Human Movement Science 59 (2018) 20–29

Contents lists available at ScienceDirect

Human Movement Science

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

Full Length Article

The effects of dual tasking on gait synchronization during over-ground side-by-side walking

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ARTICLE INFO

Keywords:
Stride length
Stride time
Synchronization
Human
Gait
Dual tasking

ABSTRACT

Recent studies have shown that gait synchronization during natural walking is not merely anecdotal, but it is a repeatable phenomenon that is quantifiable and is apparently related to available sensory feedback modalities. However, the mechanisms underlying this phase-locking of gait have only recently begun to be investigated. For example, it is not known what role, if any, attention plays. We employed a dual tasking paradigm in order to investigate the role attention plays in gait synchronization. Sixteen pairs of subjects walked under six conditions that manipulated the available sensory feedback and the degree of difficulty of the dual task, i.e., the attention. Movement was quantified using a trunk-mounted tri-axial accelerometer. A gait synchronization index (GSI) was calculated in order to quantify the degree of synchronization of the gait pattern. A simple dual task resulted in an increased level of synchronization, whereas a more complex dual task lead to a reduction in synchronization. Handholding increased synchronization, compared to the same attention condition without handholding. These results indicate that in order for two walkers to synchronize, some level of attention is apparently required, such that a relatively complex dual task utilizes enough attentional resources to reduce the occurrence of synchronization.

1. Introduction

Two people who walk together from one point to another must match their gait speeds if they wish to stay together. To achieve this goal, each person can select from an array of cadence and stride length combinations. Surprisingly, casual observation suggests and recent studies confirm that a significant fraction of people who ambulate together do this in synchrony, with near identical cadence and stride lengths. Step length and step time can be varied in numerous ways to ensure that walking partners move forward at the same rate and arrive at the desired destination together. However, instead of achieving this goal through a random, time-varying, combination of these parameters, remarkably, couples often seem to March to a single drummer. The first paper to examine this phenomenon (Zivotofsky & Hausdorff, 2007) analyzed it in a qualitative manner. More recently, this finding was quantitatively

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https://doi.org/10.1016/j.humov.2018.03.009
Received 9 November 2017; Received in revised form 19 March 2018; Accepted 20 March 2018

characterized under natural, over-ground walking conditions (Zivotofsky, Gruendlinger, & Hausdorff, 2012) and during treadmill walking (Nessler & Gilliland, 2009; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008).

Gait is not the only activity that humans synchronize. Intentional synchronization between an organism and an external cue or between two organisms is a common occurrence in nature. Humans do this during clapping, singing, dancing, and other social activities. A *meta*-analysis of 42 studies found that synchrony affects social interactions (Mogan, Fischer, & Bulbuliab, 2017). It has positive effects on pro-social behaviours, perceived social bonding, social cognition, and positive affect. Several studies showed that people were able to create improvised arm movements while staying synchronized together (Gueugnon et al., 2016). Such an improvisation situation involves the lower and upper part of the body with the creation of synchronized movements of the arms and legs, and it also requires the maintenance of balance with delicate coordination between the lower and upper parts of the body (Bardy, Marin, Stoffregen, & Bootsma, 1999; Lee, 1989; Stoffregen & Riccio, 1988). Thus, deliberate synchronization of human motor tasks is not uncommon.

Synchronization is so fundamental that it often also occurs spontaneously. While we focus here on over-ground walking, a similar phenomenon exists for other tasks. In one of the first studies to examine this question, Schmidt and O'Brien (1997) asked ten pairs of participants to swing pendulums. In trials in which the subjects had visual information about the other participant, dynamical organizing principles were involved in natural, interpersonal synchrony. Schmidt, Bienvenu, Fitzpatrick, and Amazeen (1998) examined the strength of intentional inter-subject coordination of two people oscillating their arms. Pairs of subjects were asked to coordinate pendulum swings to an auditory pulse while also looking at their partner's pendulum and visually coordinating the oscillation of their pendulum with that of their partner's. Although there was indeed interpersonal coupling, it was weaker than intrapersonal interlimb coupling. In a test of the effect of somatosensory contact, Sofianidis, Hatzitaki, Grouios, Johannsen, and Wing (2012) observed that even light fingertip contact can increase the spontaneous coordination dynamics of two persons performing rhythmic sway together, and that this synchronization is more pronounced in expert dancers. In addition, "pro-social" individuals were more likely to spontaneously synchronize their repetitive arm curls with another person (Lumsden, Miles, Richardson, Smith, & Macrae, 2012). Demos, Chaffin, Begosh, Daniels, and Marsh (2012) reported that pairs of participants seated side by side in rocking chairs spontaneously coordinated their rocking when they saw or heard the other person, another example of synchronization that occurs during the performance of a motor task even in the absence of deliberate decisions to couple the movements.

