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Assisting Limb Advancement During Walking After Stroke Using a Wearable Soft Hip Exosuit: A Proof-of-Concept

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Abstract. Following stroke, altered gait biomechanics contribute to inefficient walking. Aside from assisting the ankle, there is also potential in augmenting locomotion by actuating the hip. We describe a proof-of-concept wearable, soft, hip exosuit, that assists with paretic hip flexion during late stance and swing phases. The exosuit allows for adjustment of force and timing parameters. Parameter tuning was guided by a physical therapist based on their observations during study sessions. In a sample of survivors of stroke, we demonstrated that the hip exosuit was able to deliver low, comfortable levels of hip flexion assistive forces. When powered, the exosuit effectively increased thigh angle and angular velocity during paretic swing phase compared to unpowered condition. These preliminary findings highlight the feasibility for clinicians to use a hip exosuit to directly target deficits in limb advancement in hemiparetic gait.

1 Introduction

Stroke gait is slow, asymmetric, and metabolically inefficient [1]. Motor deficits of hip flexors and ankle plantarflexors are known to contribute to impairments in gait speed and symmetry [2]. While several soft, modular, robotic systems seek to target the paretic ankle [3], actuating the hip may also augment locomotion in stroke. This study presents a proof-of-concept of a wearable exosuit that assists hip flexion during walking in chronic stroke survivors. The aim of the study was to examine the effect of a hip exosuit on limb advancement during walking guided by clinical observations of a physical therapist.

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2 Materials and Methods

2.1 Exosuit Hardware and Instrumentation

The hip exosuit [4] consisted of apparel-based waist and thigh components worn by the user (Fig. 1, left panel). Mechanical power was delivered to the paretic hip via Bowden cable-driven off-board actuation to textile anchors on anterior hip and thigh. The Bowden cable applies relatively low tensile forces (60–80 N) creating an assistive flexion torque (6–8 N • m) around the hip during the late stance and the swing phases of gait. We secured tri-axial inertial measurement units (IMUs) (XSens, Enschede, The Netherlands) on the user's thighs and ankles to determine gait events, and a load cell (LSB200, Futek Advanced Sensor, USA) mounted in series with the Bowden cable to measure applied force. Primary outcomes of interest included thigh angle and angular velocity.

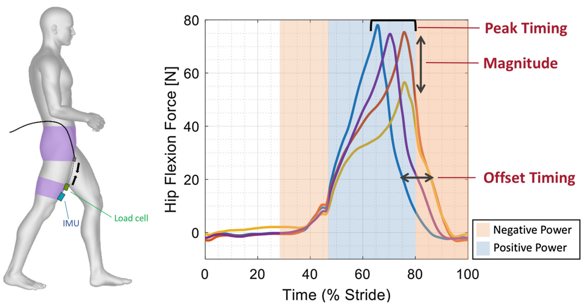

Fig. 1. Schematic diagram of hip exosuit (left). Adjustable assistive profiles allow change in parameters based on clinician-based tuning.

2.2 Control and Clinical Tuning

The initial onset timing of hip flexion assistance was determined by maximum hip extension as detected by thigh IMUs, which coincides with the switch of hip power from negative to positive. The assistive profile was tuned by adjusting force (magnitude) and timing (peak and offset) parameters (Fig. 1, right panel) by means of a force-based, position controller similar to [4]. The tuning process included a series of 3 to 5-minute bouts of treadmill walking per assistive profile. During tuning, clinical gait analysis was performed by a physical therapist, focusing on magnitude and timing characteristics of leg swing, limb symmetry, and overall stability. Observations drawn were used for iterative adjustment of individual parameters, implemented by controls engineers. Final selected parameters were based on assessment of physical therapist, together with suit-based data from IMUs and the load cell.

2.3 Walking Protocol

Using the clinician-selected parameters, participants were asked to walk on a treadmill for 5 min at their comfortable speed, under two conditions: (1) exosuit unpowered (Slack); and (2) exosuit powered (Active). Participants tolerated walking without holding the handrail during all conditions.

2.4 Subject Demographics

Table 1 summarizes subject characteristics. We studied three community-dwelling participants with chronic stroke. We excluded participants with other neurologic or orthopedic conditions. Our research protocol was approved by the Harvard Medical School IRB.

