Quantifying the Relationship Between Prosthesis Work and Metabolic Rate

Joshua M. Caputo and Steven H. Collins
Department of Mechanical Engineering, Carnegie Mellon University, Pittsburgh, PA, USA
email: stevecollins@cmu.edu, web: biomechatronics.cit.cmu.edu

1. Motivation

Powered ankle-foot prostheses can increase preferred walking speed and reduce metabolic rate as compared to conventional passive-elastic devices [1]. In these devices, motors and batteries are typically used to provide net positive work; to increase net work requires an increase in device mass [2]. Added mass to the lower limbs increases metabolic rate [3], so a design tradeoff between assistive power and mass must be made. Quantifying the relationship between prosthesis work and metabolic rate would enable design choices that provide the most benefit for the user.

2. State of the Art

Robotic prostheses have typically used the behavior of the human ankle as a template, targeting 0.1 $W{\cdot}kg^{-1}$ of net ankle power (net work per stride divided by stride time) at speeds of 1.25 $m{\cdot}s^{-1}$ [1, 4]. These devices suggest that providing powered prosthetic ankle control is beneficial, but it is not clear if mimicking the biological ankle will minimize metabolic rate.

3. Own Approach

We used an ankle-foot prosthesis testbed [5] to systematically vary ankle push-off across a broad range while measuring human biomechanical response. We defined net prosthesis power as positive work minus negative work per stride divided by stride time. Negative work behavior was held constant across conditions. We targeted net prosthesis power values ranging from -1 to 3 times the values observed at the human ankle joint, which we expected to include the value corresponding to optimal assistance. We measured human metabolic rate using indirect respirometry, and performed a second order fit to prosthesis power for each subject. Fit order was chosen based on predictions from simple dynamical models of gait. The metabolic rate corresponding to zero prosthesis power was then removed to estimate of the energetic effects of deviation from passive prosthesis behavior. Data for all subjects were then combined and fit. Finally, the implied cost of added mass was estimated.

4. Current Results

Results (N=4, 1.8m, 82.0kg, 28.5yrs.) show decreasing metabolic rate with increasing prosthesis power (Fig. 1). It appears that the optimal value of push-off work is greater than the range tested here and several times greater than the values targeted in current robotic prostheses, even when accounting for the implied costs of motors and batteries.

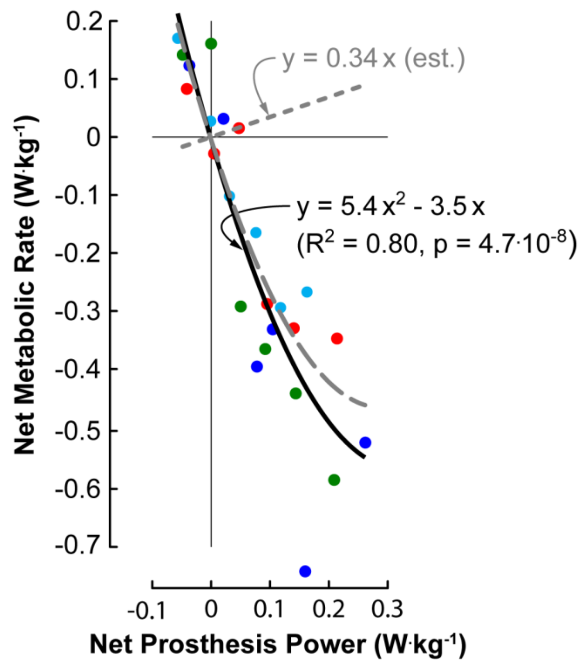

Fig. 1: Net metabolic rate vs. net prosthesis power.

5. Best Possible Outcome

Quantitative characterization of the human response to key aspects of robotic device functionality will create the foundation for rational choices in the design of prosthetic limbs. This framework will also enable customization for individual users.

References

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