Getting ‘under the skin’ to examine how exoskeletons steer muscle dynamics during locomotion

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**Summary**

Exoskeletons are a class of wearable devices that attach to lower-limb joints and provide torque in parallel with biological muscle-tendons during locomotion. A primary goal of exoskeleton technology is to improve the economy of a given locomotion task, as measured by reduction in whole-body metabolic energy expenditure.

Conventional exoskeleton designs for improving ‘gas-mileage’ rely on motors to transfer net energy from machine to user with the intention of reducing net muscle work and thus, heat loss. But, in our view, this approach will inevitably reach a ceiling, where the energy losses associated with the mass and power consumption of the exoskeleton will outweigh the energy savings of the user.

Our design philosophy is that unpowered or minimally powered exoskeletons offer a streamlined way to modify limb-joint morphology in order to steer underling muscle behaviour, rather than transfer energy *per se.* Indeed, muscles consume energy to fuel force production, modify joint impedance for rejecting disturbances and contain the sensory organs that may be involved in feedback control and motor learning/adaptation during movement. Thus, in anticipation of the ‘diminishing returns’ from powered devices we have focused on developing unpowered systems, inspired by neuromechanical mechanisms borrowed from animals, including humans, that lead to economy during steady locomotion and stability in the face of perturbations.

A major challenge of the muscle-centric approach to exoskeleton design is that it is difficult to move top-down, ‘get under the skin’, and measure muscle neuromechanics in intact freely-moving humans - especially in the context of wearable devices. In this talk, I will outline our efforts to ‘steal a page’ from the field of comparative neuromechanics by merging *in silico* (simple models + computer simulations) and *in vitro/situ* (isolated muscle experiments) to take a ‘bottom-up’ approach to understanding the neuromechanical response to exoskeletons, one muscle-tendon at a time.

I will focus on two central questions: (i) How do exoskeletons improve economy of muscle force production? (ii) Can a passive, elastic exoskeleton improve the perturbation response of a muscle-tendon? Then I will preview a few new questions: (i) How do exoskeletons alter sensory feedback? (ii) What are the long-term effects of exoskeletons on structural properties of a muscle-tendon? (iii) Can exoskeletons improve economy of locomotion in deformable terrain? I will end by discussing our collaborative effort to develop a guinea fowl model of locomotion with a soft, elastic exosuit (i.e., exo-bird) and how it can enable integration of ‘bottom-up’ and ‘top-down’ approaches to understanding human-machine interaction in the ‘real-world’.