Designing exoskeletons and prosthetic limbs that enhance human performance

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First: A difficult design problem.

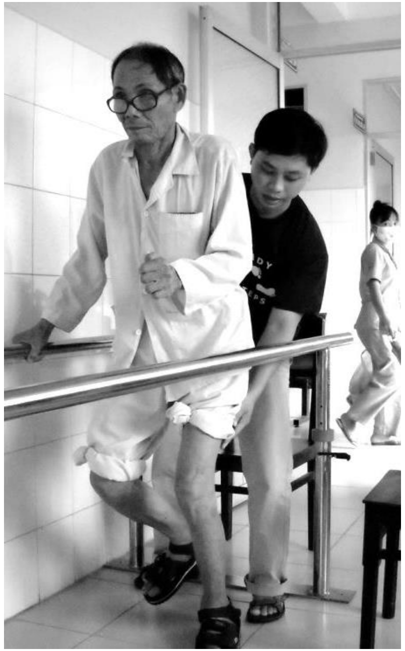
Then: Tools that help.

Finally: Energy-efficient embodiments.

Goal: Restore and enhance mobility

[Daily Herald (2013)]

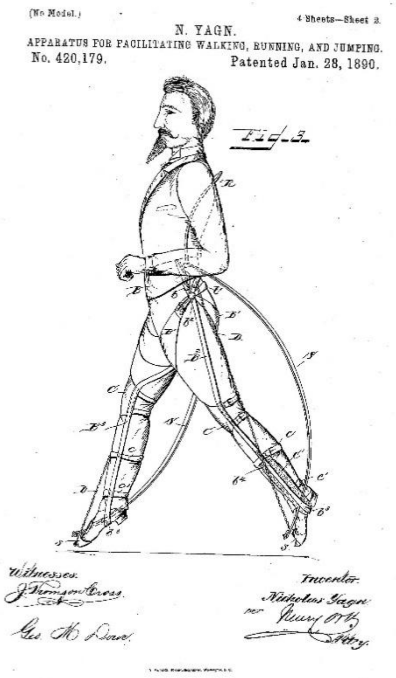
[Duncan et al. (2007)]

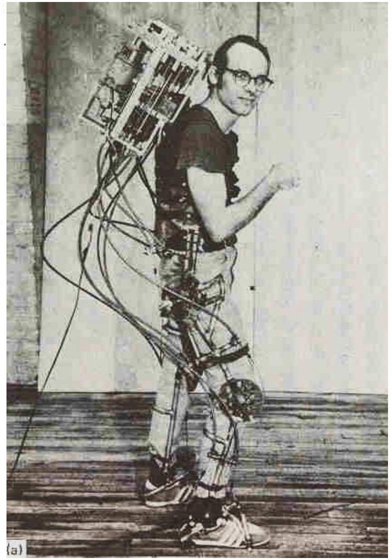


[V. Lockett (2016)]

[UNICEF (2016)]

Challenge: Improving performance is hard



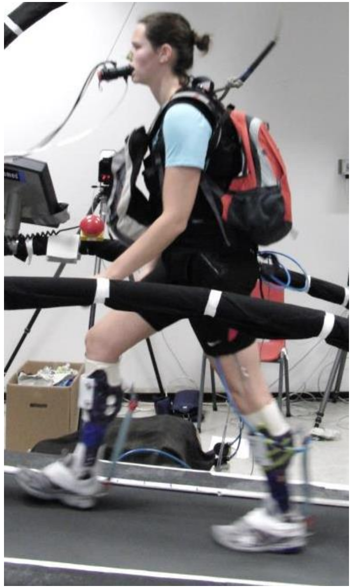


[Yagn (1890); Seireg (1971); Zoss et al. (2006) ; van Dijk et al. (2011)]

Best results: Modest improvements


[MIT]


[Harvard]


[Ghent]


[NCSU/CMU]

Problem: What should the device do?

Intuition (only) inspires

Present models don’t predict

Solutions:

