

## **Research Report**

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**TITLE:** Soft Wearable Robots Can Reduce the Energy Cost of Poststroke Walking: A Proof-of-Concept Study

**PURPOSE/HYPOTHESIS:** Advances in exoskeleton technology<sup>1</sup> have made walking again following a major loss of neuromotor function—e.g., following a spinal cord injury—an achievable reality. However, for those that retain the ability to walk, such as the majority poststroke, rigid systems may not be practical nor appropriate as they require substantial power and induce a slow and inefficient gait. Indeed, metabolically-expensive gait asymmetries<sup>2</sup> resulting from impaired paretic limb function<sup>3</sup> contribute to an already high energy cost of poststroke walking (EC), and reducing EC may be necessary to increase walking activity and facilitate community participation<sup>4</sup>. This report presents the next generation of wearable robots, which are softer, more lightweight (~3kg), and require minimal power<sup>5</sup>. Integrated sensors also allow the measurement of key gait metrics in free-living settings, facilitating targeted interventions outside of the clinic. For this proof-of-concept study we hypothesized that these soft robots (exosuits) could produce improvements in EC<sup>6</sup>, step length symmetry (SS)<sup>2</sup>, and propulsion symmetry (PS)<sup>7</sup>, as well as accurately monitor gait parameters.

**SUBJECTS:** 4 subjects >6 months poststroke.

**MATERIALS/METHODS:** An exosuit designed to assist paretic ankle plantarflexion during stance phase and dorsiflexion during swing phase was tested. Assistance was tuned based on body weight and feedback from clinicians trained in gait analysis. The exosuit powered and unpowered conditions were tested on an instrumented treadmill at participants' overground comfortable walking speeds. EC, SS, and PS data were collected using a Cosmed K4b2 system and a 9-camera Vicon motion system. Changes in SS and PS were compared to known minimal detectable change scores (MDCs)<sup>8</sup>. Participants were also surveyed for their perception of the exosuit's effects. Specifically, the question, "compared to walking with no assistance, how did your walking feel in this trial?" was asked using an 11 point scale from -5 (much worse) to +5 (much better). Finally, the accuracy of the exosuit sensors was validated using Vicon data.

**RESULTS:** All 4 participants presented with a reduction in EC. The observed percent change from baseline for participant (P) 1 was 11%, P2: 7%, P3: 17%, and P4: 10%. All 4 participants also reported perceiving improvements in walking ability (P1: +3, P2: +2, P3: +5, P4: +5). Interestingly, only P3 and P4 presented with improvements larger than the MDC for SS (P3: 0.042 and P4: 0.056) or PS (P3: 13.9% and P4: 5.3%). Finally, strong agreement (<5% error) was observed between exosuit- and Vicon-measured temporal data.

**CONCLUSIONS:** Exosuits offer a new opportunity for assisting individuals who may not benefit from existing powered assistive devices. Future work will identify effective exosuit-based rehabilitation approaches and test feasibility and effectiveness in free-living settings.

**CLINICAL RELEVANCE:** The exosuit technology can enable physical therapists to target factors contributing to walking-related disability after stroke both in the clinic and directly in free-living settings.

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#### **REFERENCES:**

1. Chen G, Chan CK, Guo Z, Yu H. A review of lower extremity assistive robotic exoskeletons in rehabilitation therapy. *Critical reviews in biomedical engineering*. 2013;41(4-5):343–63.
2. Awad LN, Palmer JA, Pohlig RT, Binder-Macleod SA, Reisman DS. Walking speed and step length asymmetry modify the energy cost of walking after stroke. *Neurorehabilitation and neural repair*. 2015;29(5):416–23.
3. Stoquart G, Detrembleur C, Lejeune TM. The reasons why stroke patients expend so much energy to walk slowly. *Gait & posture*. 2012;36(3):409–13.
4. Franceschini M, Rampello A, Agosti M, Massucci M, Bovolenta F, Sale P. Walking performance: correlation between energy cost of walking and walking participation. new statistical approach concerning outcome measurement. *PloS one*. 2013;8(2):e56669.
5. Asbeck AT, De Rossi SMM, Holt KG, Walsh CJ. A biologically inspired soft exosuit for walking assistance. *The International Journal of Robotics Research*. 2015:1–19.
6. Reisman DS, Binder-MacLeod S, Farquhar WB. Changes in metabolic cost of transport following locomotor training poststroke. *Topics in stroke rehabilitation*. 2013;20(2):161–70.
7. Bowden MG, Balasubramanian CK, Neptune RR, Kautz SA. Anterior-posterior ground reaction forces as a measure of paretic leg contribution in hemiparetic walking. *Stroke: A Journal of Cerebral Circulation*. 2006;37:872–876.
8. Kesar TM, Binder-Macleod SA, Hicks GE, Reisman DS. Minimal detectable change for gait variables collected during treadmill walking in individuals post-stroke. *Gait & posture*. 2011;33(2):314–7.