Functional Electrical Stimulation (FES) of Ankle Muscles Moves Patients Towards the Decoupling of Lower-limb Muscle Modules for Individuals with Post-Stroke Gait

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Summary

We used Non-negative Matrix Factorization (NMF) to discover muscle modules (groups of co-activated muscles) of patients with post-stroke hemiparetic gait before and after gait retraining. Patients who have suffered a stroke often have an impaired gait due to the merging of these modules, which are distinct in healthy gait cycles [1]. We found that functional electrical stimulation (FES) gait treatment helped to initiate the decoupling of these merged modules in some patients. The patients that displayed evidence of early modular decoupling responded to treatment and increased their Trailing Limb Angle (TLA).

Introduction

In the US alone, nearly 800,000 people will experience a stroke each year [2] with approximately 80% of the survivors experiencing some form of one-sided weakness, or *hemiparesis* [3]. The propulsive force, or the posterior component of the ground force produced by the lower-limb during late stance, governs walking speed and is largely modulated by the TLA (defined as the angle between the lab vertical and vector between the femur origin and metatarsal phalangeal joint) [5]. This force is diminished in post-stroke gait, thus limiting survivors to a slower walking speed [4]. In addition to the TLA, muscle modules offer new insights for analysis and treatment of post-stroke gait. During healthy gait 4 modules, each contributing to a distinct biomechanical function, work to produce a smooth gait cycle [6]. In post-stroke gait, muscle modules become merged together so that the unique contribution of each is lost [1]. We hypothesize that the variance accounted for (VAF) in the activation pattern by the merged muscle modules will decrease following FES gait treatment, which is indicative of early modular decoupling. Our goal was to investigate the effects of FES gait treatment on the early modular decoupling and its relationship to improved TLA.

Methods

Eight patients (age 61 ± 8.2 years, 3 male, > 6 months post-stroke) with hemiparetic post-stroke gait were instructed to walk on a treadmill at a self-selected speed. Then for 12 weeks, patients trained with a combination of fast-treadmill walking and FES of the ankle muscles. Following treatment, patients were again instructed to walk at a self-selected speed on a treadmill. Each patient's post-treatment self-selected speed was compared to his/her pre-treatment self-selected speed, with responders categorized by an increased self-selected speed of at least 0.2 m/s following treatment [7].

For each patient, we scaled a generic musculoskeletal model with 23 degrees of freedom and 92 muscle-tendon actuators to represent the patient's size and mass using OpenSim. We used Computed Muscle Control to determine optimal muscle excitations over 210 gait cycles for all subjects (ranging from 10 – 14 per subject).

We used NMF used to discover each patient's muscle modules based on the activation patterns of 38 major lower-limb muscles (consistent with [1]). NMF generates an estimated signal of the activation pattern, and the accuracy of the estimated signal is measured by its VAF. We tested our hypothesis regarding decreased VAF of merged muscle modules following treatment with a right-tailed paired t-test at $\alpha = 0.05$.

We determined TLA at the instant that maximum propulsive force was produced before and after treatment.

Results and Discussion

For half of the patients, the VAF of merged muscle modules significantly decreased ($p = 0.0101$) following treatment (Table 1, gray shaded rows).

Table 1: NMF results and TLA values before and after FES treatment of patients with post-stroke gait. *responder, and ΔTLA > 0 indicates an *increase* in TLA following treatment.

Patient	Before treatment		After treatment		ΔTLA
	Modules	VAF (%)	Modules	VAF(%)	
1	2	98.0	1	96.2	< 0
2	3	96.8	3	97.7	< 0
3*	2	98.8	2	96.6	> 0
4*	2	98.9	1	95.6	> 0
5*	1	96.1	1	95.1	> 0
6*	1	96.4	1	95.4	> 0
7	1	96.2	1	96.3	< 0
8*	2	97.9	2	96.8	> 0

Conclusions

Our findings suggest that FES gait treatment of the paretic ankle muscles may aid in early decoupling of merged muscle modules of post-stroke gait. These results provide additional insights for developing individualized rehabilitation programs.

References

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