Energetic performance of soft pneumatic gel muscles for hip flexion assistance

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Summary

Soft pneumatic gel muscles (PGM) are lightweight, compliant actuators that have gained attention in the field of assistive technology in recent decades. Nonetheless, it is unclear what the optimal strategies are to assist mobility with PGMs. In this study, we performed musculoskeletal simulations to understand better how hip flexion assistive devices can decrease metabolic cost during gait. We simulated gait with multiple assistive torques based on PGMs dynamics and a motor-based actuator. We parametrized the PGMs assistive torque based on start time, assistance duration, and stiffness, using multiple slack lengths. Torques provided by the motor-based actuator emulated the ones reported using an exosuit in literature. Our results suggest that, at least, a similar reduction of metabolic costs is possible to attain using PGMs compared to the motor-driven exosuit. Future experiments will be conducted to validate our predictions.

Introduction

Wearable compliant robots, also called exosuits, can reduce the metabolic demands during gait. A study by Kim et al. [1] demonstrated that an exosuit for hip flexion assistance reduces metabolic cost if the appropriate timing and force magnitude are applied. Likely, an exosuit using PGMs (Figure 1) can deliver as much benefit. Yet, experimental systematic exploration of assistive strategies is time- and resource-intensive. Computer simulations can provide insights into an optimal assistive strategy to assist mobility using PGMs [2].

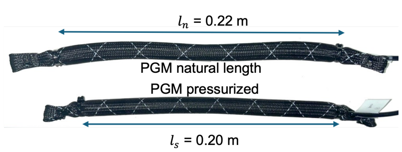

Figure 1: PGM length characteristics

Methods

We used data: scaled musculoskeletal model, inverse kinematics, and inverse dynamics, of three unimpaired subjects walking at a preferred speed from a previous study [3] to perform our simulations. We performed simulations with prescribed joint mechanics [4] in three conditions: Unassisted and ideal hip flexion assistance using motor-driven and PGM actuators as follows:

- Unassisted conditions consider no assistive torque
- Motor-driven; four torques with different peak force timing (τ_P, P), and start time (τ_r, S); 2 time characteristic features: early (E) and late (L); $\tau_r, S \, \epsilon \, \{ E{:}\, 13\ \%GC, L{:}\, 17\ \%GC \}$, and $\tau_P, P \, \epsilon \, \{ E{:}\, 0\ \%GC\ , L{:}\, 10\ \%GC \}$ as in [1] (Figure 2-A)
- PGMs; three torques based on PGMs dynamics, parameterized by start time (τ_r), assistance duration (τ_d), and stiffness (K), slack lengths ($l_s = 0.18, 0.20, 0.22\ m$) (Figure 2-B).

For each condition, we computed metabolic cost from a model in literature [5].

Results and Discussion

We predicted 6.5% metabolic cost reduction compared to unassisted conditions [1]. This serves an indirect validation from our simulation pipeline.

Our prediction showed that assisting gait based on PGMs actuator using slack length of 0.18 m reduced metabolic cost the most compared to other configuration. Also, assisting gait with PGM reduces somewhat more metabolic cost than with a motor-driven exosuit (Figure 2 C).

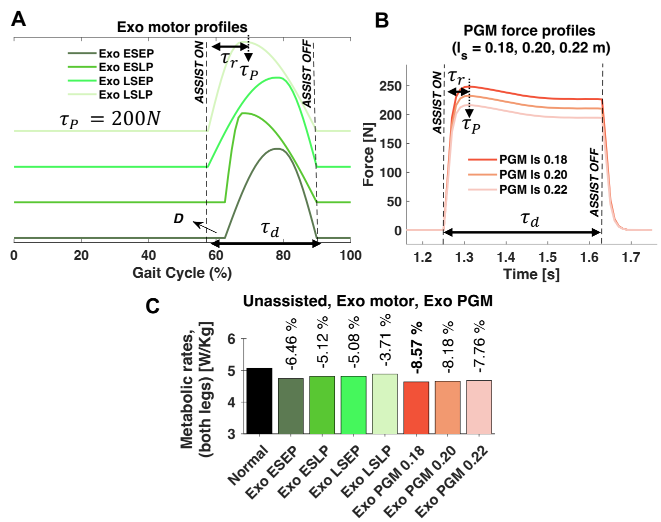

Figure 2: A. 4 Exo motor force profiles; B. PGM force profile with multiple slack lengths (l_s); C. Unassisted, Exo motor and Exo PGM net metabolic cost

Conclusion

Our simulation suggests that PGM can be as effective as a motor-driven actuator in reducing metabolic costs during gait. In our future work, we will perform experiments to validate our results.

Acknowledgments

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