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Using swing resistance and assistance to improve gait symmetry in individuals post-stroke

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A major characteristic of hemiplegic gait observed in individuals post-stroke is spatial and temporal asymmetry, which may increase energy expenditure and the risk of falls. The purpose of this study was to examine the effects of swing resistance/assistance applied to the affected leg on gait symmetry in individuals post-stroke. We recruited 10 subjects with chronic stroke who demonstrated a shorter step length with their affected leg in comparison to the non-affected leg during walking. They participated in two test sessions for swing resistance and swing assistance, respectively. During the adaptation period, subjects counteracted the step length deviation caused by the applied swing resistance force, resulting in an aftereffect consisting of improved step length symmetry during the post-adaptation period. In contrast, subjects did not counteract step length deviation caused by swing assistance during adaptation period and produced no aftereffect during the post-adaptation period. Locomotor training with swing resistance applied to the affected leg may improve step length symmetry through error-based learning. Swing assistance reduces errors in step length during stepping; however, it is unclear whether this approach would improve step length symmetry. Results from this study may be used to develop training paradigms for improving gait symmetry of stroke survivors.

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1. Introduction

A major characteristic of hemiplegic gait observed in individuals post-stroke is spatial and temporal asymmetry (Patterson et al., 2008). An asymmetrical gait pattern may increase energy expenditure (Zamparo, Francescato, Luca, Lovati, & Prampera, 1995), increase the risk of falls (Di Fabio, Kurszewski, Jorgenson, & Kunz, 2004), and cause loss of bone density of the affected leg (Jørgensen, Crabtree, Reeve, & Jacobsen, 2000). These deficits can restrict functional mobility in individuals post-stroke and have a negative impact on the quality of life. Thus, restoration of gait symmetry is an important goal in stroke rehabilitation.

There is a growing interest in robotic-assisted gait training paradigms. Robots can generate external forces to alter abnormal gait patterns in individuals post-stroke, which is one benefit to this training approach. Previous findings have shown how individuals adapt to a force perturbation applied to the leg (Emken & Reinkensmeyer, 2005; Noble & Prentice, 2006; Savin, Tseng, & Morton, 2010). Initially, the perturbation deviates the leg trajectory away from the baseline, which creates movement errors. A few steps later, the leg trajectory goes back to the baseline as individuals learn to take into account the perturbation and correct the errors. When the force perturbation is removed, the leg trajectory skews to the *opposite* direction of the force perturbation (i.e., aftereffect). Studies have used this adaptation process to increase step length in humans with incomplete spinal cord injury (Houldin, Luttin, & Lam, 2011; Yen, Schmit, Landry, Roth, & Wu, 2012; Yen, Landry, & Wu, 2013) and individuals post-stroke (Savin, Tseng, Whitall, & Morton, 2013). Specifically, a resistance force was applied to a subject's leg to hinder leg swing during treadmill walking. When the force was removed, subjects demonstrated an aftereffect consisting of increased step length. However, for individuals post-stroke with a *longer* step length on the affected side at baseline, applying swing resistance force to the affected leg actually induced an increase in asymmetry after load release (Savin et al., 2013). Thus, we postulated that for individuals post-stroke with a *shorter* step length on the affected side (in comparison to the non-affected side) at baseline, applying swing resistance to the affected leg during motor adaptation may improve step length symmetry after load release.

In clinics, applying swing assistance to the affected leg, particularly for individuals with a shorter step length on the affected leg, as needed has been used to increase step length of the affected leg during locomotor training. In traditional robotic gait training, the function of the robot is to provide assistive force (as opposed to resistive force) to move the leg into a predetermined "normal" trajectory. However, because the direction of the aftereffect is in the opposite direction of the force perturbation (i.e., individuals may demonstrate a shorter step length after swing resistance is removed), the step length in individuals post-stroke could actually deviate further away from normal after removing the assistance.

This phenomenon has been shown in a previous adaptation study with individuals post-stroke using a split-belt treadmill paradigm (Reisman, Wityk, Silver, & Bastian, 2007). During the adaptation period, the two belts of the treadmill were moving at different speeds to induce a more symmetrical or asymmetrical gait pattern in individuals post-stroke. However, some subjects tended to adapt back to the baseline asymmetry later in the adaptation period, and show a deterioration in step length symmetry once the two belts of the treadmill were adjusted to move at the same speed during the post-adaptation period. Thus, we postulated that while the application of swing assistance to the affected leg for individuals post-stroke (with a shorter step length on the affected side at baseline), may improve step length symmetry during the adaptation period, it may actually have the opposite affect after the assistance load is released, leading to a greater deterioration in step length symmetry.

The purpose of this study was to examine how individuals post-stroke with a shorter step length on the affected leg adapt to robotic assistance and resistance forces applied to the affected leg during treadmill walking. We were particularly interested in this subgroup of individuals post-stroke, i.e., individuals with a shorter step length on the affected leg, because these individuals post-stroke generally have lower walking function (based on our unpublished clinical results), and may actually need more gait training to improve their walking function compared with higher functioning individuals post-stroke. We hypothesized that following the removal of a resistance force, these individuals post-stroke would produce an aftereffect consisting of an increase in step length of the affected leg,