Effects of User-Tuned Assistance on Gait Biomechanics through a Cable-Driven Ankle Exoskeleton

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Summary

Despite growing interest in exoskeleton-assisted gait, studies on their biomechanical effects remain limited. This study examines a wire-driven ankle exoskeleton's impact on muscle activation and metabolic cost, with participants autonomously adjusting assistance parameters. The results demonstrate that optimally timed assistance reduces muscle activation by 16% and metabolic cost by 15%, whereas improper timing provides minimal metabolic benefits and may even increase muscle activation. These findings are crucial for optimizing exoskeleton design to enhance rehabilitation and mobility.

Introduction

Humans naturally optimize gait by continuously adjusting movement to maximize efficiency and stability during daily walking [1]. Wearable exoskeletons have the potential to enhance gait performance, but their effectiveness largely depends on user adaptability, emphasizing the importance of personalized tuning [2]. To address this, this study examines how user-tuned assistance, based on varying levels of perceived satisfaction, influences gait biomechanics using a cable-driven ankle exoskeleton.

Methods

A graphical user interface (GUI) was developed for real-time tuning of assistive force magnitude and timing in a cable-driven ankle exoskeleton. To ensure blinding, the system randomized the mapping of these parameters to the XY axes, preventing direct association with perceived assistance. Three healthy participants (23 ± 1 years, 176.3 ± 5.1 cm, 71.7 ± 15.0 kg) completed gait trials, rating assistive conditions on a 0-10 scale via the GUI. The experiment included parameter selection and validation phases. In the selection phase, participants walked under various assistive conditions, excluding those rated below 5. In the validation phase, three conditions were tested: No Assist (NA), Low-rated Assist (LA, 4-6), and High-rated Assist (HA, 7-10). The metabolic cost was measured using a PNOĒ metabolic mask (PNOĒ, Palo Alto, CA, USA), and muscle activity of the medial gastrocnemius was recorded via surface electromyography (s-EMG) using a DELSYS Trigno wireless system (Delsys Inc., Natick, MA, USA).

Results and Discussion

Figure 1 illustrates the metabolic cost and normalized EMG across different assistance conditions. Compared to the No Assist (NA) condition, metabolic cost decreased by 6.0% in the Low-rated Assist (LA) condition and by 16.1% in the High-rated Assist (HA) condition, indicating that increasing assistance leads to greater energy savings. However, normalized EMG responses varied: in the LA condition, EMG increased by 7.1%, suggesting that low assistance may not sufficiently reduce muscular effort and could even impose additional neuromuscular demand. In contrast, EMG decreased by 14.9% in the HA condition, indicating that higher assistance effectively offloads muscle activation, reducing the demand on the medial gastrocnemius.

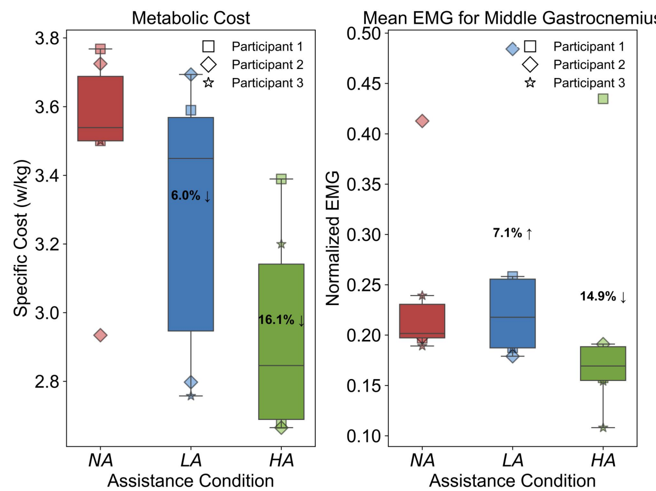

Figure 1: Effects of User-Tuned Ankle Exoskeleton Assistance on Metabolic Cost and Muscle Activation

These findings highlight the importance of precise tuning of assistive force and timing, enabled by the GUI-based adjustment framework. While High-rated Assist reduces metabolic cost and EMG, Low-rated Assist may disrupt gait synchronization, leading to human-exoskeleton mismatches and compensatory muscle activation. This suggests that suboptimal assistance can diminish its benefits, whereas well-tuned assistance enhances efficiency and reduces workload. Future research should integrate user feedback and personalized biomechanics for more intuitive assistance while expanding participant diversity to enhance validation and design refinement.

Conclusions

This study highlights the impact of personalized support from a cable-driven ankle exoskeleton on gait biomechanics. High assistance reduces metabolic cost and muscle activation, while low assistance may disrupt gait synchronization. These findings underscore the need for precise tuning to optimize assistance. Future research should explore real-time adaptive control for improved exoskeleton performance across users.

References

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