Several studies examined the role of attention on synchronization on motor tasks other than gait. Richardson, Marsh, and Schmidt (2005) used a form of a dual task paradigm in a task that manipulated attention, when they asked pairs of participants to swing handheld pendulums while engaging in a task of identifying the differences between two cartoon pictures. Visually coupled pairs showed spontaneous synchrony, while those who had only verbal interaction, i.e., intermittent attention, did not. Richardson, Marsh, Isenhower, Goodman, and Schmidt (2007) found that individuals rocking in side-by-side chairs unintentionally entrain, and that the strength of that entrainment is influenced by attention. In other words, attention apparently can influence the synchronization of certain motor tasks. In order to manipulate both the type of information transferred and the knowledge of what perceptual modality the other person has access to, Gipson, Gorman, and Hessler (2016) cleverly used visual occlusion goggles and noise cancelling headphones in a study in which twelve dyads performed a finger oscillation task. They found that there is a complex relationship between prior knowledge and the specific perceptual modality combination between the two participants.

The mechanisms whereby two people synchronize their gait, seemingly without any conscious awareness or effort, are not fully understood and there remain many unanswered questions about interpersonal gait synchronization. The aspect that we address in the present study is the role of attention in gait synchronization. Previous investigations sought to determine the degree of synchronization that occurs under varying visual, auditory, and tactile conditions during natural walking (Nessler & Gilliland, 2009; van Ulzen et al., 2008; Zivotofsky, Eldror, Mandel, & Rosenbloom, 2012). The results of these studies verified the existence of this repeatable, heretofore unrecognized, phenomenon that occurs in a subset of walking pairs and quantified the presence and degree of synchronization of gait during side by side over-ground and treadmill stepping under varying visual, auditory, and tactile conditions. That synchronization occurs is not a total surprise; entrainment of the gait rhythm to external cues has been studied in healthy adults and various patient groups, such as patients with Parkinson's disease who are known to react well to rhythmic sensory cues (Dotov et al., 2017) and, as described above, other interpersonal movement patterns like arm swing may be synchronized. Here we focus on the degree that attention is involved.

Today, it is well-recognized that gait is a highly complex, hierarchical process that is regulated by multiple internal brain networks and feedback mechanisms (Maidan et al., 2016; Mirelman et al., 2014, 2015; Nieuwhof et al., 2017; Pelosin et al., 2016) and that gait depends on attention (Al-Yahya et al., 2011; Yogev-Seligmann, Hausdorff, & Giladi, 2008). Thus, dual tasking, a condition that demands the sharing of attention among two tasks, alters the gait pattern of older adults and patients with a wide array of diseases (Amboni, Barone, & Hausdorff, 2013; Belghali, Chastan, Davenne, & Decker, 2017; Montero-Odasso, Verghese, Beauchet, & Hausdorff, 2012; Montero-Odasso et al., 2017; Yogev-Seligmann, Giladi, Gruendlinger, & Hausdorff, 2013). Even healthy young adults change certain aspects of their gait when they walk while performing another task. For example, texting while walking decreases gait speed and alters gait dynamics. The simultaneous performance of another task not only leads to a reduced gait speed in healthy young adults, it can also negatively impact the quality of the "secondary" task (Agostini, Lo, Massazza, & Knaflitz, 2015; Agostini et al., 2015; Lim, Amado, Sheehan, & Van Emmerik, 2015; Srygley, Mirelman, Herman, Giladi, & Hausdorff, 2009). These results highlight the idea that walking utilizes attention and it is not a rote task, even in healthy young adults.

In the present study, we set out to investigate the role of attention in gait synchronization when healthy, young adults walk side-by-side over-ground. Specifically, we addressed three questions: 1) Does dual tasking impact gait synchronization? 2) Does the level of cognitive load make a difference, i.e., is the effect on synchronization similar for a relatively simple and a more cognitively demanding dual task? 3) Is the effect of dual tasking on synchronization dependent on the presence or absence of tactile feedback?