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ORIGINAL ARTICLE

Targeting Paretic Propulsion to Improve Poststroke Walking Function: A Preliminary Study

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Abstract

Objectives: To determine the feasibility and safety of implementing a 12-week locomotor intervention targeting paretic propulsion deficits during walking through the joining of 2 independent interventions, walking at maximal speed on a treadmill and functional electrical stimulation of the paretic ankle musculature (FastFES); to determine the effects of FastFES training on individual subjects; and to determine the influence of baseline impairment severity on treatment outcomes.

Design: Single group pre-post preliminary study investigating a novel locomotor intervention.

Setting: Research laboratory.

Participants: Individuals (N = 13) with locomotor deficits after stroke.

Intervention: FastFES training was provided for 12 weeks at a frequency of 3 sessions per week and 30 minutes per session.

Main Outcome Measures: Measures of gait mechanics, functional balance, short- and long-distance walking function, and self-perceived participation were collected at baseline, posttraining, and 3-month follow-up evaluations. Changes after treatment were assessed using pairwise comparisons and compared with known minimal clinically important differences or minimal detectable changes. Correlation analyses were run to determine the correlation between baseline clinical and biomechanical performance versus improvements in walking speed.

Results: Twelve of the 13 subjects that were recruited completed the training. Improvements in paretic propulsion were accompanied by improvements in functional balance, walking function, and self-perceived participation (each $P<.02$)—all of which were maintained at 3-month follow-up. Eleven of the 12 subjects achieved meaningful functional improvements. Baseline impairment was predictive of absolute, but not relative, functional change after training.

Conclusions: This report demonstrates the safety and feasibility of the FastFES intervention and supports further study of this promising locomotor intervention for persons poststroke.

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Despite an emphasis on walking recovery during poststroke rehabilitation, locomotor deficits[1-7] that contribute to limitations in activity and community participation persist for most patients.[8,9] A recent critical review by Dickstein et al[10] revealed comparable outcomes after current poststroke walking therapies and showed that all failed to improve most subjects' capacity for community ambulation, regardless of treatment mode or sophistication. Clearly, existing rehabilitation paradigms have failed to sufficiently address the factors limiting poststroke walking performance. Until recently, the clinical measures used to evaluate the recovery of walking performance after gait rehabilitation did not have the capacity to differentiate between the restoration of impaired neuromotor processes versus the strengthening of existing compensatory strategies.[11] Without an understanding of the changes underlying intervention-mediated improvements in walking function, the ability to target the specific deficits contributing to the reduced walking performance of individuals poststroke has been limited.[11,12] Recent advances in laboratory instrumentation have allowed a detailed

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quantification of treatment effects, providing a theoretical foundation from which locomotor therapies can be developed.[11] Herein, we report on the development, implementation, and success of a targeted intervention capable of modifying specific impairments known to limit the walking performance of individuals who have sustained a stroke.

For individuals with hemiparesis after stroke, decreased propulsive force generation by the paretic limb during walking has been identified through simulation and cross-sectional studies as a major contributor to walking dysfunction.[1,2,4,13-18] Furthermore, recent studies by Bowden et al[19] show that propulsion symmetry during walking is able to differentiate individuals as limited community versus community ambulators and that individuals who achieve clinically meaningful improvements in walking speed also improve propulsion symmetry.[20] Despite the strong evidence linking paretic propulsive ability to poststroke walking performance, large-scale investigation of interventions specifically designed to improve propulsion during walking are nonexistent.[10,21] Moreover, previous articles that have considered the effects of gait intervention on measures of paretic propulsion have failed to demonstrate significant changes in the paretic limb's capacity to generate propulsive force after intervention,[12,22,23] likely, as posited by Hall et al,[12] because of subjects using a variety of compensatory strategies during training. Therefore, it is currently unknown whether paretic propulsion is modifiable through intervention specifically targeting this impairment and whether such improvements would influence walking performance. In contrast with previous interventions, we developed an intervention specifically designed to improve poststroke walking ability through improvements in paretic propulsion.