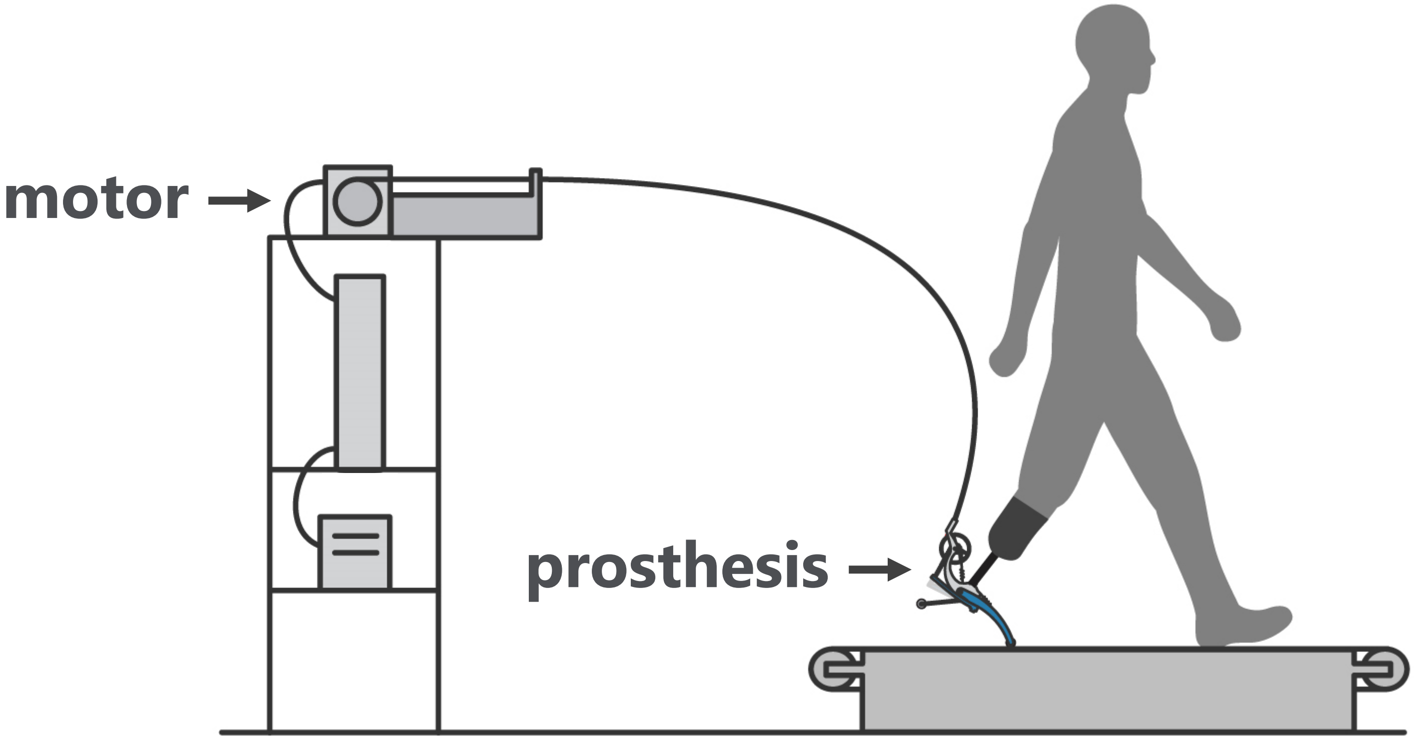
Universal Device Emulators

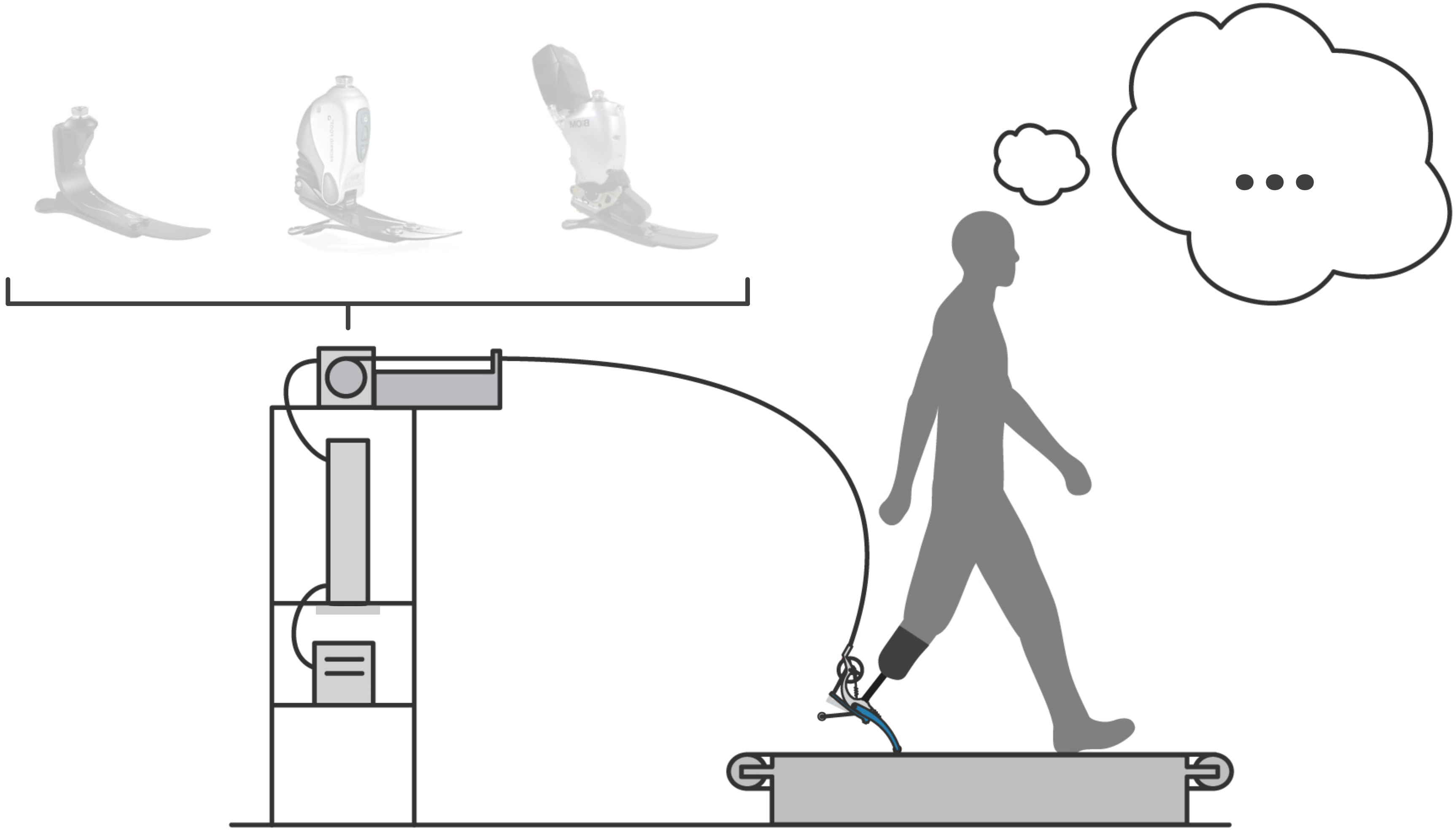
Experiments on humans, fast.

Human-in-the-Loop Optimization

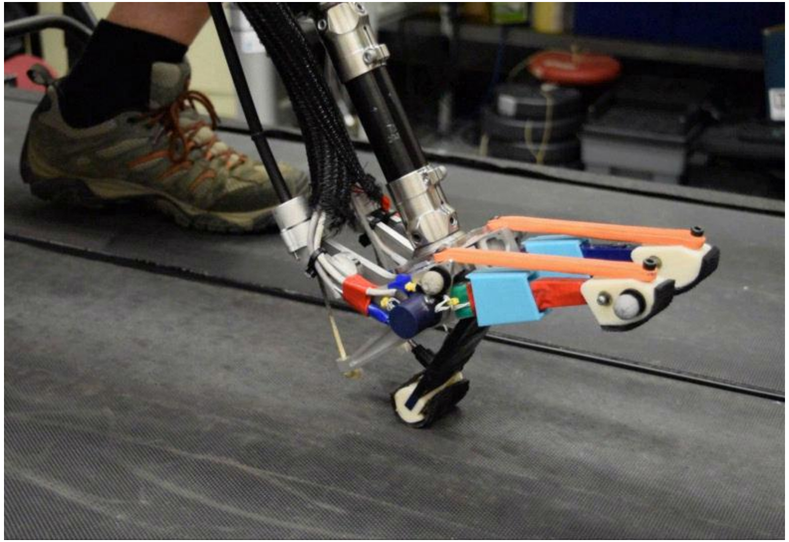
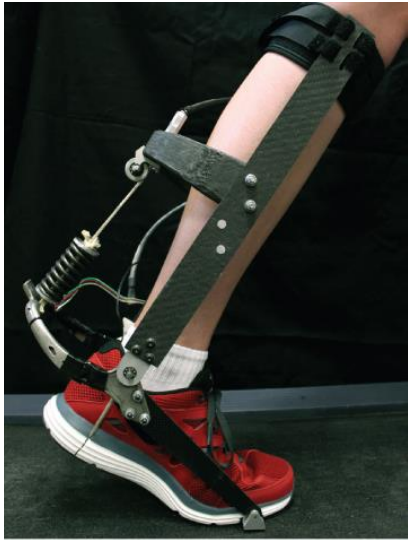
Discover, individualize and co-adapt.

