A USER-CONTROLLED POWERED ANKLE EXOSKELETON TO ASSIST GAIT PROPULSION POST-STROKE

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INTRODUCTION

The gait pattern of individuals with hemiplegia post- stroke is commonly associated with decreased ankle joint power generation in the affected limb [1] - likely contributing to an elevated metabolic cost [2] and a slower self-selected walking speed [1,2]. In healthy individuals, the ankle joint generates more mechanical energy than any other lower extremity joint [3] and plays a critical role in accelerating the body forward [4]. We anticipate, then, that restoring normal ankle mechanics in persons with stroke could greatly improve gait outcomes.

One potential solution may be to assist ankle plantarflexion via an externally powered exoskeleton. These devices have been shown to effectively reduce the metabolic cost of walking in healthy individuals by *replacing* a portion of the biological muscular work [3,4]. Yet, it is unknown whether these devices can *augment* ankle joint function in people with plantarflexion weakness due to stroke.

Here, we introduce a novel user-controlled ankle exoskeleton in which the *magnitude* and *timing* of mechanical actuation of an artificial muscle is dictated by both the user's own central nervous system (soleus electromyography [EMG]) and gait mechanics (anterior-posterior ground reaction force [AP-GRF]). We tested the feasibility of this powered exoskeleton to provide assistance to the paretic limb of a person with hemi-paretic stroke during treadmill walking.

METHODS

We recruited a stroke survivor (age 52, 1.72 m, 79.3 kg) with mild hemiparesis and medium gait impairment (preferred overgound walking speed = 0.72 m/s). The lightweight exoskeleton consisted of custom-fitted carbon fiber shank and foot components hinged at an ankle joint (mass=454 g). An artificial pneumatic muscle (length=16.5 cm) was attached along the posterior shank (moment arm=12 cm) to provide an assistive plantarflexion torque about the ankle.

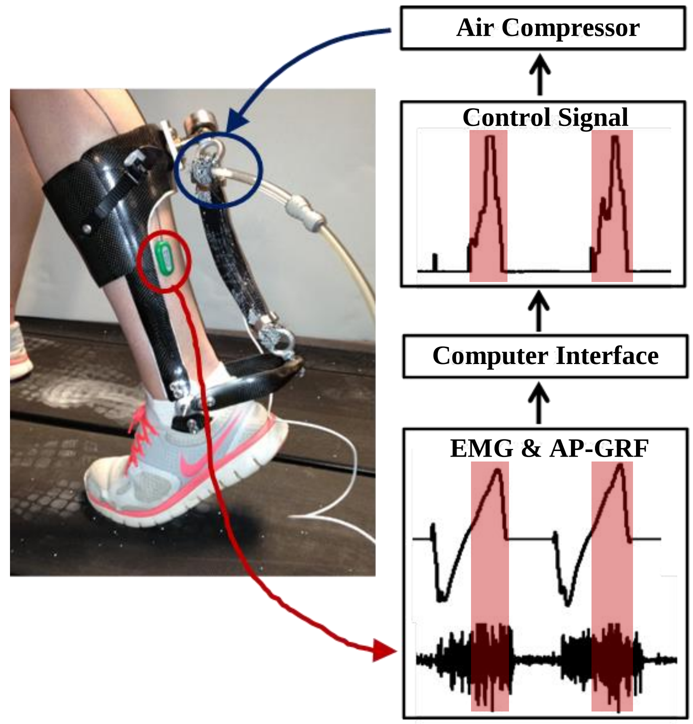

Figure 1: The soleus EMG and AP-GRF (from an instrumented treadmill) were collected in real-time to control the magnitude and timing of exoskeleton actuation. The *proportional myoelectric propulsion* (PMP) controller requires soleus EMG amplitude above a set threshold during the propulsive phase of stance, encouraging the user to activate the muscle to receive mechanical assistance.

To control the magnitude and timing of exoskeleton assistance, we collected and processed information from the subject's soleus EMG and the AP-GRF in real-time. We implemented *a proportional myoelectric propulsion* (PMP) control algorithm, in which the exoskeleton supplied assistance torque proportional to the soleus EMG signal *only* during the phase of stance when the AP-GRF was greater than 0 (Figure 1). In essence, the PMP controller strategically aims to augment the propulsive role of the ankle joint muscles under the user's volitional action.