An immediate increase in the activation of the paretic plantarflexors during walking is achievable through functional electrical stimulation (FES). However, the translation of increased plantarflexor muscle activation during FES into greater forward propulsion depends largely on the paretic limb's posterior position relative to the individual's center of mass during the double support phase of the paretic gait cycle.[16] Unfortunately, stroke survivors often do not achieve adequate paretic hip extension during walking.[7] However, walking at a faster speed is known to increase paretic hip extension,[24,25] effectively increasing the posterior placement of the paretic limb relative to the individual's center of mass during walking. Based on this framework, we hypothesized that an intervention combining walking at maximal speed on a treadmill and functional electrical stimulation of the paretic ankle musculature (FastFES) would maximize the translation of increased plantarflexor activity into forward propulsion, ultimately resulting in improved walking function. The FastFES intervention was thus conceived.

Contemporary concepts from multiple domains were integrated into the design of the FastFES locomotor program to maximize its effectiveness. The 12-week FastFES program follows principles of motor learning and neuroplasticity through massed stepping practice and task-specific training on both the treadmill and overground.[26] Alternating bouts of walking with and without FES are also included to enhance learning.[27] From a physiological perspective, FastFES incorporates stimulation patterns that better mimic the nervous system's activation of muscle (ie, variable-frequency train patterns), facilitating a more rapid rate of rise in force production[28] and yielding greater changes in walking kinematics[29] compared with traditionally used FES patterns in persons poststroke.

Prior to determining the effectiveness of the FastFES program through a randomized controlled trial, this preliminary investigation was undertaken to investigate whether improvements in paretic limb propulsion could be safely and feasibly achieved through a 12-week gait retraining program that joins walking at maximal speed with the application of FES to the paretic ankle musculature. Moreover, considering the heterogeneity of poststroke locomotor deficits, the clinical characteristics predictive of an appropriate candidate for this intervention are explored. Measurements across all levels of the World Health Organization's *International Classification of Function, Disability and Health*[30] are included in this article.

List of abbreviations:

FES	**functional electrical stimulation**
MWS	**maximal walking speed**
6MWT	**6-minute walk test**
SSWS	**self-selected walking speed**

Methods

Participants

Thirteen subjects (age, 61±8.3y; time since stroke, 3.22±3.05y; 7 men; 8 right hemiparetic) with poststroke hemiparesis participated in this study (table 1). Subject inclusion criteria included at least 6 months poststroke, ability to walk continuously for 5 minutes, and sufficient ankle passive range of motion to allow the paretic ankle joint to reach within 5° of the neutral position with the knee flexed. Exclusion criteria included evidence of moderate to severe chronic white matter disease on magnetic resonance imaging, >1 previous stroke, congestive heart failure, peripheral artery disease with claudication, uncontrolled diabetes, shortness of breath without exertion, unstable angina, resting heart rate outside of the 40 to 100 beats per minute range, resting blood pressure outside of the 90/60 to 170/90mmHg range, an inability to communicate with the investigators, pain in the lower limbs or spine, total knee replacement, cerebellar involvement, neglect (tested via the Star Cancellation Test[31]), and absence of sensation on the skin of the paretic calf or leg. All subjects completed a submaximal cardiac stress test to determine exercise safety prior to participation and signed informed consent forms approved by the University of Delaware Human Subjects Review Board. Results from each subject's cardiac stress test were used to calculate a target heart rate, which served as a maximum during training. The formula used was as follows: target heart rate = ([maximum heart rate − resting heart rate] × 70%) + resting heart rate.

Gait and clinical testing

Subjects completed biomechanical and clinical evaluations at baseline (pre), after 12 weeks of FastFES locomotor retraining (post), and 3 months after the completion of training (follow-up). Previous work has described in detail the methods used during this investigation.[32,33] Briefly, kinetic and kinematic data were collected via an 8-camera motion analysis system[a] as subjects walked at their self-selected speeds on a dual-belt treadmill instrumented with 2 independent 6 degree of freedom force platforms.[b] Data related to the paretic limb's capacity to generate propulsive force—the specific target of the FastFES intervention—were collected and served as the body structure and function variables of interest. These variables included the paretic propulsion integral, peak paretic propulsive force, propulsion

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