Emulators: Fast, cheap and in control





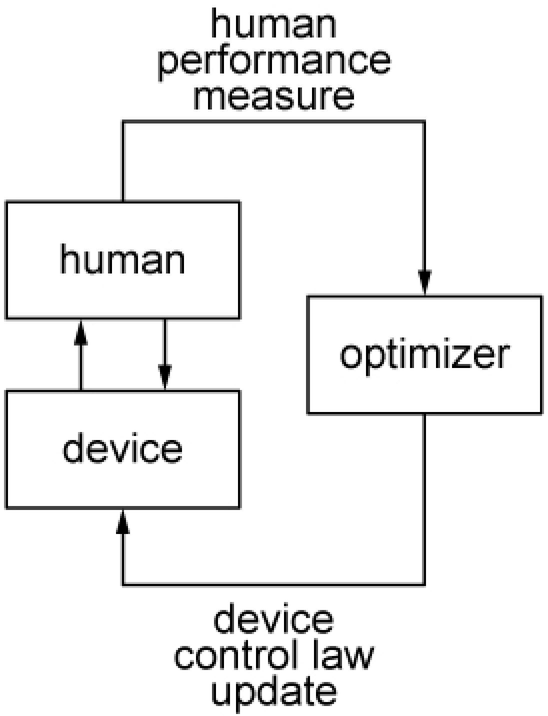
End effectors: Easy to get good performance

[Caputo & Collins (2014) *JBME*; Collins et al. (2015) *ICRA*; Witte et al. (2017) *ICORR*]

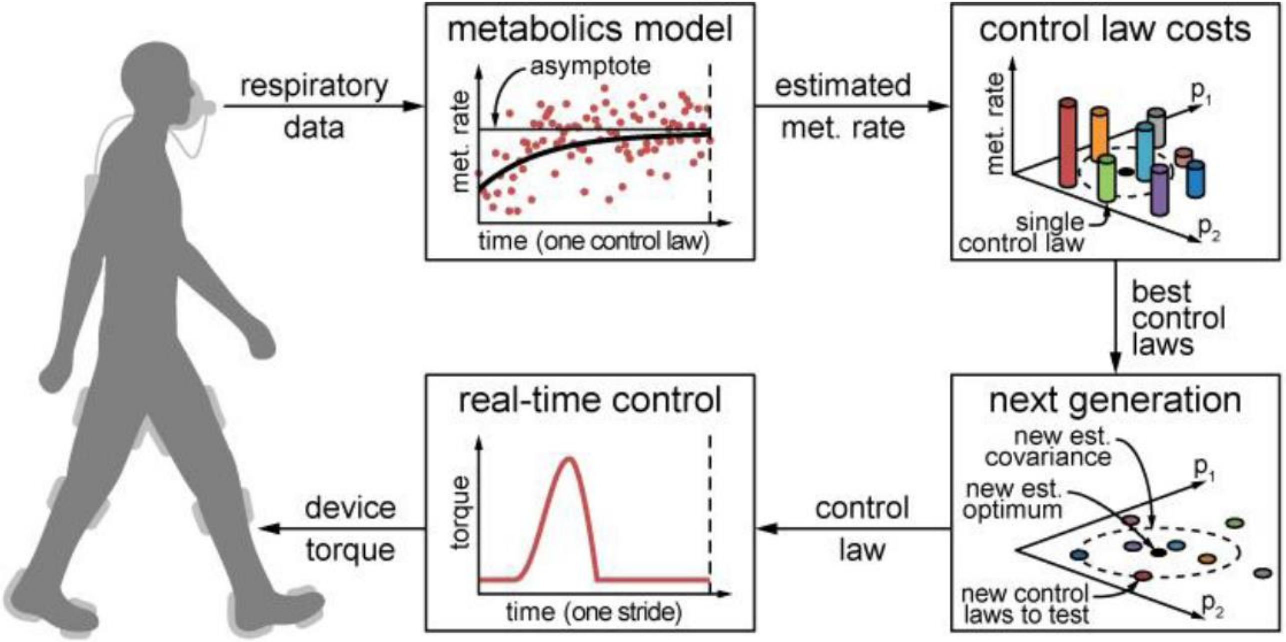
HLO: Discover. Customize. Adapt.

Big idea: Human-In-the-Loop Optimization



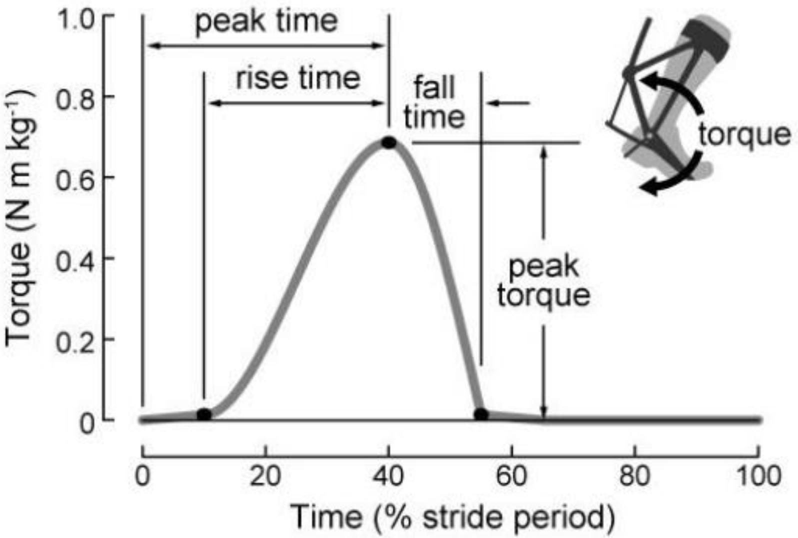
[Zhang et al. (2017) *Science*]

