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Recent technological advances have enabled robotic exoskeletons to move from the realms of science fiction to the real world. Media outlets routinely herald new robotic exoskeletons such as Cyberdyne's HAL, Berkeley Bionics' BLEEX, and Sarcos' XOS. Honda has also come out with two exoskeleton designs, the Stride Management Assist and the Bodyweight Support Assist. These and other exoskeletons are being developed for performance augmentation of healthy individuals, assistive technology for mobility- impaired individuals, and therapeutic devices for individuals with neurological disabilities.

In spite of this rapid emergence of exoskeleton prototypes for assisting human locomotion, there are major obstacles to the effective implementation of robotic exoskeletons for improving human health. Exoskeletons have to work in cooperation with the biomechanics and physiology of the human body. Early results from exoskeleton studies indicate there is a great deal that we do not understand about human movement biomechanics. For example, clinical trials of neurological gait rehabilitation with exoskeletons have demonstrated that patients can become overly passive during therapy, relying on the exoskeleton mechanics and resulting in little motor re-learning. Other data indicate that neurologically intact subjects actually increase their metabolic cost of transport when walking with robotic exoskeletons due to perturbations in gait mechanics. **These specific examples highlight the broad conclusion that we have inadequate knowledge about how to coordinate mechanical power transfer between human and machine to facilitate human locomotor performance and motor learning.** If the principles governing motor learning during human locomotion are not known, how can we optimize control algorithms for exoskeletons to be used in neurological rehabilitation? If we don't know exactly how the metabolic cost of walking is affected by the biomechanical pattern of gait, how is it possible to use mechanical assistance to reduce locomotion energetics? Based on these observations, I recommend the following objectives.

Recommendation 1: Determine the principles governing how mechanical perturbations affect motor adaptation and learning during human locomotion.
Studies using robotic assistance and resistance of human upper limb movements have found that sometimes the nervous system adapts to a robotic interface as if it is an external tool to be manipulated while other times the nervous system adapts to a robotic interface as if it was a modification of body mechanical parameters. We need to understand how the nervous system responds to different types of mechanical assistance and resistance during human locomotion. We need to identify what promotes the fastest motor adaptation and learning. We also need to document the central and peripheral changes occurring in the nervous system in response to use of robotic exoskeletons.

Recommendation 2: Determine how the metabolic cost of transport and musculoskeletal mechanics are affected by different types of robotic gait assistance.
The relative metabolic cost of muscle activation and work during human locomotion need to be better identified. In patients with physical and neurological deficiencies, we need to understand how biomechanical characteristics of their gait pattern alter their metabolic cost of transport. This will allow better predictions to be made for different types of robotic exoskeleton assistance (e.g. hip vs. knee vs. ankle assistance, bodyweight support vs. acceleration). The biomechanical and metabolic effects of different types of robotic gait assistance need to be documented and placed into a large framework so that future robotic exoskeleton devices can be more successful.

As robotic technology continues to advance, there will be increased opportunities to use it for improving gait rehabilitation in individuals with mobility impairments. However, rather than relying on scattered trial and error attempts by various research groups building prototypes, we need to establish fundamental guidelines for effective mechanical energy transfer between human and machine.