AI SYSTEMS FOR IMPROVING BIOMECHANICS OF THE MOBILITY IMPAIRED WITH WEARABLE ROBOTS

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Introduction: Robotic prostheses and exoskeletons that can personalize assistance through adaptation are of great value for individuals with mobility challenges, such as those with amputation or stroke. Studies show mobility is strongly linked to quality of life, participation and depression, and these technologies have significant ability to enhance human ambulation, reduce fall risk, and improve overall quality of life [1]. Control systems are still unable to handle community ambulation due to the difficulty of creating ubiquitous controllers that can handle both a wide range of human users with varying mobility capabilities. However, AI systems offer new possibilities to create data-driven systems that enable generalization of controllers to novel users while also personalizing to individual capabilities.

In the first study, we test the hypothesis that a user-independent machine learning system can enable scaling of biomimetic assistance similar to able-bodied biomechanics by recognizing a wide range of speeds and inclines for individuals with transfemoral amputation using a robotic knee/ankle system. In the second study, we test the hypothesis that a deep learning system that co-adapts its performance in real-time with human gait can enable personalization of robotic hip exoskeleton assistance for individuals with stroke.

Methods: In the first study, we recruited N=11 individuals with transfemoral amputation to walk on our robotic knee/ankle prosthesis (Open Source Leg – OSL [2]) across multiple speeds and inclines/declines. We trained a machine learning system (XGBoost) to recognize speed and ground slope on a novel user (user-independent) and provide biomimetic assistance that scaled ankle push-off and knee assistance based on able-bodied biomechanics [3]. We tested this system compared to a user-dependent system in real-time (N=7) during which the ML system fully modified the biomechanics of the OSL based on estimated speed and slope. In the second study, participants (N=8 able bodied & N=6 stroke) wore our robotic hip exoskeleton where a deep learning system (CNN) adapted a gait phase estimation system over 10 iterations which increased the accuracy of providing biomimetic hip flexion and hip extension assistance. After adaptation, a validation trial was performed compared the adapted profile to a generic user-independent system [4].

Results & Discussion: In the first study, the user-independent system achieved < 0.1 m/s average error in estimating walking speed and < 1° average error in estimating ground slope in real-time tests which was comparable in accuracy to a fully user-dependent system (Fig. 1). These accuracy levels enabled accurate biomimetic torque scaling of a mid-level controller for the knee and ankle.

In the second study, we first demonstrate that robotic hip exoskeleton in able-bodied controls, where AI personalization (N=10) increased performance by 40.9% where performance was measured as our ability to provide the correct timing of torque assistance. We then tested the framework in real-time tests of the robotic hip exoskeleton in individuals with stroke (n=6) which naturally had much worse baseline performance in the user-independent system trained on able-bodied individuals. However, after our novel AI adaptation routine was applied, the system increased performance by 65.9% (Fig. 1) yielding nearly identical final results as the able-bodied cohort. This demonstrates the capability of an AI system to adapt to an individual user over time from a generalized user-independent system.

Significance: These two studies together indicate that AI technology combined with wearable robotics has the potential to generalize controllers to novel subjects while simultaneously co-adapting over time to personalize assistance automatically. These generalization and personalization properties of data-driven systems can help improve and normalize biomechanics in impaired populations.

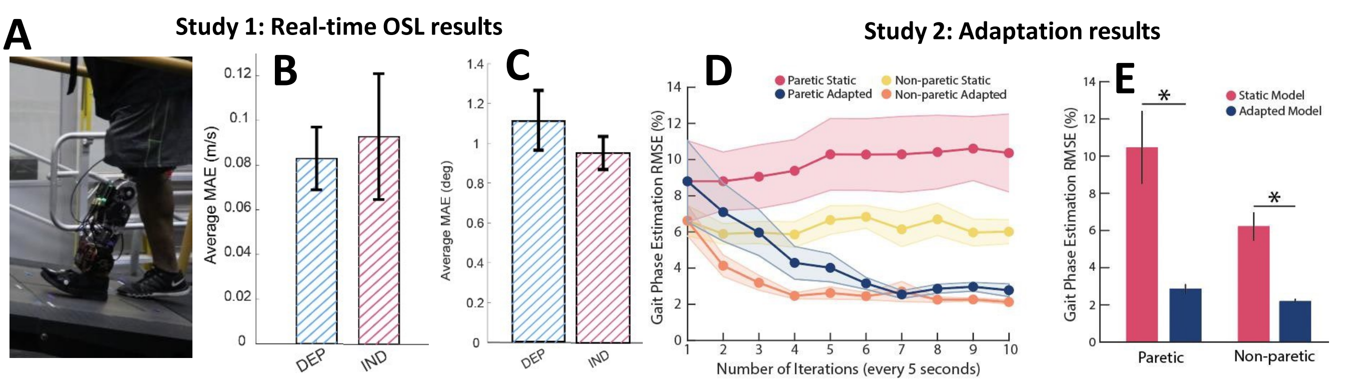

Figure 1: In the OSL study (A), N=7 individuals with TFA showed comparable performance with a user-independent (red) speed (B) and slope (C) ML estimation system for scaling biomimetic assistance compared to a user-dependent system (blue). In the stroke study, adaptation significantly improved gait phase estimation (D and E) on both paretic and non-paretic sides in N=6 individuals with stroke, but the magnitude of improvement was much greater for the paretic side.

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References: [1] Metz (2000), *Transport policy* 7(2); [2] Azocar et al. (2020) *Nature Biomedical*, 4(10); [3] Camargo et al. *Journal of Biomechanics* (2021) 119 (15); [4] Kang et al. (2021) *Robotics and Automation Letters* 6(2).