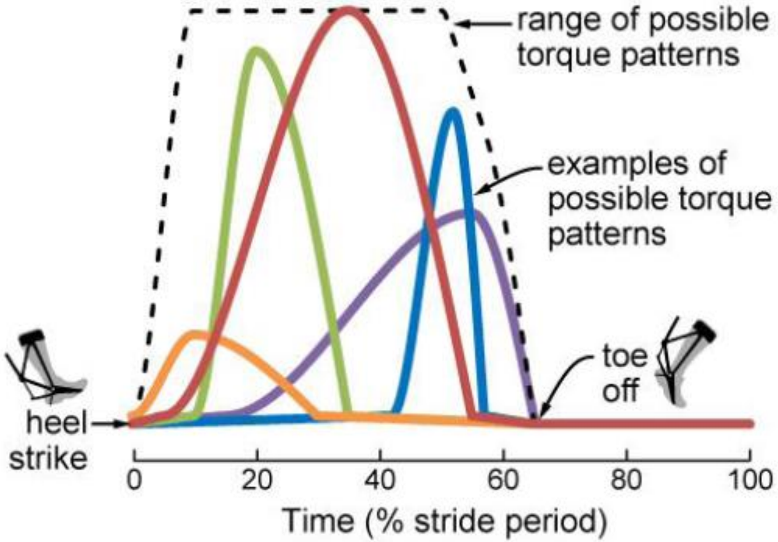
Specific method: Minimize metabolic rate



[Zhang et al. (2017) *Science*]

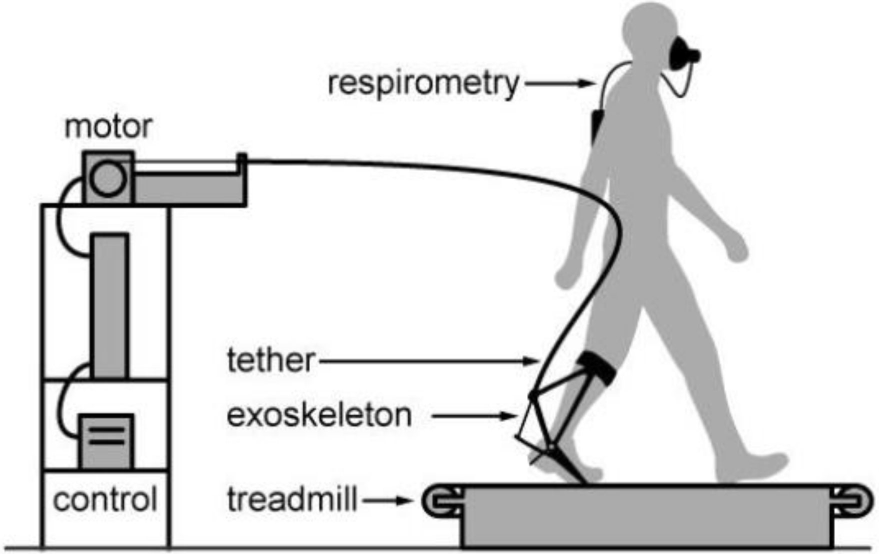
Application: Ankle torque pattern

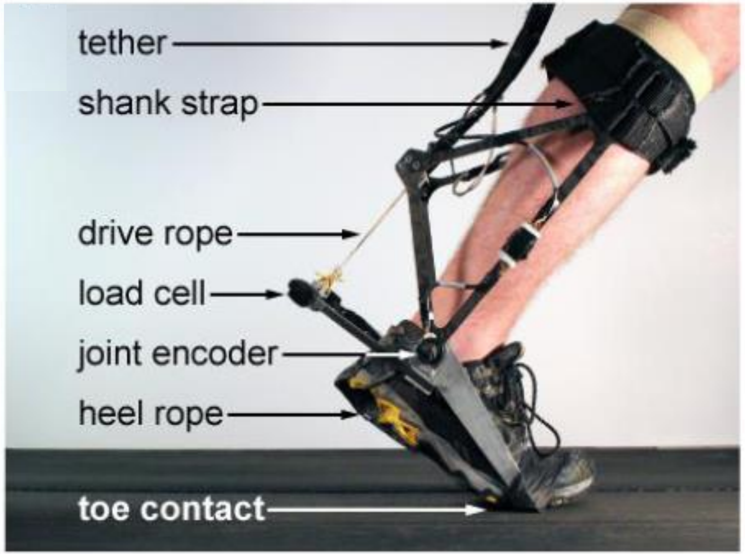




[Zhang et al. (2017) *Science*]

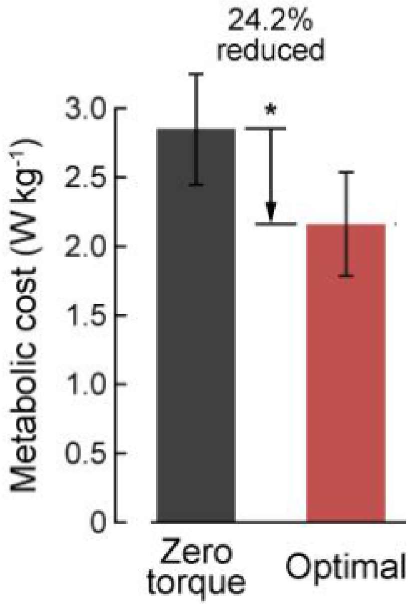
Application: Exoskeleton on one ankle





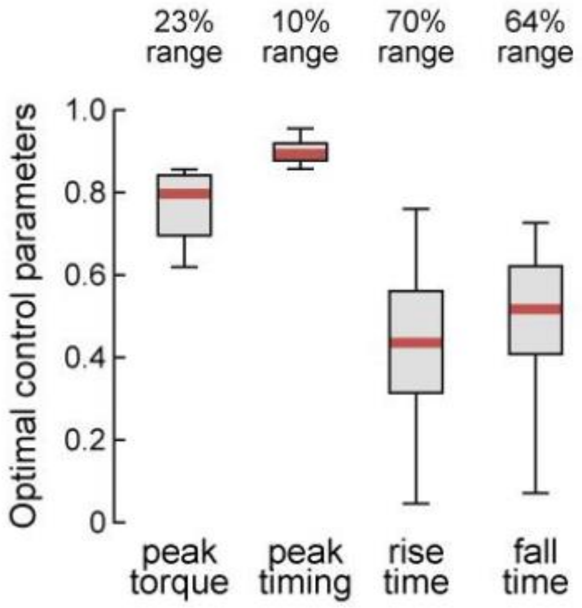
[Zhang et al. (2017) *Science*]

