Human Movement Science 41 (2015) 32–45

Contents lists available at ScienceDirect

Human Movement Science

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

Side by side treadmill walking reduces gait asymmetry induced by unilateral ankle weight

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A R T I C L E I N F O

PsycINFO classification:
2330

Keywords:
Gait
Asymmetry
Synchronization
Entrainment
Side by side walking

A B S T R A C T

Asymmetric gait is a hallmark of many neurological and musculoskeletal conditions. This behavior is often the result of a decrease in the stability of interlimb coordination, and synchronization to external signals such as auditory cuing or another walking individual may be helpful for altering abnormal movement patterns. The purpose of this study was to investigate the interaction between interlimb coordination and unintentional, interpersonal synchronization of gait in healthy individuals in response to unilateral ankle loading. Fifty participants completed four trials while walking on a motorized treadmill: (1) by themselves, (2) with a partner on an adjacent treadmill, (3) by themselves with additional weight applied unilaterally to their right ankle, and (4) with both a partner and unilateral weight. As expected, the addition of unilateral weight increased asymmetry according to several spatiotemporal measures of gait, but the presence of a partner on an adjacent treadmill significantly reduced this effect. Further, the amount of unintentional, interpersonal synchronization among pairings was relatively unaffected by the addition of ankle weight to one of the partners. All pairings realized a beneficial effect on asymmetrical gait but this effect was greater for pairings that consistently synchronized unintentionally. These results suggest that side by side walking might be an effective approach for influencing bilateral coordination of gait and may hold insight for understanding gait asymmetry and interlimb movement variability.

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http://dx.doi.org/10.1016/j.humov.2015.02.005
0167-9457/

1. Introduction

Asymmetric gait is a complex behavior of both mechanical (Gregg, Dhaher, Degani, & Lynch, 2012; Laroche, Cook, & Mackala, 2012) and neurological origin (Chen, Patten, Kothari, & Zajac, 2005; Kalron, Frid, & Gurevich, 2014; Plotnik, Giladi, & Hausdorff, 2007; Rao, Mazzoni, Wasserman, & Marder, 2011). In some cases, gait asymmetry may be beneficial by helping to improve walking stability (Schaarschmidt, Lipfert, Meier-Gratz, Scholle, & Seyfarth, 2012). However, asymmetry is generally considered problematic because it results in increased metabolic cost (Ellis, Howard, & Kram, 2013; Skinner & Barrack, 1990) and appears to be related to increased risk of falling in older adults (Yogev, Plotnik, Peretz, Giladi, & Hausdorff, 2007), Parkinson's patients (Plotnik, Giladi, Balash, Peretz, & Hausdorff, 2005; Yogev et al., 2007), and individuals post-stroke (Lewek, Bradley, Wutzke, & Zinder, 2014). Consequently, a great deal of research has been devoted to understanding and improving gait asymmetry in multiple populations (e.g., (Aruin & Kanekar, 2013; Kim et al., 2011; Laroche et al., 2012; Reisman, Wityk, Silver, & Bastian, 2007; Yang et al., 2012)).

Human gait is often modeled as a coupled oscillator system, and its symmetry (or lack thereof) can be examined as a form of intrapersonal coordination of rhythmic oscillations (Garcia, Chatterjee, Ruina, & Coleman, 1998; Kurz & Stergiou, 2007; Nessler, 2009; Nessler & Gillilland, 2009; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008). There is a growing body of research devoted to intrapersonal coordination of rhythmic movements, much of which is based upon the coupled oscillator model proposed by Haken, Kelso, and Bunz (Haken, Kelso, & Bunz, 1985; Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007; Richardson, Marsh, & Schmidt, 2005; Schmidt & O'Brien, 1997; Schmidt, Shaw, & Turvey, 1993). Generally speaking, this model predicts that rhythmic motion between two oscillators will settle at one of two stable states of coordination, or relative phases: 0° (i.e., in-phase) or 180° (anti-phase), with the in-phase state demonstrating greater stability. Several examples of intrapersonal, rhythmic human movement have been shown to exhibit similar coordination dynamics (Coey, Varlet, Schmidt, & Richardson, 2011; Haken et al., 1985; Richardson et al., 2005; Schmidt, Beek, Treffner, & Turvey, 1991; Schmidt & O'Brien, 1997). The HKB model has also been shown to apply to several examples of interpersonal synchronization (Richardson, Campbell, & Schmidt, 2009; Richardson et al., 2005, 2007; Schmidt, Carello, & Turvey, 1990; Schmidt & O'Brien, 1997), even for certain cases where co-actors are visually coupled and synchronize unintentionally (Oullier, de Guzman, Jantzen, Lagarde, & Kelso, 2008; Richardson et al., 2007; Schmidt & O'Brien, 1997; Schmidt & Turvey, 1994). Currently, the extent to which the intrapersonal coordination of human gait adheres to a coupled oscillator model is somewhat unclear. Some studies suggest that such a model can be useful in the prediction of several important features of human gait (Diedrich & Warren, 1995, 1998; Holt, Hamill, & Andres, 1990). Others have described conditions where the HKB model does not readily apply (Kao, Ringenbach, & Martin, 2003; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2010). Taken together, there is sufficient evidence to suggest that the coupled oscillator approach to modeling rhythmic movement can provide some insight into the complex nature of the control of human gait and may help to inform rehabilitation strategies designed to correct problems with interlimb coordination.

If human gait adheres to a coupled oscillator model, then gait asymmetry can be described as a reduction in the stability of intrapersonal coordination. This idea might be applied to multiple patient populations who are known to exhibit problems with intrapersonal coordination, including those with neurological impairment (Chen et al., 2005; Kalron et al., 2014; Lewek et al., 2014; Plotnik et al., 2005), and mechanical imbalance resulting from amputation (Schaarschmidt et al., 2012; Yang et al., 2012). Though there are multiple factors related to poor coordination during gait, a difference in the inertial properties between the lower extremities is of particular interest in the context of the coupled oscillator model. In lower limb amputees for example, an alteration in the mass of one oscillator (e.g., one limb) represents a detuning factor for harmonic oscillation. This detuning factor can alter the natural frequency of each limb, thereby creating a difference in the preferred frequency of each oscillator in the system (Richardson et al., 2007; Schmidt & Turvey, 1994). Under the assumptions of the coupled oscillator model, this difference in the preferred frequency can lead to both a phase lag between oscillators and a decrease in the stability of the relative phase, typically described as an increase in the