Chapter 57
Gait Rhythm of Parkinson's Disease Patients and an Interpersonal Synchrony Emulation System based on Cooperative Gait

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ABSTRACT

Parkinson's disease (PD) and basal ganglia dysfunction impair movement timing, and this impairment leads to gait instability and falls. Gait disturbances of PD can occur in numerous ways, including festinating (accelerating) gait, slow shuffling gait, or highly variable random stride-timing. The authors' research group is studying an ambulatory assistive system that is based on the cooperative gait among human beings for locomotion rehabilitation. In this chapter, they introduce gait disturbances of PD, especially festinating gait, and they introduce an Interpersonal synchrony emulation system between a human and a virtual biped robot, which entrains the gait timings of the human and the robot in a cross-feedback manner by presenting auditory stimulation that indicates the timing of the partner's foot contact with the ground. In a pilot study that evaluated walking with the system, the festinating gaits of the PD patients were improved, and carry-over effects were observed. These results suggested that the interpersonal interaction seems to be effective for the welfare support of locomotive ability.

INTRODUCTION

Parkinson's disease (PD) is one of the neurodegenerative diseases of the substantia nigra. The disease decreases dopamine in the basal ganglia, which causes dysfunction of the basal ganglia and their associated networks (Alexander *et al.*, 1990; Alexander & Crutcher, 1990; DeLong, 1990). Human timing systems involve a distributed and interactive network that relies heavily on the basal ganglia (Buhusi & Meck, 2005). Impairments of the basal ganglia, such as those found in PD, lead to problems of movement timing and rhythm (Grahn & Brett, 2009; Graybiel, Aosaki, Flaherty, & Kimura, 1994; Schwartze, Keller, Patel, & Kotz, 2010). Gait timing disturbances in PD are highly debilitating, as they can lead to falls and reduced independence, and these disturbances can lead to associated problems of isolation, cognitive decline, and increased mortality (Hausdorff, 2009). These gait disturbances can occur in numerous ways, including festinating (accelerating) gait, slow shuffling gait, or highly variable stride-timing (Jankovic & Tolosa, 2006).

It is important to mitigate and to improve such disease symptoms because they decrease patients' quality of life. Treatments for locomotion disturbances include drug administration, deep brain stimulation, and behavioral therapy. Regarding drug treatments, dopaminergic medication is used successfully to treat the shortage of the dopamine neurotransmitter in PD. In deep brain stimulation, brain areas that are involved in PD and that relate to its symptoms are inactivated by placing electrodes, for example, in the globus pallidus. Behavioral therapy is applied to PD patients of various levels because this approach is a noninvasive therapeutic method that is employed without medication or surgery. The PD patients that suffer locomotion disorders often train their gait with caregivers.

Our research group is studying an ambulatory assistive technology by focusing on cooperative gait between human beings for locomotion reha-

bilitation. In this chapter, we introduce a method of gait assistance based on Interpersonal synchrony and the Interpersonal synchrony emulation system in implementing this concept. Moreover, we describe a pilot study that has shown the influence of the system on PD patients with festinating gait.

BACKGROUND

Gait rehabilitation is often performed by cooperating the step timing between a caregiver and the patient with the gait disturbance. One characteristic of such a process is to generate appropriate assistance relations in real time (Muto & Miyake, 2004). Our research group focuses on the process of generating the cooperative functions that are used in the interactions of gaits between humans.

Regarding interpersonal interactions, considerable research attention has been devoted to Interpersonal synchrony and to locomotive control (Condon & Sander, 1974; Ivanenko, Poppele, & Lacquaniti, 2007; Matarazzo, Saslow, Wiens, Weitman, & Allen, 1964; Nagaoka, Komori, & Yoshikawa, 2007). However, for their interactions, the interpersonal synchronization of stepping rhythms, which is widely observed in our daily life, remain relatively unexplored, despite being a common phenomenon that has considerable rehabilitation potential. Therefore, from the perspective of mutual entrainment (Kuramoto, 1984; Strogatz, 2003; Winfree, 1980) of gait rhythm (Muto & Miyake, 2004; Zivotofsky & Hausdorff, 2007), our research group has constructed an Interpersonal synchrony emulation system between a patient and a virtual biped robot that generates pacing signals using nonlinear oscillators (Miyake, 2009; Miyake, Miyagawa, & Tamura, 2004; Miyake & Shimizu, 1994; Miyake, Taga, Ohto, Yamaguchi, & Shimizu, 1994). This system entrains the gait timings of the human and the robot in a cross-feedback manner by presenting auditory stimulation that indicates the timing of the partner's foot contact

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