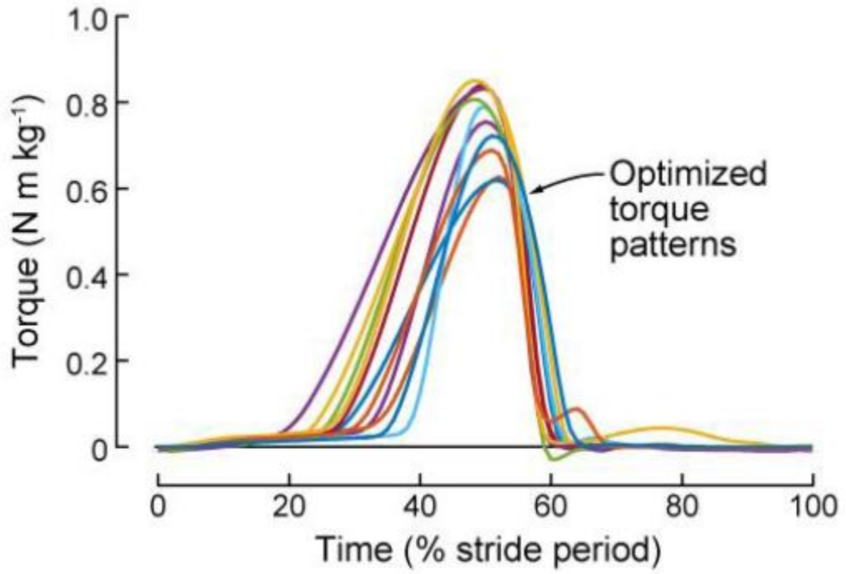
Metabolic cost: Exceptionally large reduction



[Zhang et al. (2017) *Science*]

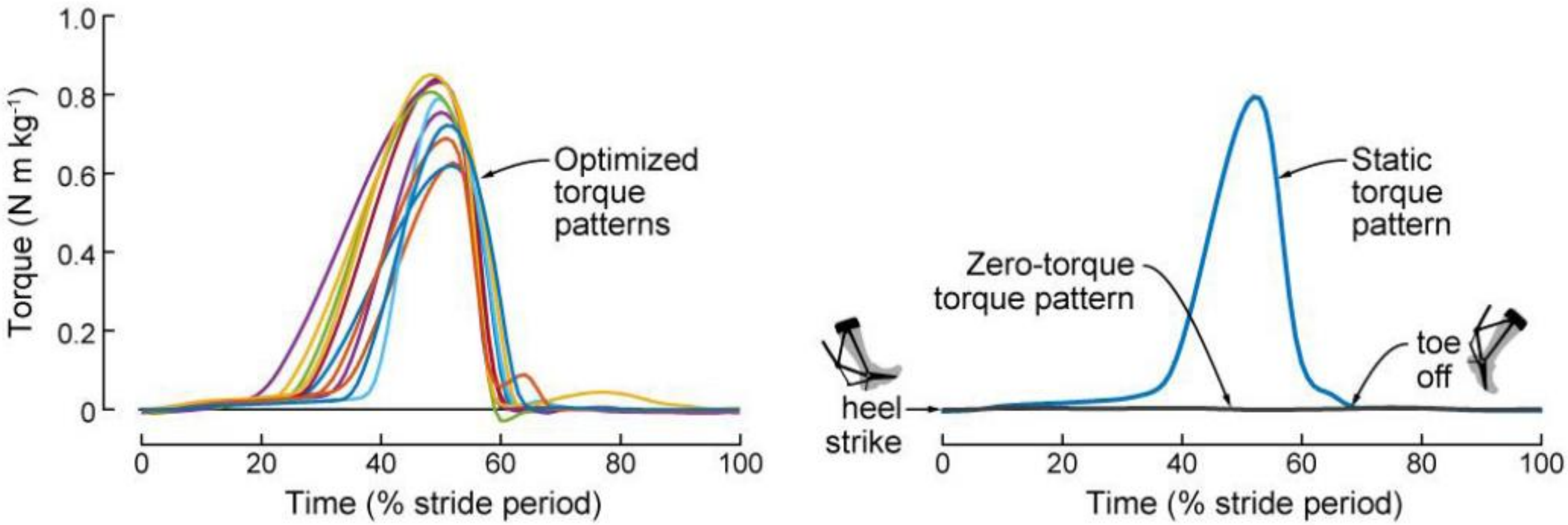
Optimized settings: Substantial variation





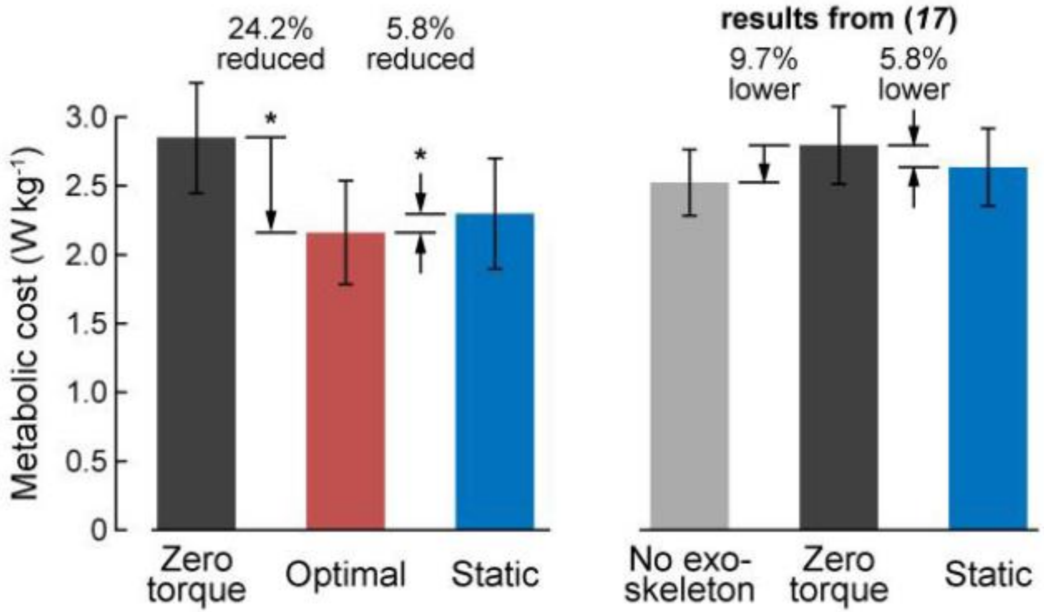
[Zhang et al. (2017) *Science*]

