The Relative Benefits of Work Assistance and Torque Assistance in Ankle Exoskeletons

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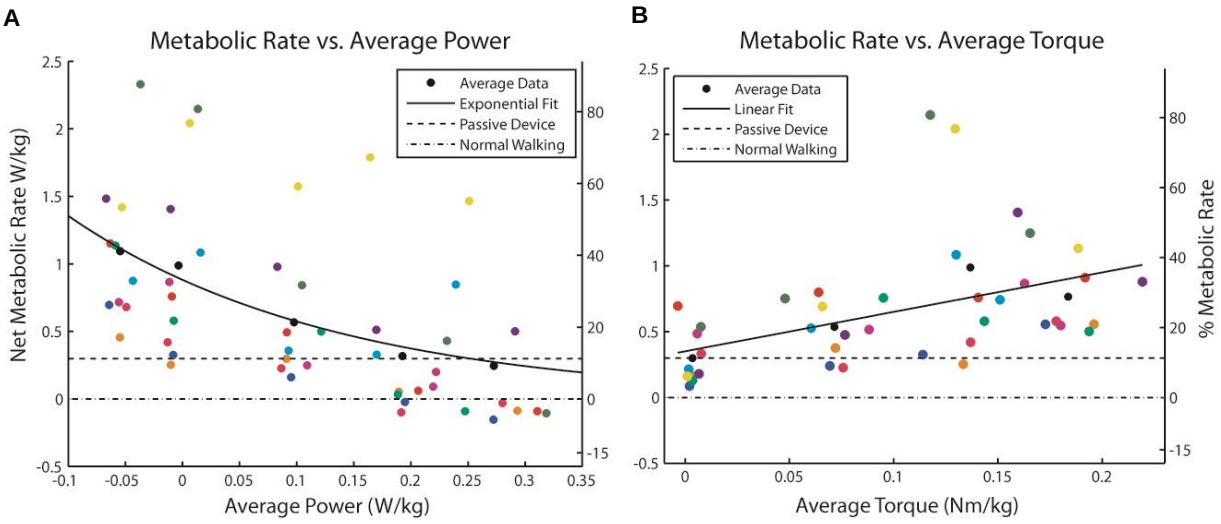
Many techniques have been proposed for assisting locomotion with ankle exoskeletons, most of which involve a combination of providing mechanical work and supporting joint torques. Actively powering ankle push-off may reduce metabolic energy costs associated with muscle work, e.g., for redirecting the body's center of mass. Applying torques in parallel to the ankle joint may reduce costs associated with muscle force production, e.g., for supporting body weight. These techniques have different implications for device design; work augmentation may require actuators, while torque support could be provided by purely elastic mechanisms. This study aims to characterize and compare the independent effects of work input and torque support on human performance during walking in order to guide effective device design.

We performed an experiment in which we first systematically varied net work while maintaining constant (moderate) average torque, then systematically varied average exoskeleton torque while maintaining constant (zero) net work. Work and torque were applied using a universal ankle-foot exoskeleton emulator [1] worn by healthy subjects (N=10) on one leg. We controlled the trajectory of an off-board motor such that work and torque at the ankle arose dynamically through interactions between the user, the device, a compliant series spring, and the motor. We used adaptive online control to maintain desired average work and torque values despite variability in subject kinematics. In order to make additional interesting comparisons, we included two baseline conditions, one in which the device was passive (zero work and torque) and one in which subjects wore street shoes.

As expected, independently increasing device work decreased metabolic rate (Figure 1a). For some subjects, high work input even reduced metabolic rate below that of normal walking, a barrier that has rarely been crossed. Surprisingly, increasing average exoskeleton torque, while maintaining zero net work, actually increased metabolic rate for this controller (Figure 1b). These results suggest that work input may be an important feature for ankle exoskeletons designed to make walking easier. We will discuss how these trends relate to changes in joint mechanics, muscle activation patterns, and muscle fascicle mechanics.



[1] Collins, S. H., Jackson, R. W. (2013) Inducing self-selected human engagement in robotic locomotion training. In Proceedings *International Conference on Rehabilitation Robotics* (ICORR), pages 1-6.