Table 1. Subject Characteristics

Subject	Age (yrs)	Sex	Paretic side	Stroke onset (yrs)	Type of stroke	Device	Activity
1	32	F	R	9.8	Hemorrhagic	AFO	Pre-conference Workshops
2	53	M	L	5.8	Ischemic	Cane	Conference
3	59	M	L	9.0	Hemorrhagic	None	Conference
							Conference

AFO: Ankle foot orthosis; yrs: years

3 Results

All participants tolerated walking with the hip exosuit without discomfort. For all subjects, as targeted, the thigh angle increased towards flexion during the swing phase (Fig. 2A), with the maximum thigh angles significantly increasing during Active compared to Slack (Subject 1: $t(47) = 61.4$, $p < .05$; Subject 2: $t(29) = 49.0$, $p < .05$; Subject 3: $t(39) = 17.1$, $p < .05$). Further, Subject 2 demonstrated an increase in thigh angle towards extension during late stance (Subject 2: $t(29) = 9.0$, $p < .05$), which may indicate a potential benefit on trailing limb angle. All subjects demonstrated increased thigh angular velocities towards flexion during swing (Fig. 2B), with peak angular velocities increased in Active compared to Slack conditions (Subject 1: $t(47) = -3.0$, $p < .05$; Subject 2: $t(29) = 23.9$, $p < .05$; Subject 3: $t(39) = 6.3$, $p < .05$). With the exosuit, thigh velocity profiles of paretic limb approached resemblance of the non-paretic limb especially for Subjects 1 and 2, thus suggesting the potential in improving symmetry in thigh velocity during walking in stroke.

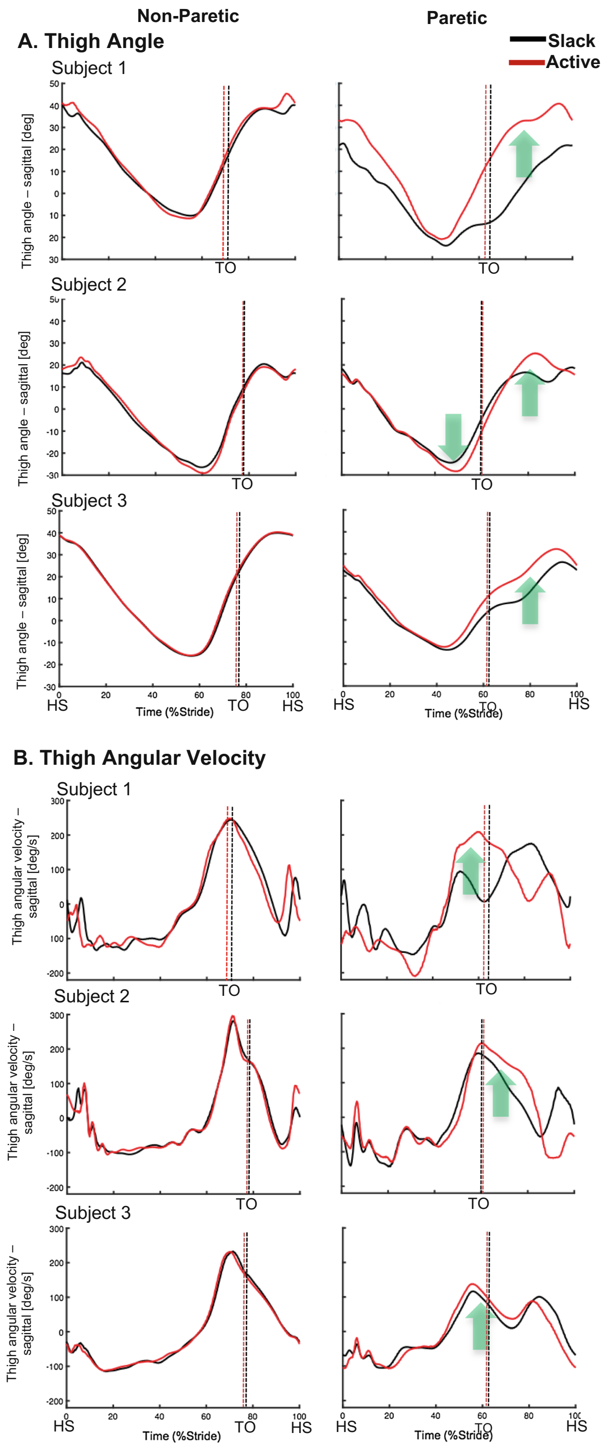

Fig. 2. Plots showing thigh (A) angle and (B) angular velocity during Slack (black) and Active (red) walking trials. Green arrows highlight the changes in angle and velocity. Gait cycle is segmented based on consecutive heel strikes (HS). Dashed, vertical lines indicate toe-off (TO).

4 Discussion and Conclusion

In this study, we demonstrated that a hip exosuit was capable of delivering hip flexion assistance during late stance and the swing phase of gait. Relatively low and comfortable force levels were sufficient to increase thigh angle and velocities, which are needed in promoting limb advancement. Finally, the determination of assistance parameters can be guided by observations of a physical therapist, thus offering the possibility of a robotic hip device that is feasible for clinic use. Future work is directed towards development of control algorithms to accommodate a range of gait presentations, and development of a compact, mobile unit for community use. In conclusion, this proof-of-concept demonstrates the ability of a soft hip exosuit in assisting paretic leg movements during walking in stroke survivors administered in a clinical context.

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