

A biomechanical analysis of adaptive assistance strategy for uphill walking using a powered hip exoskeleton

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Introduction

Over the last decade, research groups have explored methods to optimize different assistance strategies to maximize the human-exoskeleton performance in different environmental settings¹. However, these studies were often conducted at a specific condition and did not capture what a user would experience in a realistic setting. Our previous study indicates that, for a given environmental setting, there is an optimal assistance to maximize the energetic benefit of using an exoskeleton². To maintain an optimal control strategy for dynamic settings, the effect of adapting exoskeleton assistance across different locomotion intensities needs to be investigated. We utilized a powered hip exoskeleton to evaluate the biomechanical effect of applying adaptive assistance during uphill walking. Our hypothesis is that providing hip assistance during uphill walking that scales relative to the degree of incline will have a greater reduction in the corresponding electromyography (EMG) activation compared to the static assistance strategy.

Methods

One able-bodied subject participated in an IRB approved experiment walking with a preferred walking speed on a height adjustable ramp in four different inclines (7.79°, 9.21°, 10.99°, and 12.42°) while wearing a powered hip exoskeleton (Fig. 1A). Our exoskeleton utilized a state machine-based torque controller providing a hip flexion/extension torque during the region where the corresponding biological hip moment is exhibited. Three exoskeleton conditions were tested: 1) scaling hip extension assistance magnitude relative to inclines, 2) static hip extension assistance across all inclines, and 3) no assistance (exoskeleton controlled to be transparent to the user's movement). Each condition at a given incline consisted of 8 trials of uphill walking. For both scaled and static assistance, flexion assistance magnitude was set constant. We utilized the biological hip moment data during ramp ascent to compute the desired hip extension assistance magnitude (20% of the user's biological hip moment) for different inclines for the scaled assistance condition³. For the static assistance condition, we computed the assistance magnitude to be nominal to the scaled assistance across all inclines. During the experiment, we collected motion capture data to analyze the user's kinematic data, instrumented force plate on the ramp for the ground reaction force data, exoskeleton data including the measured joint torque, and EMG data from the user's hip flexor and extensor region.

Results and Discussion

Overall, our exoskeleton's hip extension assistance (for both controllers) was able to alleviate the corresponding biological demand from the user via reduction in joint moment and EMG activation. While our study is preliminary (N=1), biomechanical benefits of using our assistance strategy were consistent across trials. Across all inclines, scaled and static controllers reduced the average maximum biological hip extension moment (Fig. 1B) by $8.84 \pm 2.94\%$ and $4.66 \pm 1.30\%$, compared to no assistance

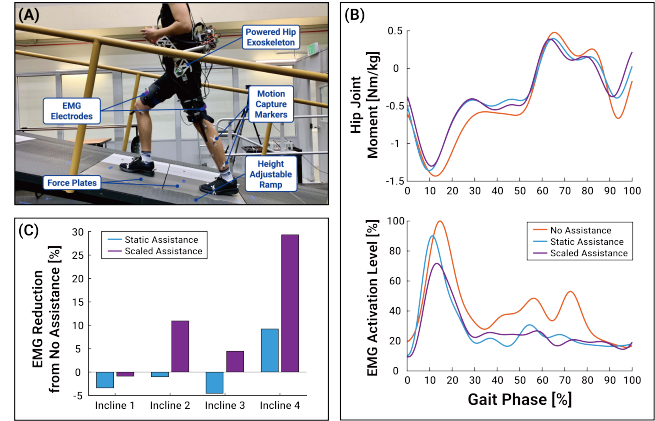


Figure 1: A) Experimental setup for the study. Powered hip exoskeleton provides hip flexion and extension assistance during the gait cycle. B) Biomechanical effects of providing exoskeleton hip extension assistance during uphill walking (incline 4). Hip joint moment (top) and EMG activation for GM (bottom) are shown for scaled (purple), static (blue), and no assistance (red) conditions. C) Maximum GM EMG activation reduction relative to no assistance mode for scaled and static controllers across different inclines.

mode, respectively. Additionally, the scaled controller reduced the average maximum Gluteus Medius (GM) EMG activation by $10.98 \pm 13.19\%$ compared to no assistance mode. However, across all inclines, scaled and static controllers increased the average maximum Vastus Medialis (VM) EMG activation by $21.76 \pm 19.22\%$ and $24.76 \pm 23.24\%$, Rectus Femoris (RF) EMG activation by $15.19 \pm 14.18\%$ and $24.08 \pm 25.89\%$ compared to no assistance mode, respectively.

Significance

Our results indicate that providing hip extension assistance during the early stance phase of the gait cycle can aid the user in reducing the relevant hip extensor EMG activation. While the kinetic results showed similar behavior between two controllers, the effect of these assistances showed significant differences in EMG activation. Not only did the scaled controller outperform the static controller by reducing a greater hip extensor EMG, it had lesser effects in antagonist muscles. From an energetics perspective (utilizing our analysis in multi channel EMG), our preliminary results illustrate that scalable assistance magnitude for the assistance may further improve the overall exoskeleton performance in uphill walking.

Acknowledgments

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References

¹Sawicki et al. (2020). *JNER*, **17**: 25. ²Kang et al. (2019). *IEEE RA-L*, **4**: 430-437. ³Bovi et al. (2011). *Gait & Posture*, **33**: 6-13.