RELATIONSHIP BETWEEN PUSH-OFF WORK AND STRIDE-TO-STRIDE FLUCTUATIONS IN TRANSTIBIAL PROSTHESIS USERS

[1] Chase G. Rock, [2] Shane R. Wurdeman, [1] Nicholas Stergiou, and [1]Kota Z. Takahashi

[1] Department of Biomechanics, University of Nebraska at Omaha, Omaha, NE, USA
[2] Hanger Clinic, Houston Medical Center, Houston, TX, USA
email: crock@unomaha.edu

INTRODUCTION

Variability during locomotion is an important marker of human health [1]. Specifically, the pattern of limb movement across many consecutive strides presents subtle fluctuations that vary across time. These stride-to-stride fluctuations resemble a highly structured organization that is characteristic of healthy gait [1]. This organization is disturbed in lower-limb prosthesis users, who display different stride-to-stride fluctuations than their anatomically intact counterparts [2]. The factors contributing to this difference are difficult to identify, as stride-to-stride fluctuations are the end result of the neuromuscular control system interacting with an external device (i.e. prosthesis).

Stride-to-stride fluctuations may be largely influenced by the mechanics of the limb. For example, Kurz and Stergiou used a passive walking model to show that stride-to-stride fluctuations are related to the magnitude of propulsive (push-off) force [3]. Push-off impairment is common in persons with transtibial amputation [4], suggesting that abnormal stride-to-stride fluctuations in these individuals could be related to the prosthetic mechanical characteristics (i.e., energy storage and return).

Our purpose was to determine the relationship between changes in prosthetic mechanics and stride-to-stride fluctuations. We examined individuals that wore two types of prostheses that were expected to exhibit disparate profiles of energy storage and return. We hypothesized that: 1) Push-off work will increase from ‘low activity’ to ‘high activity’ prostheses, 2) stride-to-stride fluctuations will change from the low activity to high activity prostheses, 3) increases in push-off work between prostheses will be correlated with changes in stride-to-stride fluctuations.

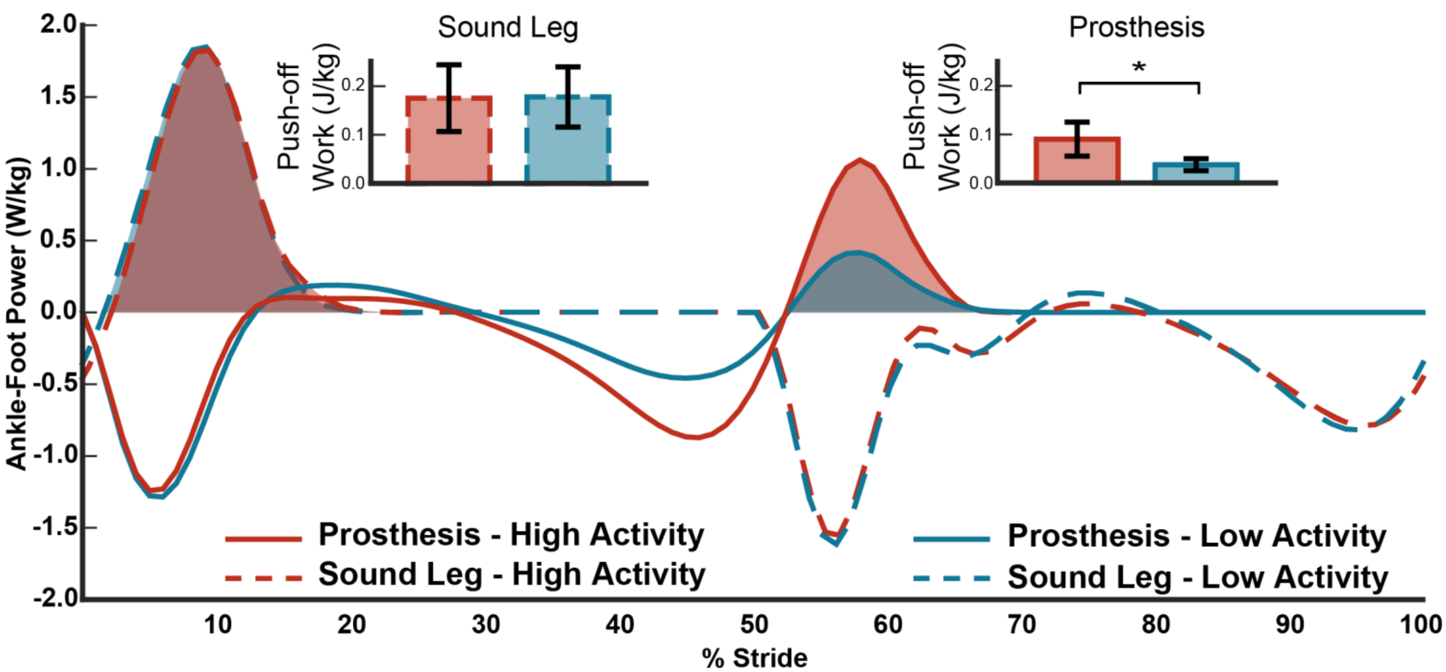

Figure 1: Push-off work increased from the low to high activity prosthesis. * indicates $p < 0.001$

