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Modality-specific communication enabling gait synchronization during over-ground side-by-side walking

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ABSTRACT

An attentive observer will notice that unintentional synchronization of gait between two walkers on the street seems to occur frequently. Nonetheless, the rate of occurrence and motor-sensory mechanisms underlying this phase-locking of gait have only recently begun to be investigated. Previous studies have either been qualitative or carried out under non-natural conditions, e.g., treadmill walking. The present study quantitatively examined the potential sensory mechanisms that contribute to the gait synchronization that occurs when two people walk side by side along a straight, over-ground, pathway. Fourteen pairs of subjects walked 70 m under five conditions that manipulated the available sensory feedback. The modalities studied were visual, auditory, and tactile. Movement was quantified using a trunk-mounted tri-axial accelerometer. A gait synchronization index (GSI) was calculated to quantify the phase synchronization of the gait rhythms. Overall, 36% of the walks exhibited synchrony. Tactile and auditory feedback showed the greatest ability to synchronize, while visual feedback was the least effective. The results show that gait synchronization during natural walking is common, quantifiable, and has modality-specific properties.

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1. Introduction

Two people who walk from one point to another and wish to travel together need to match their momentary gait speeds. To achieve this, each can select from an array of cadence and stride length combinations. Surprisingly, casual observation suggests that people who ambulate together side-by-side often appear to be walking in perfect synchrony, with an identical stride length, cadence, and even heel strike timing. This phenomenon has recently been studied in a qualitative manner under natural, over-ground walking conditions (Zivotofsky & Hausdorff, 2007) and more quantitatively during treadmill walking (Nessler, De Leone, & Gilliland, 2009; Nessler & Gilliland, 2009, 2010; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008). The fact that bipedal locomotion is so central to the human movement repertoire, together with the observed existence of interpersonal synchronization in both movement amplitude (stride length) and movement frequency (cadence), makes its study especially interesting within the field of interpersonal synchronization. However, the emotional, cognitive, motor, and sensory mechanisms whereby two people synchronize their gait, either with or without any conscious awareness or effort, are not well understood and have only recently begun to be studied.

A previous paper investigated synchronized walking (Zivotofsky & Hausdorff, 2007) in a qualitative manner by having experts review and score videos of the walkers' leg movements to determine the degree of synchronization under varying visual, auditory, and tactile conditions during natural walking. Nessler and Gilliland (2009) documented interpersonal synchronization patterns for the same sensory modalities during treadmill walking. It is important to note, however, that treadmill walking differs from natural over-ground walking in that it involves a quasi-periodic visual, auditory, and tactile sensory environment and is known to alter gait kinematics. For example, it reduces the natural variability of speed, stride length, and stride time (Frenkel-Toledo et al., 2005) observed in over-ground walking, likely affecting the temporal structure, mechanisms, and even likelihood of occurrence of interpersonal gait synchronization. Thus, quantitatively studying this phenomenon in natural over-ground walking is likely to yield different synchronization structures from treadmill walking and may more closely reflect the natural phenomenon. The aim of the current study is to evaluate interpersonal, unintentional gait synchronization of two people during natural over-ground walking and to evaluate the ability of each sensory modality to induce it.

Previous studies have demonstrated that healthy adults and different patient groups can match their gait rhythm to external cues, essentially synchronizing with the external source (Hausdorff et al., 2007; Roerdink, Lamoth, Kwakkel, van Wieringen, & Beek, 2007; Rubenstein, Giladi, & Hausdorff, 2002; Thaut et al., 1996; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2010).

Visual cues (e.g., stripes on the floor), auditory cues (e.g., a metronome, rhythmic music), tactile cues (e.g., vibration inside the shoe), and combined tactile/mechanical/proprioceptive cues (e.g., a treadmill) have successfully entrained the speed, stride length, or stride time of patients with Parkinson's disease (Hausdorff et al., 2007; Herman, Giladi, & Hausdorff, 2009; Herman, Mirelman, Giladi, Schweiger, & Hausdorff, 2010; Holt, Hamill, & Andres, 1990; Nieuwboer et al., 2007; Rochester et al., 2005; Rubenstein et al., 2002; van Wegen et al., 2006). In other words, visual, auditory and tactile cues can be used therapeutically to provide a pacemaker for walking, at least when one person is involved. Given that two people walking together can synchronize, the question is which, if any, of the cues known to be effective at entraining a single walker may be at work during the mutual synchronization of a pair of walkers.

The present study was designed, therefore, to address the following questions under natural, over-ground walking conditions: (1) Which sensory modalities may be utilized to achieve rhythm entrainment during side-by-side, over-ground walking? (2) Does the sensory modality affect the properties of the synchronized state? (3) Does the gait of synchronized walkers differ from that of unsynchronized walkers?

2. Methods

2.1. Subjects

Fourteen pairs of healthy young adults (mean age: 26 ± 2 yrs; $M \pm SD$) were studied. Subjects within each pair were matched for height (less than 3% difference; mean height: 175 ± 6 cm) and gender (2