Mobile Unilateral Hip Flexion Exosuit Assistance for Overground Walking in Individuals Post-Stroke: A Case Series

Richard W. Nuckols, Franchino Porciuncula, Chih-Kang Chang, Teresa C. Baker, Dorothy Orzel, Asa Eckert-Erdheim, David Perry, Terry Ellis, Louis Awad, and Conor J. Walsh

***Abstract*— Stroke is a leading medical issue that can impact the person's ability to walk effectively. There is limited research into the design and biomechanical response for exosuits that assist more proximal joints such as the hip. For this case series, three subjects with chronic stroke participated in a single-session study to evaluate hip flexion exosuit assistance in overground walking. We iteratively tuned the unilateral hip flexion assistance profiles in overground gait. Compared to the initial unpowered baseline, walking speed at the end of tuning and with the device powered increased for 2 of 3 individuals and on average by 0.16 m s^{-1}. We then compared powered versus unpowered overground walking during a 5 minute evaluation period. Circumduction was reduced by 9 ± 1 mm and cost of transport was reduced by 8.6 ± 1.7% for the 3 participants.**

I. INTRODUCTION

Gait deficits following stroke can have varied effects on the joints of the paretic limb [1]. While much effort has focused on improving ankle function [2], the hip also provides important contributions to gait particularly in swing. In fact, for ground clearance during swing, hip flexion contribution to limb shortening is potentially more important than the contribution from ankle dorsiflexion [3]. Recently, there have been efforts to assist more proximal joints such as the hip during walking [4], [5], [6], but how exosuits can affect the mechanics of the hip and how best to apply assistance at the hip for individuals after stroke needs further understanding.

Our aim was to develop an initial prototype of a mobile soft hip flexion exosuit for individuals post-stroke. We started by first examining which biomechanical deficits may be addressed with a hip flexion system. Next, given the heterogeneity of post-stroke gait, we systematically tuned a hip flexion system to offset specific deficits and examined the exosuit-induced effects of the assistance on three individuals.

II. METHODS AND MATERIALS

Three subjects with chronic stroke (Table I) participated in this single-session study that included a familiarization/tuning phase followed by an evaluation phase. The hip exosuit used for preliminary investigation was adapted for unilateral hip flexion assistance from a device similar to what was shown in [7]. A hip mounted mobile actuator (2.6 kg) delivered an assistive force ranging from 60-100 N through a Bowden cable-driven transmission to anterior textile anchors on the waist and thigh. This force across the paretic hip textile components produced a flexion torque about the hip.

A. Familiarization and tuning

To gain familiarization with the hip exosuit, subjects were asked to walk at comfortable speeds in a 36.3 m oval indoor gait lab track with the exosuit providing assistance for a series (3-5) of 2 minutes bouts. Each participant started with a baseline assistance profile. Following each bout, the assistance profile was modified based on user and device performance. This iterative tuning process was based on:

1) Visual gait analysis [8] performed by a physical therapist to assess the individual's needs and understand how the hip flexion exosuit might augment the participant's gait.
2) Quantitative gait metrics generated from body-mounted IMUs complemented visual gait analysis, with summary reports after each bout that provided insights on hip exosuit-induced changes on gait [9].
3) Walking speeds during the 2-minute walk to assess whole-body response to exosuit assistance measured by a researcher following with a measuring wheel.

The "optimized" assistance profile was identified based on settings that provided fastest walking speed without clinical gait decline per quantified metrics and physical therapist observations.

B. Evaluation of Assistance: Five Minute Walk Tests

To evaluate hip exosuit-induced effects, we asked participants to walk for 5 minutes around the indoor gait lab track at comfortable walking speed under the following conditions: (a) hip exosuit powered on (Active), and (b) unpowered (Slack). We collected data on energy consumption of walking using a mobile metabolic system (Cosmed K5, Italy), and kinematic data using motion capture (Qualysis, Sweden). To examine within-subject changes between Active vs Slack, we used the Wilcoxon Exact test.

III. RESULTS

Relative to the initial unpowered baseline, walking speeds at the end of tuning with the device powered increased for 2 of 3 individuals and on average by 0.16 m s^{-1} (Subjects 1-3: 0.0, 0.33, 0.15 m s^{-1}, respectively). For the evaluation phase, Subjects 1, 2 and 3 were provided peak applied forces

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R. Nuckols, F. Porciuncula, C-K. Chang, A. Eckert-Erdheim, D. Orzel, D. Perry and C. J. Walsh (email: walsh@seas.harvard.edu) are with the School of Engineering and Applied Sciences at Harvard University, Cambridge, MA, USA.

T. C. Baker and T. Ellis, L. Awad are with the Department of Physical Therapy and Athletic Training, Sargent College, Boston University, Boston, MA, USA.

