The effect of ankle-foot prosthesis push-off work on walking kinetics and overall effort

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People with lower limb amputation exhibit reduced walking economy and preferred speed compared to able-bodied individuals. Robotic devices show promise for restoring lost functionality and improving performance. Several robotic strategies have been explored, but it remains unclear why some approaches are more effective than others. We developed a universal ankle-foot prosthesis emulator that can quickly embody and evaluate an exceptionally broad range of candidate designs [1]. Active ankle push-off is a major feature of interest that conventional passive devices lack and which simple models of walking predict influences energy efficiency. Robotic ankle-foot prostheses can implement active push-off, typically they have targeted biological push-off, but it is unclear how to best deliver push-off to the user. We seek to understand the effect of ankle push-off on walking performance through experiments in which we vary push-off parameters and measure the human response. Here we explore the magnitude of ankle push-off work using able-bodied subjects wearing the prosthesis unilaterally via a simulator boot. Leveraging the versatility of the universal ankle-foot prosthesis emulator [1] a broad range of work was provided (Figure 1, from approximately -200 to 900% of the push-off work measured in normal walking trials). We found that metabolic energy consumption decreased with increased ankle push-off, initially along a linear prediction based on the mechanical efficiency of human muscle, and then with diminishing returns (Figure 1). Using center of mass work and inverse dynamics analyses, metabolic rate reductions seem to be primarily associated with reductions in positive work done by the prosthesis-side hip during push-off. The effectiveness of ankle push-off diminishes as prosthesis-side positive and negative knee work during push-off steadily increase and negative work at the hip appears in the highest work conditions. Contrary to predictions from simple models of human walking, ankle push-off does not seem to reduce energy consumption by reducing intact limb collision losses, though peak ground reaction force and knee torques are markedly reduced with increased push-off work. These results suggest that robotic ankle-foot prostheses which provide push-off work in excess of the magnitude observed in able-bodied normal walking may benefit amputee walking efficiency.

[1] Caputo, J. M., Collins, S. H. (2013) A universal ankle-foot prosthesis emulator for experiments during human locomotion. *J. Biomech. Eng.*, **accepted**.