Static comparison: Suggests three contributors



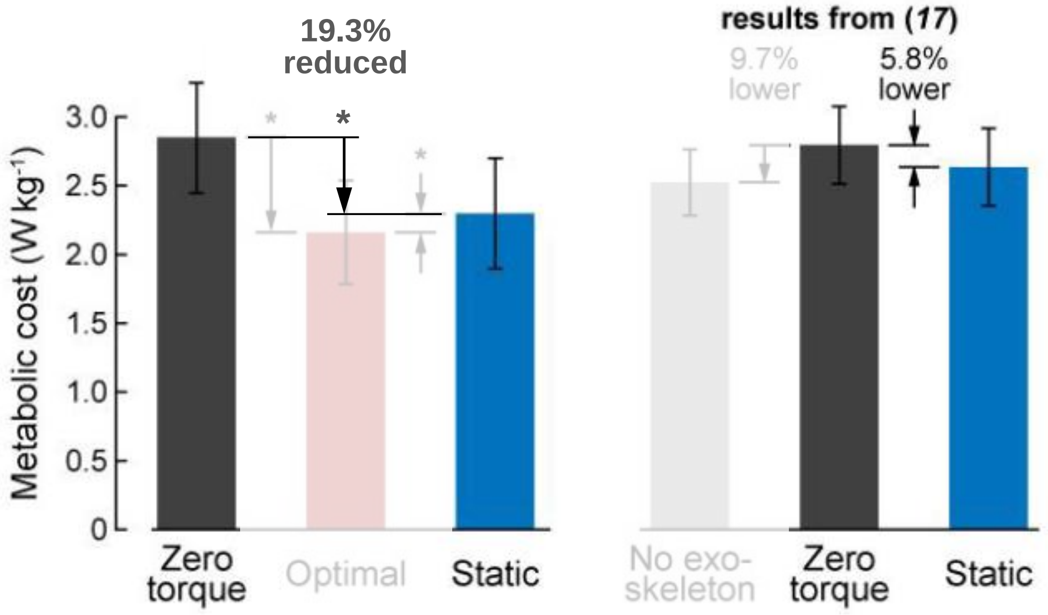
[Zhang et al. (2017) *Science*]

Static comparison: Facilitating motor learning



[Jackson & Collins (2015) *J. Appl. Physiol.*; Zhang et al. (2017) *Science*]

Static comparison: Facilitating motor learning



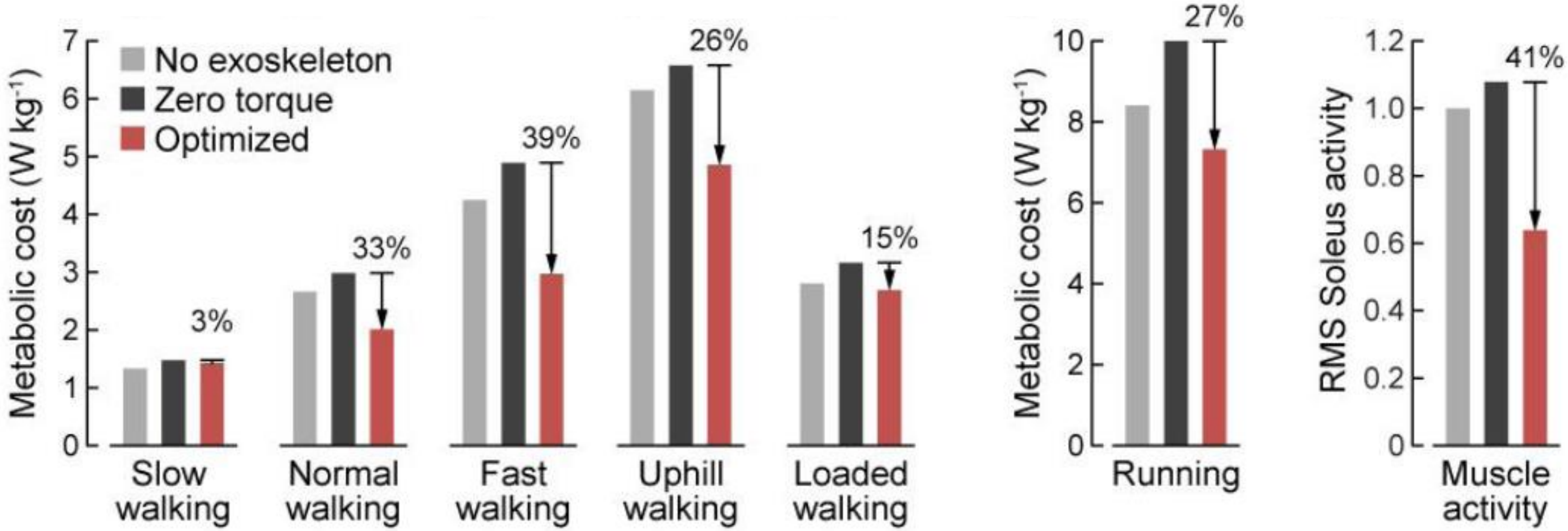
[Jackson & Collins (2015) *J. Appl. Physiol.*; Zhang et al. (2017) *Science*]


Normal Walking

Single-subject studies: Test generality

[Zhang et al. (2017) *Science*]

Single-subject studies: Test generality



[Zhang et al. (2017) *Science*]

Implications: Great tools for design.

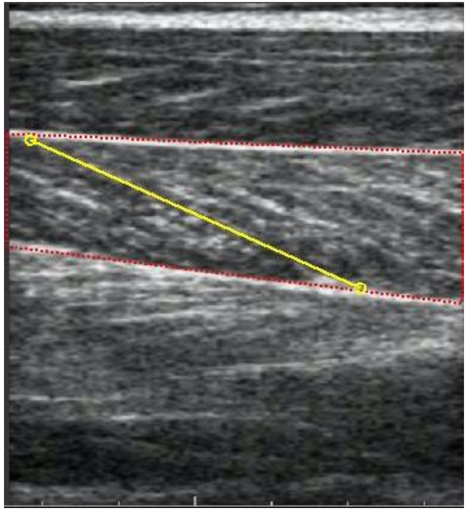
Future work: Faster learning + optimization

Questions?