TABLE I

PARTICIPANT BASELINE CHARACTERISTICS AND GAIT PERFORMANCE

Subject	Age	Sex	Stroke Onset (months)	Paretic Side	Height (cm)	Weight (kg)	Device	Baseline Speed (m/s)
1	45	M	90	Left	179	100.5	AFO	1.05
2	60	M	92	Right	178	72.5	None	0.97
3	50	F	91	Right	166	60	None	1.35

of 83.7, 90.7, 63.5 N, with timing onsets at 40%, 23%, and 40% of the gait cycle, respectively (Fig. 1). For the Active condition, circumduction was reduced on average by 9 ± 1 mm (Subjects 1-3: 11, 7, 7 mm) compared to Slack. Only modest changes to walking speeds were observed in response to Active assistance (Subjects 1-3: 1.22 (+0.02), 1.24 (-0.04), 1.51 (+0.04) m s^{-1}). Reductions in cost of transport (walking efficiency) were observed in Active relative to Slack, with average reduction of 8.6±1.7% (Subjects 1-3: 6.4, 7.7, 10.4%).

Subject 1 responded with significant changes in various kinematic measures: increased ground clearance (2.2±.02 mm, $p<0.0001$), increased peak knee flexion angle (12.2±1 deg, $p<0.0001$), and decreased circumduction (11±5 mm, $p=0.0196$). Subject 2 demonstrated small reduction in circumduction ($p>0.05$), and Subject 3 had slight decrease in knee hyperextension during mid/ late stance (4 deg, $p>0.05$), however these were not statistically significant.

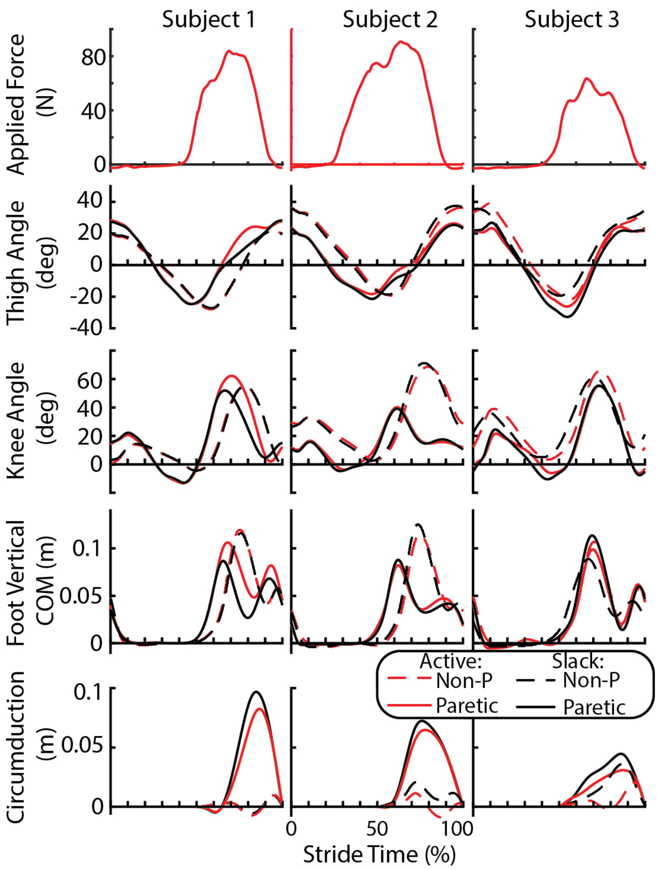

Fig. 1. Average stride biomechanical changes resulting from tuned hip flexion exosuit assistance.

IV. DISCUSSION

These results support the idea that users may respond to hip flexion assistance differently based on their specific gait deficits. Despite similar baseline kinematic deficits between subject 1 and 2, the effect of the assistance on the kinematics was different. While subject 1 seemed to use the assistance to correct gait kinematics, subject 2 kinematics did not change despite the large applied assistance force.

Although our approach of tuning did not result in faster walking speed in the evaluation phase, our limited data suggest that the tuning process resulted in a 0.16 m s^{-1} improvement in walking speed with the device powered compared to initial unpowered baseline. We were also able to elicit improvement in walking efficiency for each participant when walking with device powered versus unpowered, but we did not compare to a condition where the participant walked without a device.

V. CONCLUSIONS

This initial work suggests that individuals use unilateral hip flexion to improve walking efficiency through different biomechanical mechanisms. Additional work will need to dig deeper into these findings to understand how individuals effectively use the assistance and address additional metrics such as spatiotemporal parameters. Future work will also focus on developing a smaller and more lightweight system designed for the requirements of unilateral hip flexion support.

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