METHODS

Twenty-two participants with transtibial amputation were recruited to a 6-week cross-over design study. At their initial visit, participants were fitted with a new prosthesis and allowed a 3- week adaptation period, after which they were fitted with a second prosthesis and allowed another 3-week adaptation period. The prostheses were classified as ‘high activity’ or ‘low activity’ according to the Medicare Functional Classification Level. Data collections were performed each week, where the participants walked on a treadmill as well as overground. Data presented here are from the third week of the adaptation period.

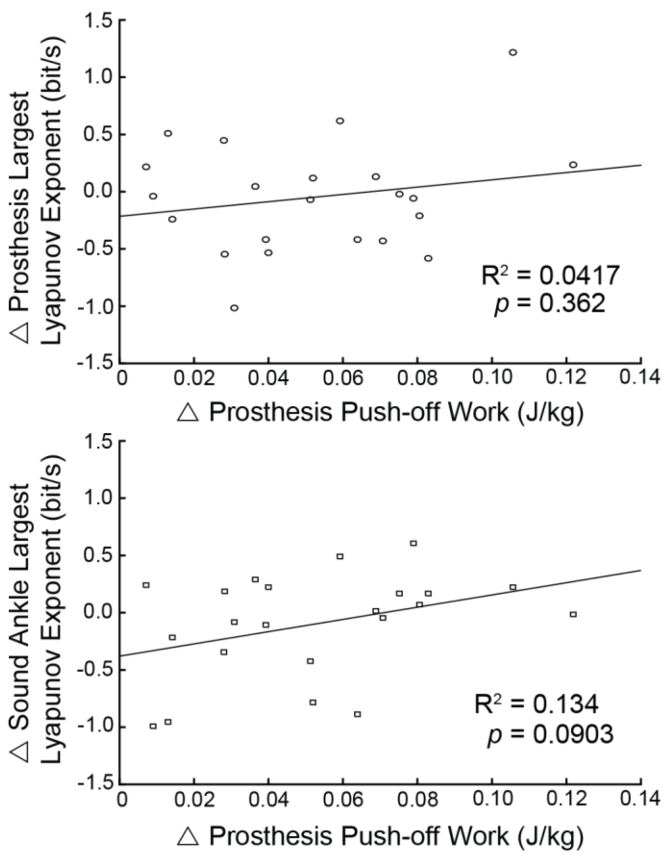

Figure 2: No correlation was found between changes in prosthesis push-off work and largest Lyapunov exponent of the prosthesis or sound ankle (Δ = High Activity minus Low Activity prostheses).

Total power of the prosthetic device, as well as total ankle-foot power of the intact limb were quantified using the unified deformable segment analysis [5]. Positive push-off work was calculated by integrating the positive power during late stance (Fig. 1, shaded regions). A paired t-test was used to compare push-off work between prostheses. The largest Lyapunov exponent was used to quantify the pattern of stride-to-stride fluctuations at the prosthesis and sound ankle joint [2]. A paired t-test was used to compare largest Lyapunov exponent between prosthetic conditions. A linear regression was used to determine the relationship between changes in the largest Lyapunov exponent and push-off work between prostheses.

RESULTS AND DISCUSSION

For the prosthetic leg, push-off work was 140% greater in the high activity prosthesis compare to the low activity prosthesis ($p < 0.001$). In the sound leg, no significant changes were observed in push-off work ($p = 0.576$; Fig. 1).

No significant changes in stride-to-stride fluctuations at the ankle were observed between the prosthetic conditions, including the prosthetic ($p = 0.652$) and the sound ankle ($p = 0.325$). There was no significant correlation between changes in prosthetic push-off work and largest Lyapunov exponent (Fig. 2).

CONCLUSIONS

We found a substantial change in push-off work between two types of prostheses, which emphasizes the importance of appropriate prosthesis prescription. The lack of change in gait variability may indicate that the user is able to adapt to a new prosthesis within three weeks’ time. The stride-to-stride fluctuations in prosthesis users may be influenced by factors other than prosthesis mechanics, such as the neuromuscular control of the user.

ACKNOWLEDGEMENTS
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REFERENCES

1. Stergiou, N, et al. *Hum Mov Sci* **30**, 869-888, 2011
2. Wurdeman SR, et al. *PLoS ONE* **9**, 2014.
3. Kurz MJ, et al. *J Neuroeng Rehabil* **4,** 2007
4. Adamczyk PG, et al. *IEEE Trans. Neural Syst. Rehabil. Eng* **23,** 2015
5. Takahashi KZ, et al. *J Biomech* **45**, 2662-2667, 2012.