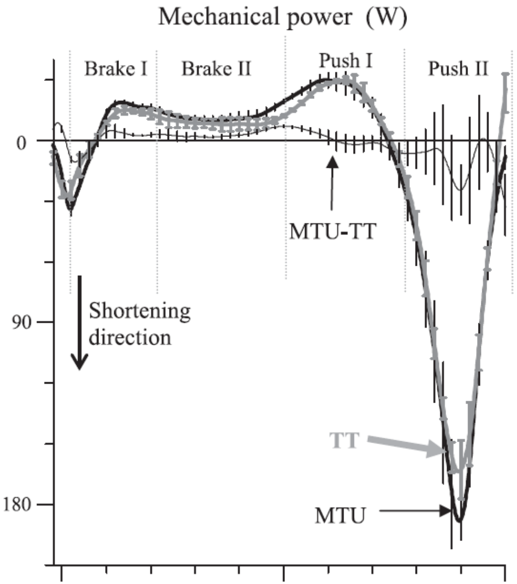
Going mobile: Efficient assistive robotics

Bioinspiration: Ankle catapult mechanism

Ultrasound imaging: Calf muscles nearly static

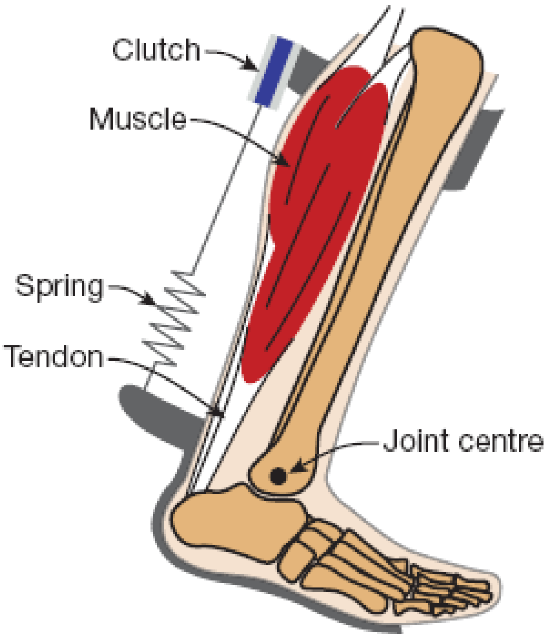


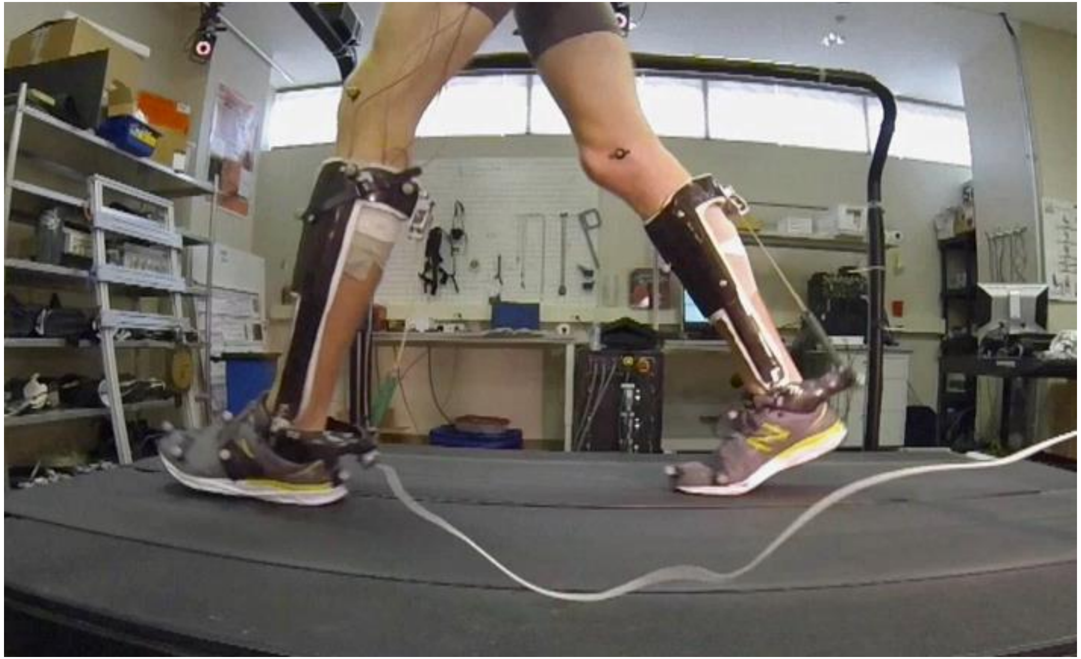
[Farris et. al. (2013) *J Appl Physiol*]



[Ishikawa et. al. (2005) *J Appl Physiol*]

