Entrainment of Gait Phase during Rhythmic Electrical Stimulation of the Gastrocnemius

Jenna E. Thorp
Department of Mechanical Engineering
University of Wisconsin-Madison
Madison, WI, USA
jlynne@wisc.edu

Peter G. Adamczyk
Faculty of Mechanical Engineering
University of Wisconsin-Madison
Madison, WI, USA
peter.adamczyk@wisc.edu

***Abstract*—This study investigated whether the human gait cycle spontaneously entrains to rhythmic electrical stimulation of the gastrocnemius muscle with phasing that aligns the stimuli with ankle push-off. Some, but not all, participants entrained their gait to the stimulation. In entrained trials, stimulus phase was near push-off or heel strike in both treadmill and overground walking trials, which coincided with increased Achilles tendon tension.**

Keywords—gait entrainment, electrical stimulation, tendon tensiometer

I. Introduction

Adding rhythmic bursts of ankle torque can influence gait timing while walking on a treadmill and during overground walking. When the perturbation period is close to the stride period, the gait entrains to the pulse rhythm, with phase alignment such that the torque adds to ankle push-off (roughly 50% of the gait cycle) [1]. Rhythmic electrical stimulation (RES) of the calf and hamstring muscles also causes some level of timing entrainment during treadmill walking [2]. This study investigated whether gait phase entrainment with biomechanically beneficial phasing can be elicited using RES of the plantarflexors during treadmill and overground walking. To determine whether entrainment was driven more by biomechanical benefits or by sensory cues, we measured the muscle force response to stimulation throughout the gait cycle.

II. Methods

A. Entrainment

Subjects walked on a treadmill and overground while RES was applied to the right gastrocnemius muscle. Subjects wore an inertial measurement unit (IMU) on each shoe to determine gait parameters [3]. Stimuli (350 µs pulses at 40 Hz for 0.1 s; RehaStim, Hasomed GmbH) were applied at each subject's natural stride frequency, determined from the first 10 s of each trial using IMU data. Stimulus amplitude was tuned to elicit ankle movement during quiet standing without causing pain. Motion and stimulation data were recorded synchronously, and the gait phase at which each stimulus occurred was determined relative to successive ipsilateral footfalls. A trial was considered entrained if it contained 20 successive strides with constant phase (+/- 3%).

B. Muscle Forces

In addition to wearing an IMU on each shoe, subjects wore a shear wave tensiometer (SWT) over their right Achilles tendon. SWT uses micron-scale taps and skin-mounted accelerometers to track shear wave propagation speed along the tendon during movement. Shear wave speed increases with the square root of axial stress in the tendon [4], thus giving an estimate of muscle force during gait. Stride frequency was determined from the first 10 s of trials and used to create an array of delay times. Electrical stimulation was applied throughout the gait cycle using the delay times and heel off detection from real-time IMU data. In total, eight times during stance and four times during swing phase were tested, with each repeated seven times.

III. Results and Discussion

A. Entrainment

Seven of eight treadmill subjects and four of six overground subjects showed gait phase entrainment to RES. A bimodal distribution of entrainment phase was seen in both conditions, both when considering all strides walked and entrained strides only (Fig 1). The dominant phase alignments corresponded to ankle push-off (biomechanically beneficial) and just before heel strike (as observed with auditory cueing [5]).

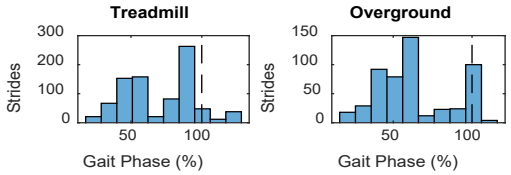

Fig. 1. Histogram of gait phase during entrained strides

B. Muscle Forces

Electrical stimulation applied just before push-off or heel strike led to an increase in shear wave speed shortly thereafter (Fig. 2). Entrainment around push-off suggests the additional force may be harnessed for biomechanical benefit.

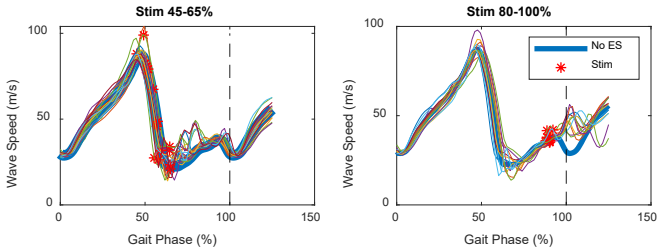

Fig. 2. Achilles tendon wave speed vs gait phase of electrical stimulation

References

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