of gait initiation speed on these APA's has been extensively investigated, including effects on both anteroposterior and mediolateral spatiotemporal features and COM stability (e.g., Brenière, Do, & Bouisset, 1987; Caderby et al., 2013; Ito, Azuma, & Yamashita, 2003; Lepers & Brenière, 1995; Singer, Prentice, & McIllroy, 2013). Further, previous work has investigated the effects of initial stance conditions: heel-on vs. heel-off position (Couillandre & Brenière, 2003), anteroposterior (AP) foot placement (Dalton et al., 2011), and mediolateral (ML) stance width (Rocchi et al., 2006) on COP displacements and velocities, force production, and step kinematics. More recently, several investigations have manipulated the initial step trajectories (stepping over obstacles of differing heights, widths, and distances or to targets) to determine how the central nervous system adapts the GI motor program (Kim, Brunt, & Je, 2015; Yiou, Fourcade, Artico, & Caderby, 2015, 2016).

In contrast, the question of how initial body orientation, particularly in the sagittal plane, modulates COP trajectories and step kinematics is far less documented (Fortin, Dessery, Leteneur, Barbier, & Corbeil, 2015; Leteneur, Simoneau, Gillet, Dessery, & Barbier, 2013). This is surprising because extant physical conditions are known to alter the body's orientation during quiet stance. For example, persons with depression and Parkinson's disease often exhibit a forward stooped posture (Bloem, Beckley, & van Dijk, 1999; Bloem, Van Vugt, & Beckley, 2001; Schieppati & Nardone, 1991). Additionally, some current experimental methodologies aimed at altering GI behavior, such as presentation of stimuli with emotional properties, may inherently cause reactionary postural sway (leaning forward or backward) prior to overt movement (e.g., Azevedo et al., 2005; Facchinetti, Imbiriba, Azevedo, Vargas, & Volchan, 2006; Fawver, Beatty, Naugle, Hass, & Janelle, 2015; Hillman, Hsiao-Wecksler, & Rosengren, 2005; Huffman, Horslen, Carpenter, & Adkin, 2009). Evidence from a recent study corroborates this view (Fawver et al., 2015). Unfortunately, to our knowledge, no study has systematically evaluated the effects of forward body orientation (lean) on modulation of the APA's and stepping kinematics and kinetics.

The purpose of this study was to determine the relative impact of anterior postural leaning positions on the spatiotemporal characteristics of GI behavior. To accomplish this aim, we measured participants' ability to initiate gait following sustained forward postural lean to different target positions that represented the anterior position of COP. Manipulated lean positions were based on a percentage of the maximum distance each participant could lean (at the ankle) in the anterior direction without picking up their heels (maximum voluntary lean: MVL; Fawver, Amano, Hass, & Janelle, 2012). Real-time visual feedback of COP was used to guide 6 s of a sustained anterior lean position and gait was initiated immediately following feedback removal. Because in the greater MVL conditions, the center of mass is farther forward within the boundary of the feet, we hypothesized that participants would exhibit decreased magnitude and velocity of APA's to maintain the development of comfortable walking speed.

2. Methods

2.1. Participants

Thirty-three undergraduate students from the university population volunteered to participate in this study. All subjects were naïve to the purpose of the study, reported no injuries in the lower extremity in the past six months, and were free of any neurological disorders which would have influenced their movement. Four participants were excluded from the final analysis due to technical issues during data collection and/or reduction, leaving twenty-nine remaining participants who completed the experimental protocol (mean [*M*] age = 20, standard deviation [*SD*] = 1 yrs).

2.2. Procedure

Upon arrival, participants signed an informed consent form approved by the University of Florida's Institutional Review Board. Participants were barefoot and wore tight fitted clothing before being fitted with thirty-five retroreflective markers over bony landmarks in accordance with the Vicon Plug-in-Gait model. Kinematic data were collected using a nine-camera motion capture system (120 Hz; Vicon, Oxford, UK), and kinetic data were collected from force plates embedded into the floor (360 Hz; Bertec Corporation, Columbus, OH) oriented in a straight line approximately 4.5 m from a rear-projection screen. Following marker