The subject walked on an instrumented treadmill (Bertec, OH, USA) at 70% of the preferred overground walking speed (0.50 m/s), with and without exoskeleton power assistance (i.e., EXO and NoEXO conditions). Within a single data collection session, the subject completed a 5 minute trial of the NoEXO condition, and three repetitions of 5 minute trials of the EXO condition. We obtained measurements of lower extremity mechanics (using inverse dynamics), exoskeleton mechanics (using a compression load cell), and metabolic energy estimates (using indirect calorimetry). We compared the data from the NoEXO condition to the last repetition of the EXO condition.

RESULTS AND DISCUSSION

The magnitude of positive mechanical work done by the paretic ankle joint during the EXO condition was 118% greater than the NoEXO condition (0.074 J/kg versus 0.034 J/kg) (Figure 2). The exoskeleton accounted for 28% of the total ankle positive work during the EXO condition (0.021 J/kg). The average metabolic energy expenditure during the NoEXO and EXO conditions were 3.55 W/kg and 3.52 W/kg, respectively.

CONCLUSIONS

Over three 5 minute bouts of walking, a person with post-stroke hemiparesis demonstrated the ability to use the exoskeleton to increase ankle joint power generation during the propulsion phase of gait. With repeated training sessions, we expect to see further increases in ankle joint power output, an improvement in lower limb mechanical symmetry, and larger reductions in the metabolic cost of walking. We have on-going efforts to improve the PMP control algorithm, including optimizing the timing and magnitude of the exoskeleton actuation that is unique to a given individual's impairment.

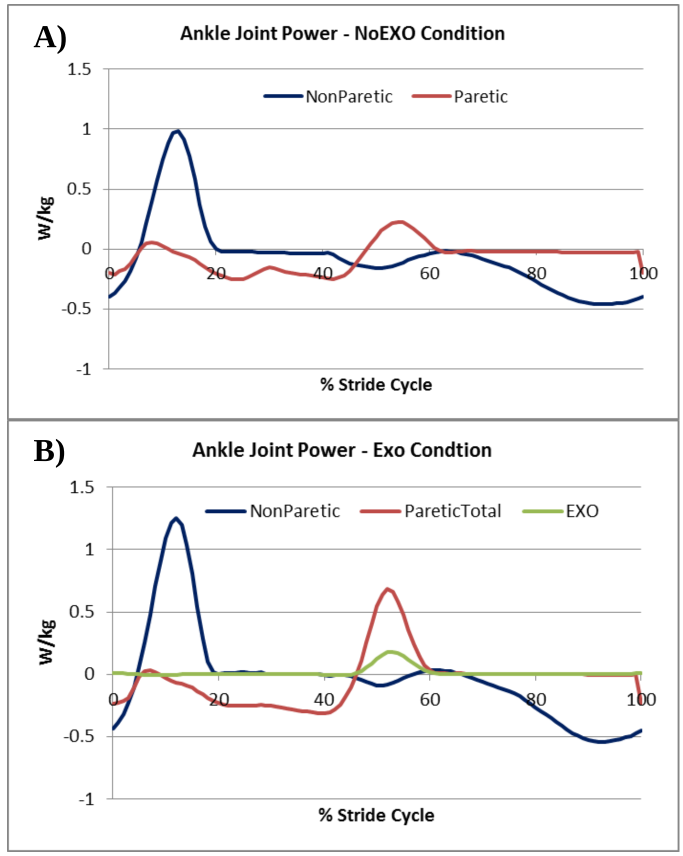

Figure 2: The total ankle joint power profiles during the NoEXO condition (A) and the last repetition of the EXO condition (B). The data were averaged from 10 consecutive steps obtained during the last minute of each condition. In the EXO condition, the total paretic ankle joint power (red) contains contributions from both the exoskeleton (green) and the biological muscles (not shown).

REFERENCES

1. Jonkers I et al. *Gait & Posture* 29, 129-137, 2009
2. Stoquart G et al. *Gait & Posture* 36, 409-413, 2012
3. Farris DJ and Sawicki GS. *J R Soc Interface* 9, 110-118.
4. Neptune RR et al. *J Biomech* 34, 1387-1398, 2001
5. Sawicki GS and Ferris DP. *J Exp Biol* 211, 1402-1413
6. Malcom P et al., *PLoS One* 8, e53137, 2013

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