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For an Exo to Be, as Good as Can Be, Help the Ankle, the Knee, the Hip or All Three?

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Motivation

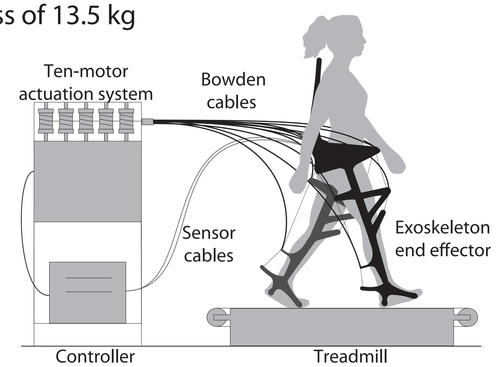
Exoskeletons can reduce the metabolic cost of walking, but what are the best ways to do so?

- Is it better to assist the hip or the ankle?
- Can knee-only assistance reduce metabolic cost?
- If we assist all three joints simultaneously, will the benefits be greater than the sum of their parts?
- How close can we come to eliminating the cost of walking?

Methods

Exoskeleton Hardware

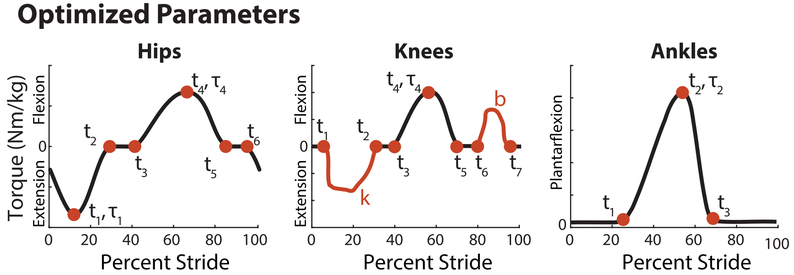
- Hip-knee-ankle exoskeleton emulator
- Max 200 Nm in hip flexion, hip extension, and ankle plantar-flexion, 250 Nm in knee extension, and 140 Nm in knee flexion
- Worn mass of 13.5 kg



Experimental Protocol

- Used human-in-the-loop optimization to optimize hip-only, knee-only, ankle-only, and hip-knee-ankle assistance
- 3 participants (2M, 1F, 61-90kg)
- Muscle activity measured using surface EMG

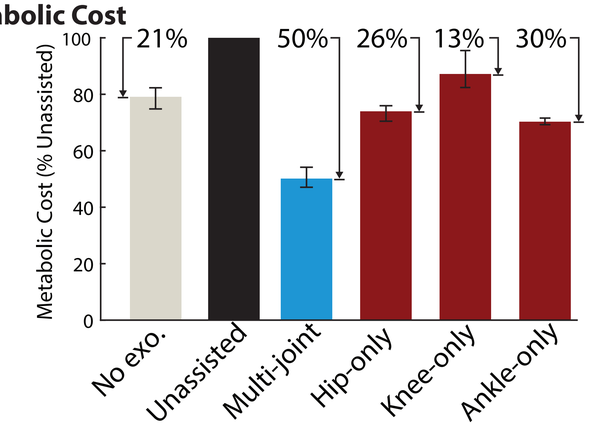
Optimized Parameters



- Optimized 8 parameters for hips, 10 for knees, 4 for ankles
- Knee spring during stance: $\tau = k \cdot \Delta\Theta_{joint}$ with k optimized
- Knee damping during late swing: $\tau = b \cdot \dot{\Theta}_{joint}$ with b optimized

Results and Discussion

Metabolic Cost

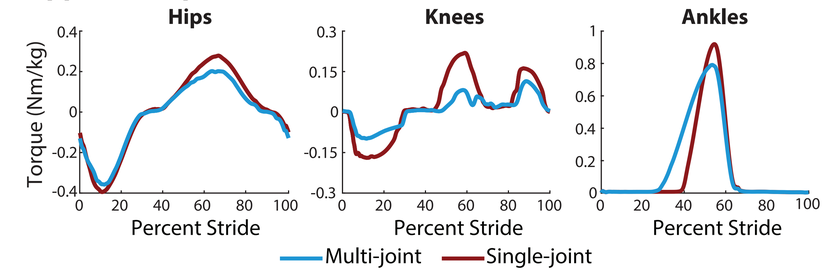


- Hip-only and ankle-only assistance reduced metabolic cost by 26% and 30% respectively, indicating both are effective
- Knee-only assistance reduced metabolic cost by 13%, demonstrating that effective knee assistance is indeed possible
- Assisting all three joints reduced cost by 50%, indicating at least half of the energy expended during walking can be saved

video

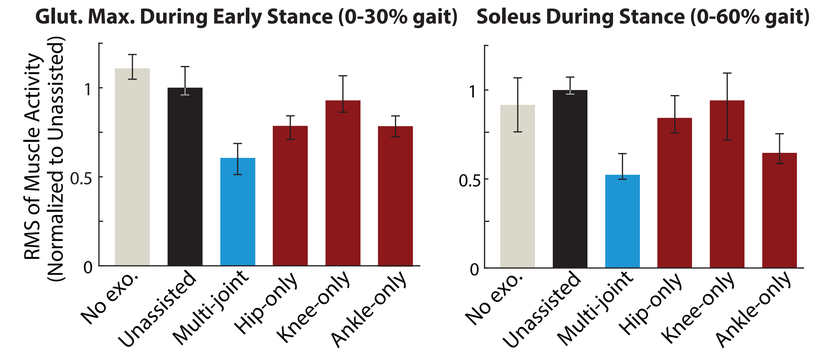
Discussion area
Poster Session 2, Room 5 (2 pm ET)
pfranks@stanford.edu

Applied Torques



- Hip and knee torques optimized to smaller magnitudes during multi-joint assistance
- Ankle torque was limited to at most 1 Nm/kg for single-joint and 0.8 Nm/kg for multi-joint for user comfort

Muscle Activity



- Gluteus maximus activity (left) decreased for hip-only and multi-joint assistance, but also for ankle assistance, indicating the gluteus was indirectly assisted by ankle exoskeleton torque
- Soleus activity (right) decreased for ankle-only, multi-joint, and hip-only assistance, but hip-only assistance only slightly reduced muscle activity, indicating a similar but less-pronounced effect of indirect assistance

Conclusion

- **Assist the entire limb for maximum effect**
- **Assist a single well-chosen joint for maximum efficiency**

Acknowledgements

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