Targeting specific muscles for rehabilitation with an EMG-controlled ankle-foot orthosis

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1 Motivation

In able-bodied individuals, the ankle provides more positive work during the stance phase of gait, especially at push-off, than both the knee and the hip [1]. Neurological injuries, such as stroke, weaken neural connections to distal muscles, specifically to those muscles which act about the ankle joint. The result is a reduction in the amount of positive work the ankle can provide [2]. Therefore, people having suffered a stroke or other neurological injury experience gait deficiencies [3], including decreased walking speed and step length, asymmetric gait, and, consequently, increased metabolic cost [4], which hinder everyday mobility and functionality.

To help stroke patients relearn "normal" gait patterns, rehabilitation techniques have been developed that require active engagement of the affected limb and weakened muscles. Ultimate goals of gait rehabilitation include providing long-term energetic benefits, reducing joint wear caused by abnormal gaits, and improving overall functionality and quality of life. We propose that a potential way to improve intervention outcomes is through the development of robotic rehabilitation devices that naturally induce active patient engagement.

2 State of the Art

One of the most common rehabilitation techniques in use is manual assistive therapy. Trained physical therapists assist in the movement of a patient's leg through a "normal" walking motion [5] and provide constant verbal feedback, motivating the patients to fight their natural tendencies and increase the use of their affected limb. This type of rehabilitation has proven to be effective at improving walking ability in post-stroke patients [6]. Manual assistive therapy, however, is expensive, thereby limiting the potential to achieve greater outcomes. Multiple trained physical therapists are needed to administer physically laborious rehabilitation sessions. This necessity restricts the duration and frequency of rehabilitation sessions an individual patient can undergo. However, in order to maximize the outcomes of rehabilitation, especially during the early stages of stroke, high intensity and continual rehabilitation sessions are important [7].

Robotic exoskeleton trainers have been developed to try to make rehabilitation more accessible and increase the duration and frequency of rehabilitation sessions [8]. These devices rigidly move the affected limb through a desired trajectory, regardless of the severity of the disability or the level of patient engagement. Although patients using these devices have shown improvements in walking performance, the improvements achievable with manual assistive therapy are much greater [9]. It seems that active engagement of the paretic limb is essential for rehabilitation techniques to be most effective.

3 Novel Approach

Physical therapists are much better at encouraging patients to actively engage their affected limb than current robotic devices. However, robotic devices have different capabilities and strengths than physical therapists, including direct measurement of the force or effort exerted by the affected limb, as well as the ability to provide repeatable assistance over long periods of time. Thus, instead of using robotic devices to try to take the place of physical therapists, we plan to utilize the strengths of robotic devices to try to develop new and more effective rehabilitation techniques.

Rather than forcing patients to actively engage their affected limb, we propose using robotic devices to harness and exploit natural tendencies, such as minimization of effort during locomotion, to achieve a voluntary increase in the use of the affected limb. We have developed a method to try to reward patients for actively engaging targeted muscles in the affected limb with assistance from a robotic device. We think this could result in an overall biomechanical benefit, making it advantageous for patients to use their affected limb instead of compensate with their unaffected limb.

4 Methods

We developed an ankle-foot orthosis (AFO) actuated by an off-board motor that is capable of providing assistive plantarflexor torque during stance, as a function of the ankle angle. We are able to vary the level of AFO assistance provided on each step.

We use muscle activity, measured using electromyography (EMG), to control the level of AFO assistance. We characterize the muscle activity for a single step with the root-mean-square (RMS) of the EMG signal. We select upper and lower RMS thresholds such that muscle activity at or above the upper threshold results in the maximum amount of assistance, while muscle activity at or below the lower threshold results in the minimum amount of assistance. RMS values that fall in between these two thresholds result in a proportional level of assistance.

