Characterizing the relationship between step length asymmetry and metabolic rate during locomotion in post-stroke individuals

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I. Introduction

Each year, approximately 610,000 Americans suffer from a stroke for the first time [1]. Individuals suffering from chronic stroke consume more energy to walk compared to their able bodied counterparts [2]. Stroke often results in partial paralysis and gait impairments, reducing the survivor's mobility and quality of life. One gait deficit which some stroke survivors suffer from is asymmetric gaits. Clinicians seek to reduce gait asymmetry in individuals with chronic stroke in order to reduce loading on the unaffected limb and to improve mobility. Recent studies have examined various gait rehabilitation techniques to reduce gait asymmetry, but little work has been done to understand why individuals with chronic stroke walk with an asymmetric gait. Some stroke survivors are able to modulate their step lengths to walk symmetrically, but adopt an asymmetric gait when walking freely. Studies have shown that able-bodied individuals self-select a step length, frequency, and width to reduce their energy cost at different speeds [3]. Applying this finding to the stroke population, stroke survivors might self-select an asymmetric gait because it requires the least amount of metabolic energy. Understanding why some stroke survivors walk with an asymmetric gait could help with future developments in gait rehabilitation. The purpose of this study was to characterize the relationship between step length asymmetry and metabolic rate during walking in post-stroke individuals.

II. Methods

A. Participant Population

Four participants completed the study. All participants were chronic stroke survivors ($>$ 6 months) who met the following inclusion criteria: 1) walk unassisted, 2) history of only one previous stroke, 3) no neurological issues, and 4) BMI $\leq$ 30. Twelve potential participants were excluded from the study because they either were unable to modulate their step length asymmetry or they did not exhibit clinically significant step length asymmetry ($\geq$ 4%). Step length asymmetry was defined as (1)

$$SLA = \frac{SL_{paretic} - SL_{non-paretic}}{SL_{paretic} + SL_{non-paretic}} * 100\% \qquad (1)$$

where *SLA* is step length asymmetry and *SL* is the distance between the ankles of the leading and trailing legs.

B. Experimental Protocol

Participants were asked to modulate their step length asymmetry while walking on a treadmill. The step length asymmetry conditions were baseline asymmetry, zero asymmetry, and 2x asymmetry. The baseline asymmetry condition enforced each participants nominal asymmetry. The zero asymmetry condition enforced equal step lengths of the paretic and non-paretic legs. The 2x condition enforced step length asymmetry that was twice each participants baseline. The stride length was kept constant throughout all conditions. Each condition lasted for six minutes.

C. Visual Feedback

Visual feedback was provided to the participants to enforce the various step length asymmetry conditions. Participants were shown a screen in which a bar grew proportionally to how far their foot moved forward on the treadmill. They were instructed to initiate heel strike when the growing bar hit the virtual target.

1) Day 1: The first day consisted of selecting a speed and exposing the participants to the visual feedback. Participants were first asked to walk as far as they could in the hallway for six minutes to determine their average maximum speed, called the overground (OG) speed.

During the speed selection protocol, participants initially walked at 25% of their OG speed for three minutes to collect baseline heart rate and respiratory exchange ratio (RER) data. The treadmill speed was then continuously increased to 100% OG speed for the next three minutes. Finally, the participants walked at their OG speed for three minutes. If the participants' RER crossed into the anaerobic region or their heart rate exceeded 90% of their maximum, the speed selection protocol was stopped. The treadmill speed was selected as 75% of the maximum speed the participants could sustain while remaining in the aerobic respiration region.

The participants' walked for six minutes at the selected speed, and their baseline asymmetries were calculated. A presentation of the visual feedback system was given, and the participants were exposed to all three conditions for six minutes with rest periods in between each condition.

2) Day 2: On the second day, metabolic rate was measured for each of the different step length asymmetry conditions. First, basal metabolic rate was collected while subjects stood quietly for four minutes. Participants then walked with no visual feedback at the speed selected from the first day for six minutes to measure their baseline asymmetries and metabolic rates. The three conditions were then presented to the participants in a random order, and the first randomized condition was repeated at the end to account for learning effects. Participants were allowed to rest between each six minute trial. Metabolic rate was measured for all conditions.

III. Results

The average metabolic rate for the last three minutes of each condition was used to calculate the percent change in metabolic rate from the baseline asymmetry condition. A quadratic curve for percent change in metabolic rate was fit for the visual feedback conditions, excluding the first condition. The average step length asymmetry of the last three minutes for each condition was calculated (figure 1).

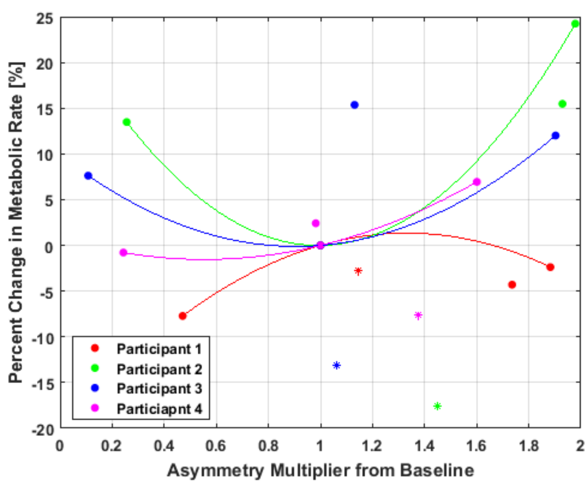

Fig. 1. Change in metabolic rate for each participant. The star marks the baseline with no visual feedback condition.

IV. Discussion

Participants 2 and 3 exhibited lower metabolic rates at their self-selected asymmetries. Participants 1 and 4 exhibited lower energy cost at asymmetries closer to zero than at their nominal asymmetry. These individuals also had smaller baseline asymmetries (9% and 10%, respectively) compared to participants 2 and 4 (24% and 19%, respectively). Participants 1 and 4 had small changes in metabolic rate, which could be due to variability in measuring metabolic rate. Of the subpopulation of chronic stroke individuals who are able to modulate their step length asymmetries, those who self-select larger asymmetries may select their most energy efficient gait. Additional participants are currently being tested to determine possible trends.

References

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