Modulating prosthetic ankle push-off work at each step may reduce balancing effort during walking for unilateral transtibial amputees

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A balance restoring effort is required to maintain stable walking in the presence of a disturbance. This effort is often associated with increased metabolic energy and step width variability. Step width is primarily controlled by the hip joint, an important balancing resource. However individuals with below-knee amputations exhibit reduced stability, despite retaining normal hip function. This deficit could be explained by the lack of ankle actuation.

In this study, we investigated whether varying the magnitude of ankle push-off work at each step could influence an individual's balancing effort. We hypothesized that an ankle-foot prosthesis could stabilize and destabilize gait by providing a controlled magnitude of ankle push-off work at each step. Ankle push-off work was calculated by multiplying a gain by the lateral velocity difference between the nominal and measured velocities. Walking experiments were conducted in healthy young adults (N=10) with two stabilizing controllers (low and high gain), two destabilizing controllers (converse of stabilizing controllers), and no control under a random landing-foot-angle disturbance. We also hypothesized that an individual would not be able to adapt to randomly given push-off work without directed control. Thus, we included a step-to-step random push-off work condition (without any landing angle disturbance). Throughout all the conditions, average push-off work was maintained using an adaptive algorithm.

We considered that at least one of the following could indicate balancing effort: metabolic energy, step-width variability, average step-width, center-of-pressure (CoP) variability, cognitive effort, and user preference. We found that directed ankle push-off work affected the metabolic energy ($p<0.01$) and step-width variability ($p<0.05$) amongst all the conditions (Fig 1) as well as the average step-width ($p<0.05$) and CoP variability ($p<0.05$) between the no-control and stabilizing controller conditions. However, cognitive effort ($p>0.4$) and user preference ($p>0.4$) were not significantly affected. Random push-off work increased metabolic energy expenditure by 7% ($p<0.05$) and negatively affected user preference ($p<0.05$) compared to the no control.

In conclusion, we demonstrated that balancing effort could be reduced by favorably controlling the magnitude of ankle push-off work at each step. In the future, we hope that this control strategy could be implemented in ankle-foot assistive devices to help maintain user stability.

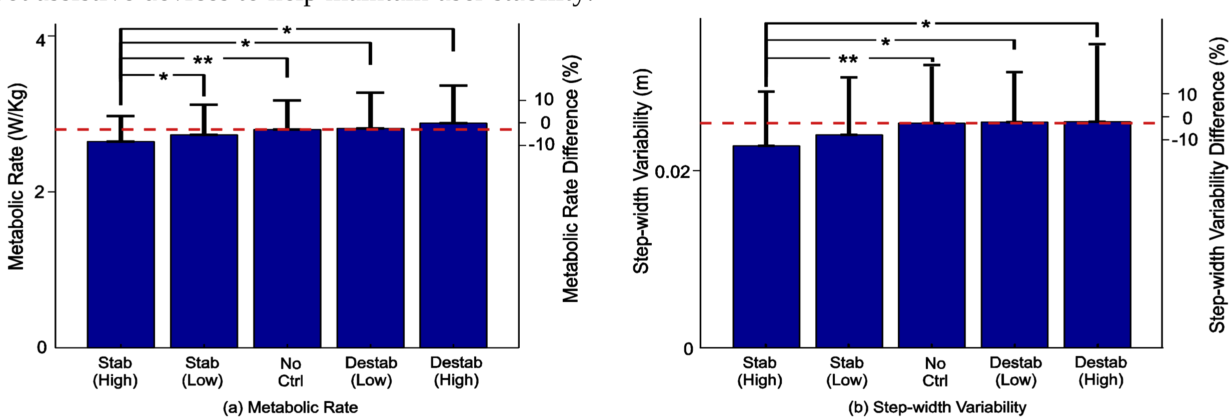

Fig 1. Metabolic rate (a) and step-width variability (b) during cognitive test period. The stabilizing controller reduced metabolic rate and step width variability. (Stab: stabilizing controller, Destab: destabilizing controller, *: $p<0.05$, **: $p<0.01$)

Reference

O'Connor et al, (2012) Energetic cost of walking with increased step variability. Gait Posture 36: 102–107.