Experimental Setup 1

In our first pilot test, an able-bodied subject walked on a treadmill with the AFO worn on the right (ipsilateral) leg (Figure 1). Soleus muscle activity of the left (contralateral) leg controlled the level of assistance provided by the AFO to the ipsilateral leg on the subsequent step. We varied the placement of the upper and lower RMS thresholds to try to understand the interaction taking place between the human and the assistive device on both the contralateral and ipsilateral limbs.

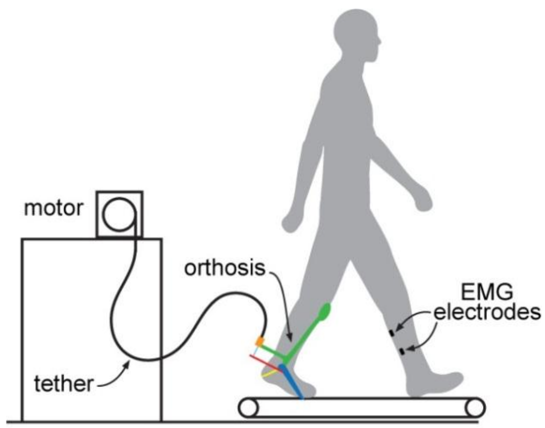

Figure 1 Depiction of experimental setup 1. An able-bodied subject walks on a treadmill with the AFO worn on the right leg. The AFO is attached to an off-board motor via a flexible tether. EMG electrodes on the contralateral limb measure soleus muscle activity for control of the assistance provided to the ipsilateral limb.

Experimental Setup 2

In our second pilot test, we simulated a gait deficiency for an able-bodied subject. We attached a spring to the right leg such that it provided dorsiflexion torques, consequently restricting plantarflexion. The AFO was worn on the leg with the artificial deficit. Soleus muscle activity from the ipsilateral limb was used to control the assistance level of the AFO. Increasing the use of the targeted muscle resulted in greater assistive plantarflexor torques from the AFO.

5 Preliminary Results

Preliminary results from running the first pilot test, where AFO assistance was controlled by the contralateral limb, are shown in Figure 2. During this trial, we applied a moving average to the level of assistance over ten steps.

We think that by imposing an artificial deficit in the second pilot test, the assistive torques provided by the AFO will be more beneficial to the subject, helping overcome the plantarflexion restriction. Therefore, it may prove to be advantageous for the subject to increase the activity of the ipsilateral soleus muscle in return for greater assistance.

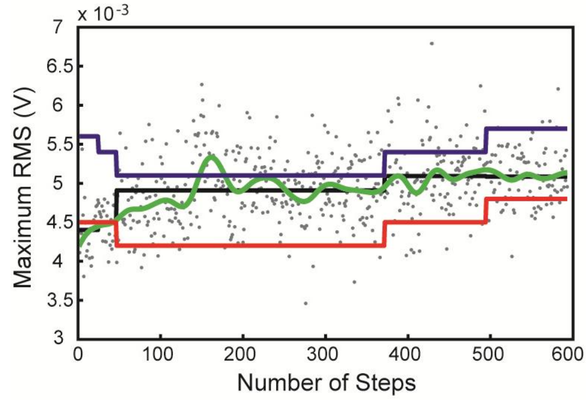

Figure 2 Preliminary data of soleus muscle activity of the contralateral limb during the first experiment (contralateral limb controls the level of assistance provided to the ipsilateral limb). The trial lasted 10 minutes. *Dots*, maximum RMS per step; *black line*, average RMS over constant condition; *green line*, filtered moving average of RMS over 10 steps; *red line*, lower threshold; *blue line*, upper threshold.

6 Open Questions

Will people realize the relationship between an increase in muscle use and the resulting increase in assistance? In addition, what are the critical factors (e.g. proximity of control muscle to assisted joint, placement of the thresholds, the number of steps averaged) that contribute to whether or not the relationship is realizable? If subjects realize this relationship, will they try to utilize the assistance to their advantage or reject it due to unpredictability?

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