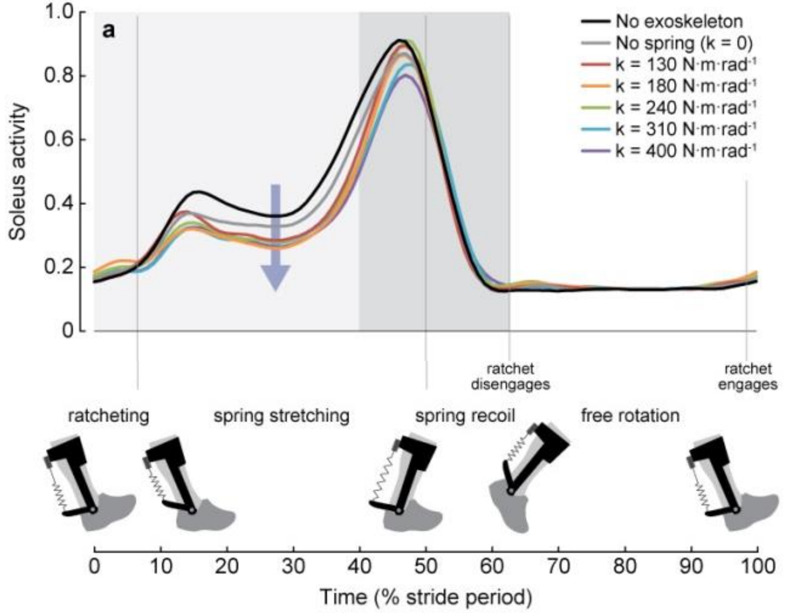
Device: Unpowered ankle exoskeleton

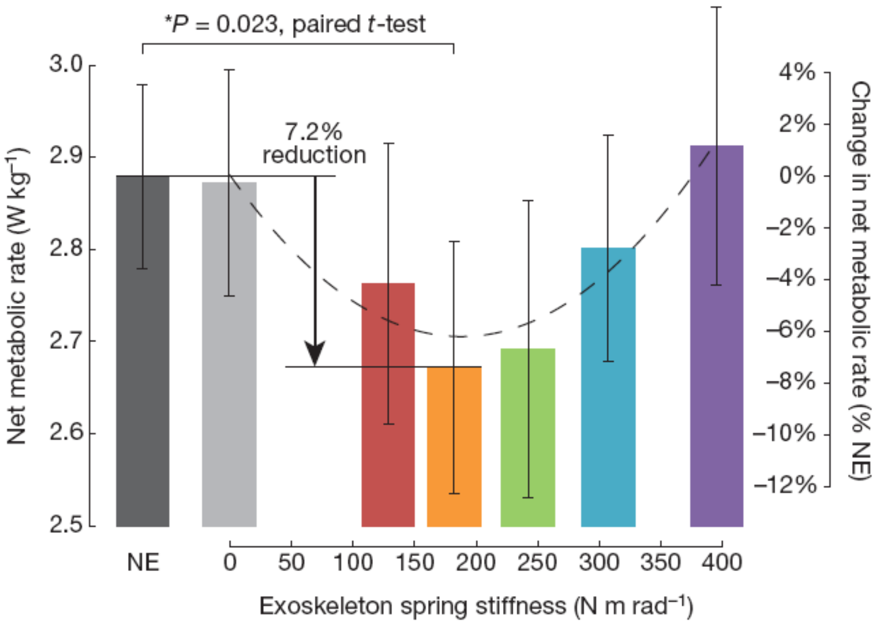




[Collins et al. (2015) *Nature*]

Results: Reduced force → more efficient walking





[Collins et al. (2015) *Nature*]

Limitation: Controllability

Actuator design: Electroadhesive clutch

[Diller et al. (2016) *ICRA*]

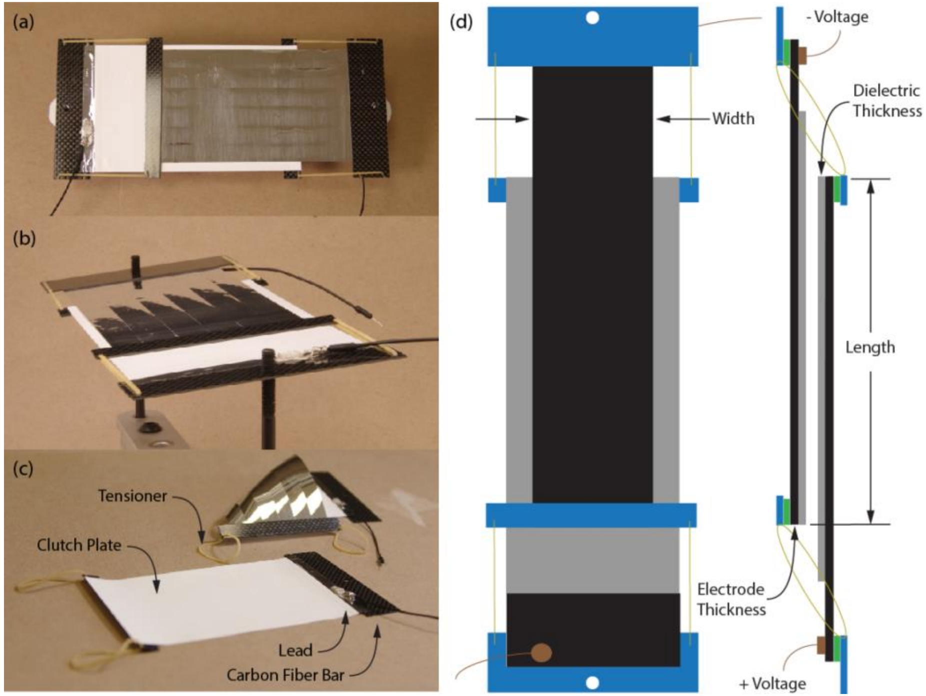
Results: Electroadhesive clutch characteristics

One clutch pair:

Peak force: 200 N
Mass: 1.5 g
Power used: 0.3 mW
Applied Voltage: 300 V
Switching time: 0.01 s

Demonstration system:

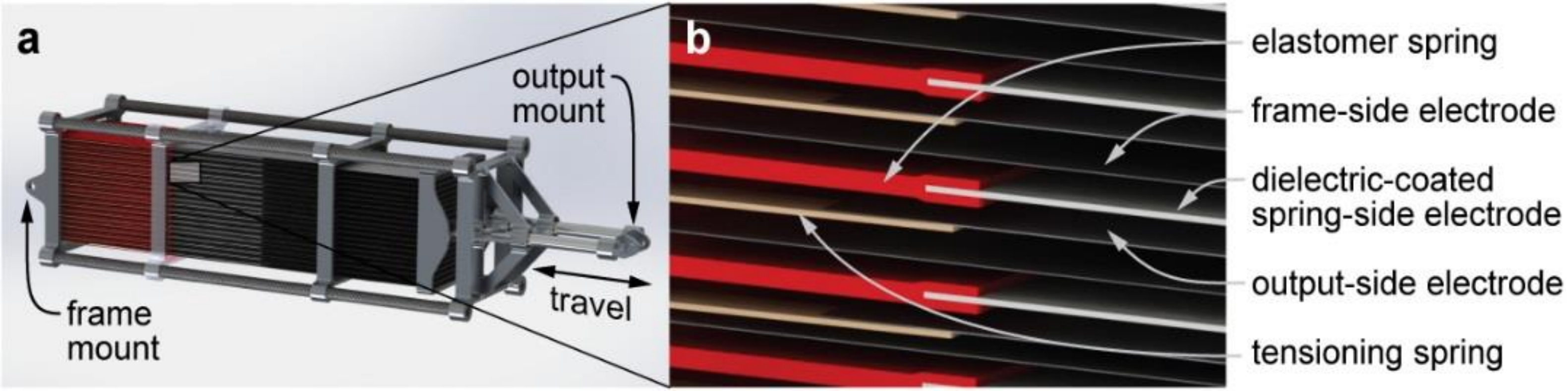
Mass: 26 g
Efficiency: 95%
Fatigue life: > 2,000,000



[Diller et al. (2016) *ICRA*]

Future work: Energy-recycling actuators

High-bandwidth, discretely-variable force control



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